

# **Transbasin Water Transfers**

**Proceedings of the  
2001 USCID Water Management Conference**

**Denver, Colorado  
June 27-30, 2001**

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U.S. Committee on Irrigation and Drainage

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## USCID

*The Mission of the United States Committee on Irrigation and Drainage is to foster sustainable, socially acceptable and environmentally responsible irrigation, drainage and flood control systems and practices for providing food, clothing and shelter to the people of the United States and the World.*

USCID is a nonprofit professional society whose members share an interest in the planning, design, construction, operation and maintenance of irrigation, drainage and flood control works; agricultural economics; water law; and environmental and social issues affecting irrigated agriculture.

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## Preface

These Proceedings include the papers presented during **Transbasin Water Transfers**, a Water Management Conference sponsored by the U.S. Committee on Irrigation and Drainage. The Conference, held June 27-30, 2001, in Denver, Colorado, brought together water resources professionals from around the world to discuss issues relating to the transbasin water transfers.

The goal of the Conference was to provide a forum for thoughtful discourse on transbasin water transfers, including water supply and water requirements, fish and wildlife enhancement, environmental concerns, biota transfer, and legal, political and diplomatic aspects. In addition to presenting experiences in planning, constructing and operating transbasin water projects in North America, the papers describe projects from several countries, including Brazil, Chile, India, Iran, Nepal, Portugal and Taiwan. Issues involved in transboundary projects, including the Garrison Diversion Project, are also featured in several papers.

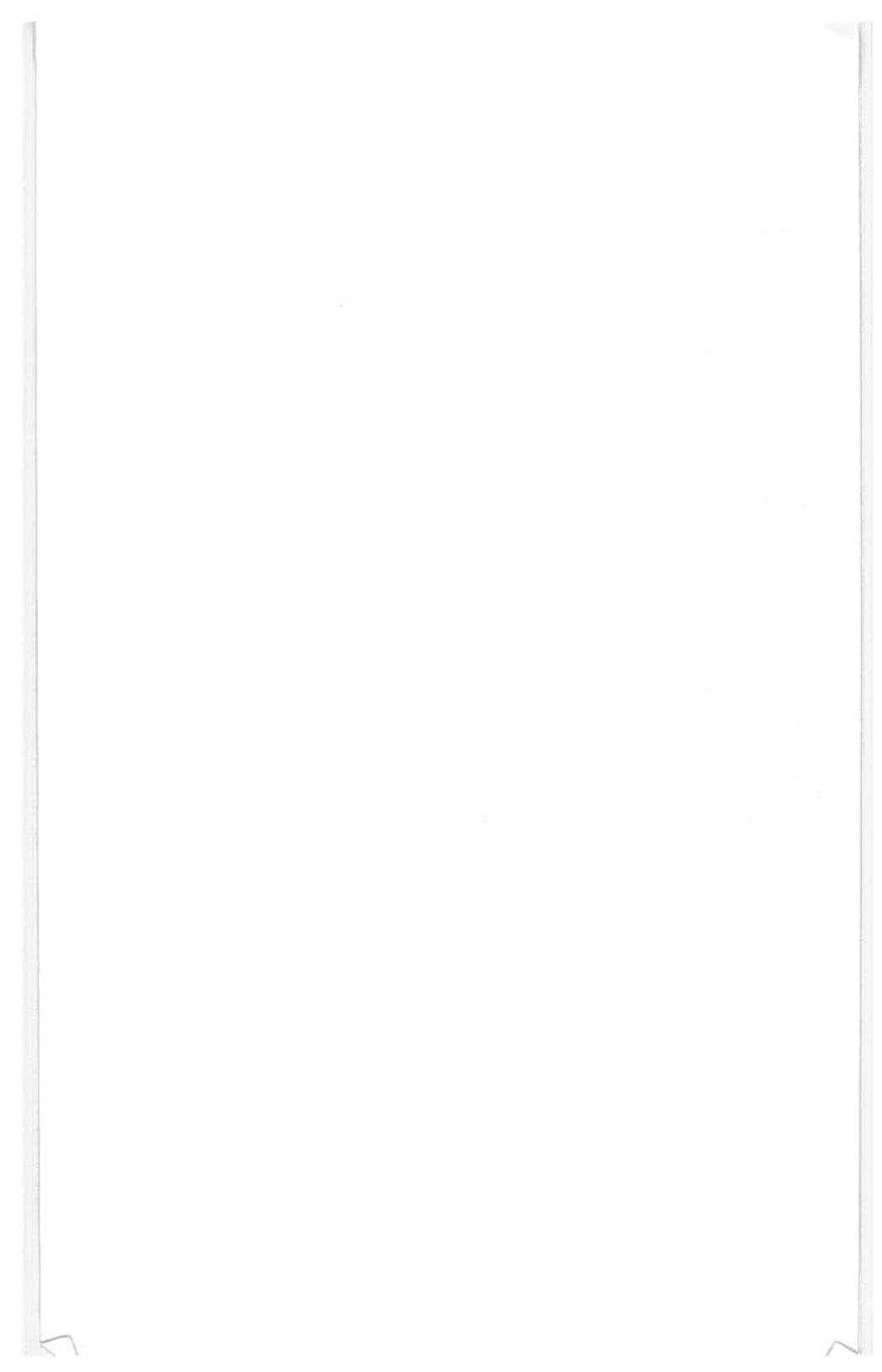
Papers included in the Proceedings were accepted in response to a call for papers and were peer-reviewed prior to preparation of the final papers by the authors. The authors are professionals from academia; federal, state and local government agencies; water districts and the private sector.

The U.S. Committee on Irrigation and Drainage, and the Conference officers express gratitude to the authors, session moderators and participants for their contributions.

Thanks are also extended to Conference Co-Sponsors Bureau of Reclamation, Garrison Diversion Conservancy District, and Northern Colorado Water Conservancy District for assisting in the Conference organization and the Study Tour.

The Office of International Affairs, Bureau of Reclamation, sponsored the Conference Proceedings and this support is acknowledged with appreciation.

**Jerry Schaack**  
Conference Chairman  
Carrington, North Dakota





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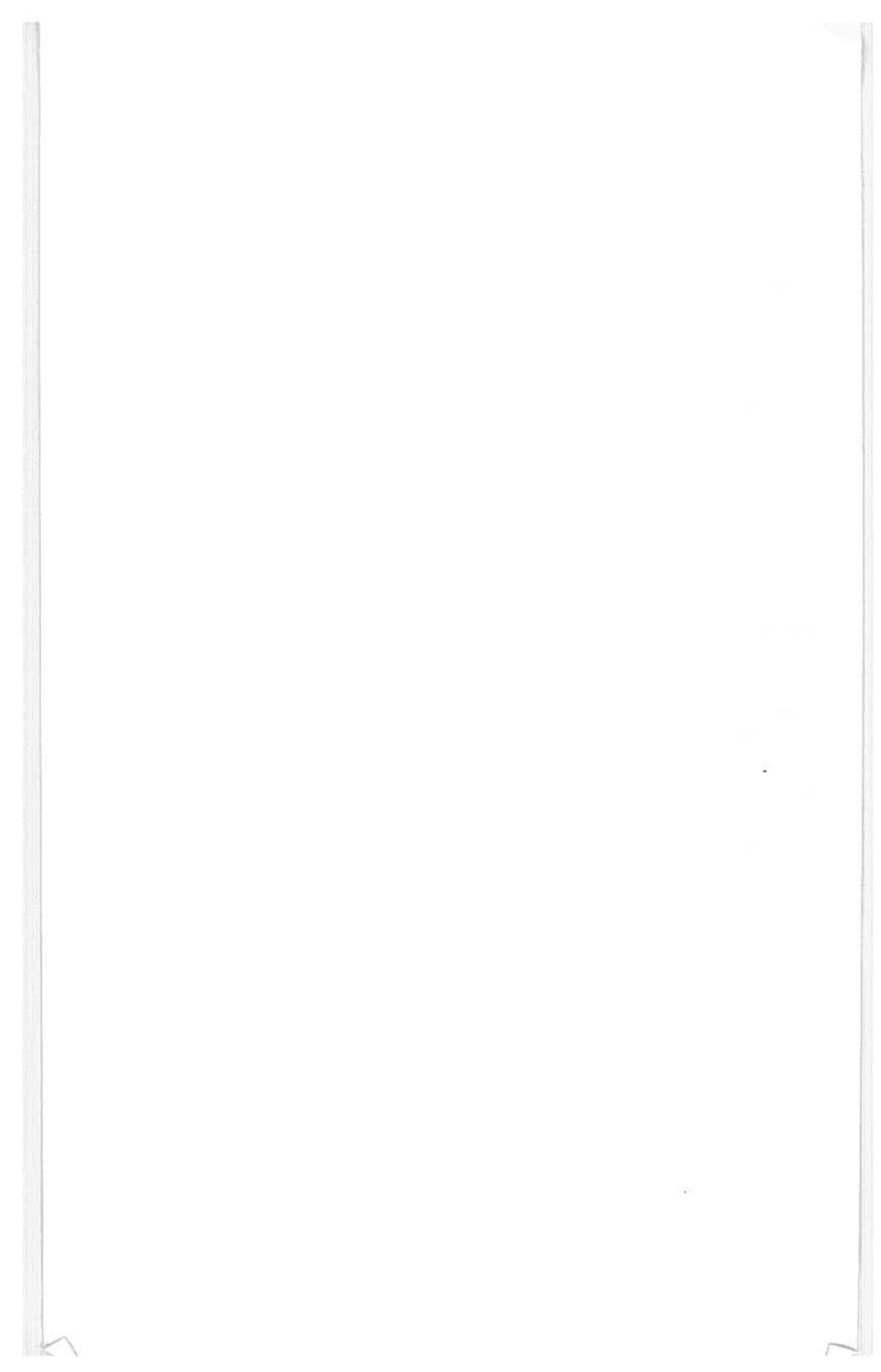
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## WATER FOR FOOD AND ENVIRONMENTAL SECURITY

Bart Schultz<sup>1</sup>

### ABSTRACT

The cultivated area on earth is 1,500 million ha. At 1,100 million ha agriculture takes place without a water management system. Irrigation covers 260 million ha and is responsible for 40% of crop output. Drainage of rainfed crops covers 130 million ha and is responsible for 15% of crop output. Thus 55% of the food production is obtained with the support of a water management system.

During the Second World Water Forum in March 2000 a sector vision of 'Water for Food and Rural Development' was presented. It indicates a required duplication in food production - primarily from already cultivated land - in the forthcoming 25 years and gives recommendations how this can be achieved.

In this contribution focus is on how the concerned issues may play a role in the development of irrigation and drainage under different climatological and socio-economic conditions. It is illustrated which measures may be required, including increase in storages and transbasin water transfers. In line with this the Strategy for Action of the International Commission on Irrigation and Drainage (ICID) is presented, showing which contributions ICID is planning to give to the realisation of the challenges.

*The pace of change in our world is speeding up, accelerating to the point where it threatens to overwhelm the management capacity of political leaders. This acceleration in history comes not only from advancing technology, but also from unprecedented world population growth, even faster economic growth, and the increasingly frequent collisions between expanding human demands and the limits of the earth's natural systems.*

Lester R. Brown, 1996

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## INTRODUCTION

During the Second World Water Forum in March 2000 a sector vision of 'Water for Food and Rural Development' was presented. It indicates a required duplication in food production - primarily from already cultivated land - in the forthcoming 25 years and gives recommendations how this can be achieved.

Having in mind the required increase in food production in the forthcoming decades, the increased water use by other users and the general recognition of the need for sustainable rural development a wide range of issues is of major importance. In this contribution focus will be on how the concerned issues may play a role in the future development of irrigation and drainage under different climatological and socio-economic conditions. It will be illustrated what measures may be required, including increase in storages and transbasin water transfers. In line with this the Strategy for Action of the International Commission on Irrigation and Drainage (ICID) is presented, showing what ICID considers of relevance and which activities the Commission is planning to develop to contribute to the realisation of the future challenges.

## POPULATION, ITS GROWTH AND ITS STANDARD OF LIVING

Basis for the water management requirements is the worlds' population, its growth and its standard of living. The present worlds' population and a prognoses of the population growth are shown in Figure 1 (after Van Hofwegen and Svendsen, 2000). Of special interest in this figure is the distinction in least developed countries, emerging developing countries and developed countries. The majority of the worlds' population lives in the emerging developing countries. This category comprises Asia (excluding Japan), Latin America, the Caribbean and some other small regions. From Figure 1 it can be further derived that population growth will take place in the least developed countries and the emerging developing countries. In the developed countries a slight reduction of the population is expected.

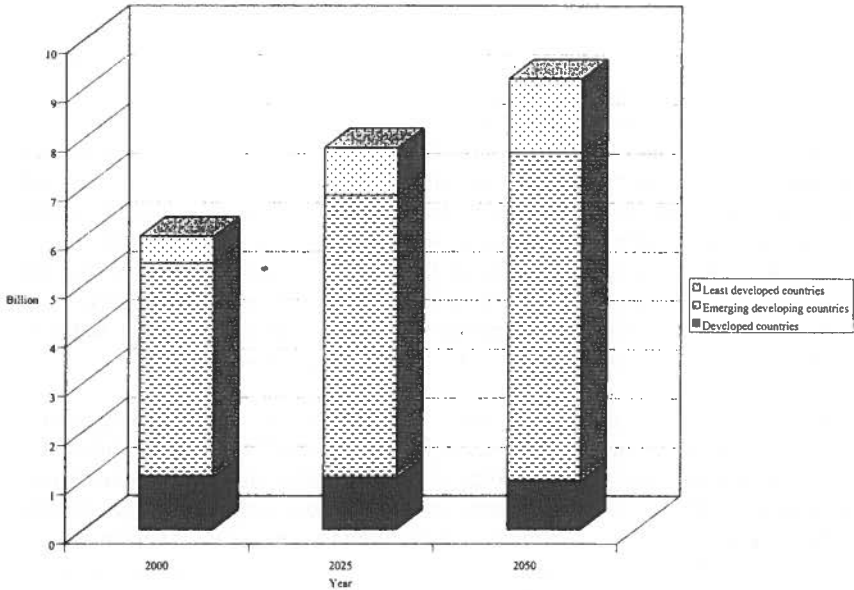


Figure 1. World population and growth in least developed countries, emerging developing countries and developed countries (van Hofwegen and Svendsen, 2000)

Another interesting feature related to population growth are the migration from rural to urban areas. The expectation is that due to these developments the population in the rural areas in the least developed and emerging developing countries will more or less stabilise and that the growth will be concentrated in the urban areas in these regions.

Especially in the emerging developing countries the standard of living is rapidly rising. One of the implications is the increase and change in food consumption per person. However, about 1.2 billion people in the least developed and emerging developing countries are still poor and have to live from a minimal diet, or has hunger. Out of them about 70% live in the rural area.

### WATER MANAGEMENT FOR AGRICULTURE

With respect to water management related to agricultural production there are broadly speaking three agro-climatologic zone's, being: temperate humid zone, arid and semi-arid zone and humid tropical zone. In addition, in principle, four types of cultivation practices may be distinguished, being:

- rainfed cultivation, without or with a drainage system;

- irrigated cultivation, without or with a drainage system.

Dependent on the local conditions different types of water management with different levels of service will be appropriate (Schultz, 1993). In the temperate humid zone agriculture generally takes place without a water management system, or with a drainage system only. Supplementary irrigation may be applied as well. In the arid and semi arid zone agriculture is normally impossible without an irrigation system. Drainage systems may be applied as well for salinity control and the prevention of water logging. In the humid tropical zone generally a distinction is made in cultivation during the wet and the dry monsoon. During the wet monsoon cultivation is generally possible with a drainage system only, although quite often irrigation is applied as well to overcome dry spells. In the dry monsoon irrigation is generally required to enable a good yield.

In Figure 2 the development of the cultivated area without a water management system and under irrigation since the beginning of the 19<sup>th</sup> century are shown. For drainage only the present area is given, while no reliable data on the development are available. The total cultivated area on earth is about 1,500 million ha, which is 12% of the total land area. At about 1,100 million ha agricultural exploitation takes place without a water management system. However, in a certain part of these areas methods like water harvesting, or soil treatment may be applied. Presently irrigation covers more than 260 million ha, i.e. 17% of world's arable land. Some characteristic figures of the ten countries with the largest irrigated area are given in Table 1. Irrigation is responsible for 40% of crop output. It uses about 70% of waters withdrawn from global river systems. About 60% of such waters are used consumptively, the rest returning to the river systems, in principal enabling its reuse downstream. Drainage of rainfed crops covers about 130 million ha, i.e. 9% of world's arable land. In about 60 million ha of the irrigated lands there is a drainage system as well. From the 130 million ha rainfed drained land it is roughly estimated that about 15% of crop output is obtained. Some characteristic figures of the ten countries with the largest drained area are given in Table 2. In this Table the total drained areas are given, while it is very difficult to differentiate between rainfed drained areas and drainage in irrigated areas.

30% of water withdrawn is put to other uses like drinking, municipal, industrial, hydropower generation, and recreation. Only a small part of this is used up consumptively, while a large unconsumed part either treated or untreated is returned to the river systems and reused. Due to population growth, increase in standard of living - especially in the emerging developing countries -, urbanization and industrialization the withdrawals for these uses are increasing.



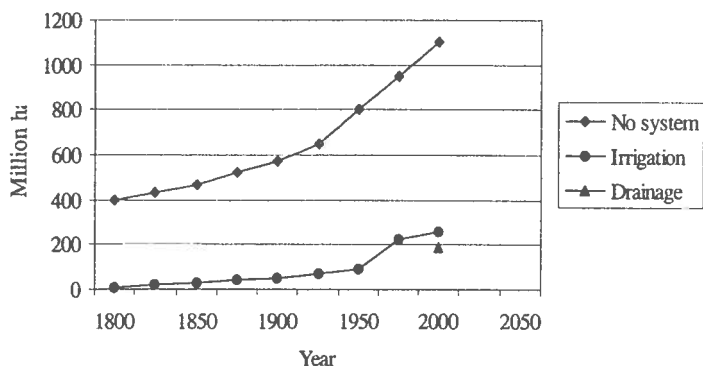


Figure 2. Development of cultivated area in the world without a water management system and under irrigation and the presently drained area

Table 1. Some key figures for the ten countries with the largest irrigated area (International Commission on Irrigation and Drainage, 2000)

Country	Population in 10 <sup>6</sup>	% of population in agriculture	Total area in 10 <sup>6</sup> ha	Arable land in 10 <sup>6</sup> ha	Irrigated area in 10 <sup>6</sup> ha
India	960	61	329	170	57
China	1,243	68	960	96	50
USA	272	2	936	188	21
Pakistan	144	48	80	22	17
Iran	72	28	163	18	7
Mexico	94	23	195	27	6
Russia	148	11	1,171	208	5
Thailand	59	59	51	20	5
Indonesia	203	50	190	30	5
Turkey	63	48	77	27	4
Total	3,258		4,152	806	177
World	6,000		13,000	1,500	260

Water management originates from about 6,000 years ago when irrigation was practised in the plains between Tigris and Euphrates rivers. Strange is, however, that although there is such a wealth of experience, and we have at the moment the best know how, the best technology and the highest financial means, the problems in certain regions are enormous. I like to mention the major types of problems:

- water shortages;
- inefficient water use;
- waterlogging and salinization;
- inadequate operation and maintenance;
- pollution through fertilisers and pesticides;
- flooding of cultivated, urban and industrial areas.

Table 2. Indicative key figures for the ten countries with the largest drained area (International Commission on Irrigation and Drainage, 2000, and data base CEMAGREF)

Country	Population in 10 <sup>6</sup>	% of population in agriculture	Total area in 10 <sup>6</sup> ha	Arable land in 10 <sup>6</sup> ha	Drained area in 10 <sup>6</sup> ha
USA	272	2	936	188	47.0
China	1,243	68	960	96	28.5
Indonesia	203	50	190	30	15.4
India	960	61	329	170	13.0
Canada	30	3	997	46	9.5
Brazil	163	19	851	66	8.0
Yugoslavia	144	48	80	22	5.8
Pakistan	82	3	36	12	4.9
Germany	39	23	32	15	4.2
Poland					
Total					142.0
World	6,000		13,000	1,500	190

With the above in mind we can look forward. First of all I like to sketch who are the actors in the field of agricultural water management (Figure 3). Responsible are government, irrigation and drainage agencies and farmers. This implies that in order to achieve sustainable solutions these three parties have to agree on their role and share in water management and flood protection in a region. All others contribute. They are needed and have a function for various reasons, but they are not responsible.

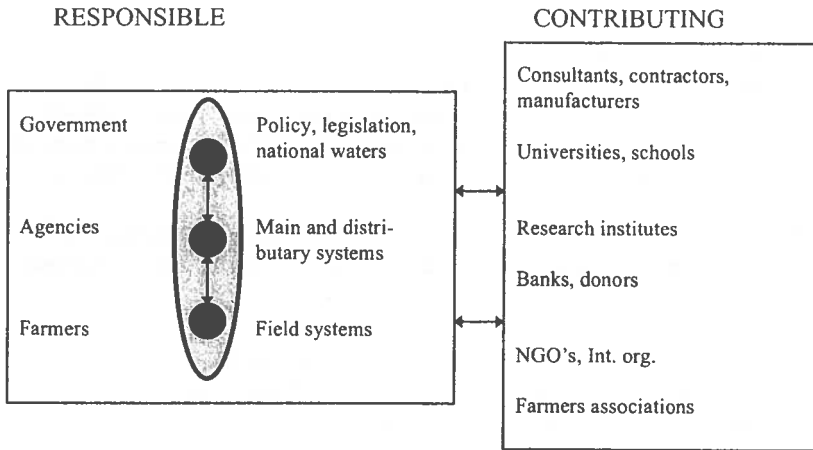


Figure 3. Indicative schematisation of actors in agricultural water management

For urban water management a similar scheme can be presented, although in this case the municipalities, and not the individual citizens, are generally in charge of the urban systems: the sewerage, the water treatment and the urban drainage. Citizens can contribute by efficient water use in their homes, as well as by proper waste disposal, and last but not least financially.

During the Second World Water Forum, which was held in March 2000 in The Hague, The Netherlands, the World Water Council (WWC) has presented a global 'Long Term Vision on Water, Life and the Environment in the 21<sup>st</sup> Century'. In the framework of the vision preparation process, among others, three major sector visions were prepared: 'Water for Food and Rural Development', 'Water for People' and 'Water and Nature'. The scope of these visions is 25 years. ICID has played a prominent role in the preparation of the sector vision of 'Water for Food and Rural Development' (Van Hofwegen and Svendsen, 2000).

The sector vision of Water for Food and Rural Development indicates a required duplication in food production and gives general recommendations how this increase can be achieved. The major part of the increase in production would have to come from already cultivated land, among others, by water saving, improved irrigation and drainage practices, and increase in storages. It became fully clear during the vision preparation process that, especially in the developing countries, huge efforts are required to feed the still growing worlds population, to improve the standard of living in the rural area, and to develop and manage land and water in a sustainable way.

In order to achieve the required increase in food production in the framework of sustainable rural development, the following issues are generally considered to be of major importance:

- availability of water and availability in space and time;
- links between irrigation, drainage and flood protection, and food security, protection of the environment, sustainable rural development and livelihood;
- rural development, agriculture based infrastructure, socio-economic and ethical issues, poverty alleviation, employment generation, migration from rural to urban areas;
- need for increasing withdrawals with 15 - 20% to bridge mismatch between demand and supply in combination with water saving and improved efficiency in irrigation;
- need for increasing storages with 10 - 15%;
- basin wide planning for integrated development and management;
- transbasin water transfers, shared rivers, conflict management;
- governance, legal, institutional and environmental issues;
- stakeholder involvement, youth and women participation;
- financing integrated water resources development and management (IWRDM), modernisation and replacement;
- equity, efficiency and economy.

Related to figures on the increase in withdrawals and storages it is questioned whether the assumptions regarding the increase in efficiency in irrigation can indeed be achieved in time and whether present unsustainable practices, like depletion of groundwater resources have sufficiently been taken into account. If not, the required increase in withdrawals and storages would become even higher.

### **FUTURE DIRECTIONS**

This brings us to the future directions. We cannot forecast these directions in detail, but tendencies can be observed that may sooner or later result in policy decisions, actual guidelines, or standards for design, implementation, operation, maintenance and management. These directions can be put under the following headings:

- integrated water management;
- developments in irrigation and drainage;
- integrated planning;
- sustainable development;
- acceptable environmental impacts.

Some background on each of these directions will be given.

#### **Integrated Water Management**

For many centuries water management was mainly focused on water quantity control, by water supply or drainage. In an increasing number of countries

nowadays we may speak about water quantity and water quality control, although at different levels of service, more or less dependent on the respective standards of living. What also can be observed is that water management in many regions is becoming more adapted to diversification in land use, and not exclusively anymore for agricultural use only. In future most probably another step will be taken and we will come to an ecosystem approach. In light of this we also have to consider the theme of this conference.

### **Developments in Irrigation and Drainage**

In irrigation and drainage there are certain specific issues that deserve our attention. Here we see that in the developed countries a lot has already been achieved, but that especially in the emerging developing countries these issues are far from being solved and that significant efforts will be required from the parties concerned (Figure 3) to find sustainable solutions. It regards especially:

- required increase in efficiency and water saving;
- institutional reforms in the direction of stakeholder controlled management and government support for modernisation, rehabilitation and reclamation;
- increased stakeholder participation;
- transfer of systems, or of responsibilities;
- modernisation;
- cost recovery.

With respect to the theme of this conference the issues of increase in efficiency and water saving are of special importance, while in several cases these are more or less linked to the need for transbasin water transfers. In light of this the modernisation of irrigation and drainage systems, especially in the emerging developing countries, will also have its influence. With respect to this it has to be realised that a significant part of the existing systems is more than thirty years old. While most of the increase in food production will have to come from existing cultivated land, the issue of modernisation, including the related institutional reforms and cost recovery aspects will deserve major attention in the coming period. Such modernisations will also have to be considered in light of water availability.

### **Integrated Planning**

Irrigation and drainage are no isolated activities. They play a role in societies and have to be treated, also taking into account such issues. Therefore of importance are:

- links between irrigation, drainage and flood protection, and food security, rural development and livelihood;
- basin wide planning for integrated development and management.

Especially related to the second issue the possibilities and constraints of transbasin water transfers will have to be considered.

### **Sustainable Development**

We are more and more concerned about the sustainability of our activities. In the past we did not have to bother so much about this, but increasing population pressure, changes in food production practices, and mining, or even exhaustion of resources have increased our concern. The following tendencies can be observed that in different ways will have an impact on our sector:

- migration of people from rural to urban areas;
- requirement of higher yields per ha;
- increase in farm sizes, higher value crops, or part time farming;
- mechanisation in agriculture;
- competition for water;
- increased application of fertiliser and pesticides;
- depletion of surface and groundwater resources.

As indicated before, especially in the emerging developing countries, there is the ongoing urbanisation and industrialisation. Another interesting feature is that within 50 years 80% of the worlds population is expected to live in coastal and deltaic areas. By far the majority of them in urban areas. In light of this the issue of flood management and flood protection of densely populated areas deserves special attention. In many densely populated flood prone areas the safety against flooding is less than once in fifty years, which is in fact significantly below the optimal level when the risk of loss of human lives and economic damage are evaluated. However, most of the countries where such situations exist don't avail of sufficient financial resources to realise higher levels of safety. In such cases transbasin water transfer may be an effective means for on the one hand realising the reduction in risk of flooding and on the other hand transferring water to an adjacent water scarce river basin.

### **Acceptable Environmental Impacts**

All our projects have side effects. The challenge has been and will be to keep the negative environmental impacts at an acceptable level and to support positive environmental impacts as far as reasonably possible. Of special importance for our sector are:

- controlled application of fertiliser and pesticides;
- quality criteria and quality control for drainage waters;
- prevention of water logging and salinization;
- prevention of depletion of surface and groundwater resources.

Transbasin water transfers may play a role related to the last issue. Increasingly we see depletions occurring, especially in the arid and semi-arid region. When solutions by way of transfers are being considered, the acceptable environmental impacts will also have to play a considerable role in decision making. This makes the decision making process generally very complicated while the environmental impacts of these, quite often large scale, works may be far reaching and very difficult to forecast and to quantify. Elaborate studies are generally required to identify the environmental values in the concerned areas and to forecast the environmental impacts of the envisaged works.

### RESERVOIRS AND TRANSBASIN WATER TRANSFERS

In the past years there has been quite some discussion on dams and reservoirs. The issue of transbasin water transfers did not get so much attention yet, although related to specific projects the discussions may be heated and decisions increasingly controversial.

In light of the global debate on dams and reservoirs ICID was asked in 1998 to clarify its position. This has resulted in a position paper on the 'Role of dams for irrigation, drainage and flood control', which was almost unanimously approved by our National Committees during the International Executive Council meeting in Granada, Spain (International Commission on Irrigation and Drainage, 1999). Most probably this was the first time that ICID took a position regarding a certain issue. In the near future ICID may prepare more of such position papers on topics that concern our National Committees. One main statement in the position paper reads.

*Irrigation, drainage and flood control of agricultural lands are no longer options. They are necessary for feeding billions of people, for providing employment for rural poor and for protecting the environment. With respect to this ICID stresses that dams have played and will continue to play an important role in the development of water resources, especially in developing countries. A balance needs to be found between the requirements based on the needs of society, acceptable side effects and a sustainable environment.*

*From ICID Granada Statement, 19 September 1999*

While irrigated agriculture is the largest water user at a global scale and an increase in withdrawals for irrigation is considered to be required in realising the required increase in food production, more storages will have to be developed for irrigation water as well. We may expect that increasingly such storages can only be developed in conjunction with transbasin water transfers. Therefore our sector may be considered as a major stakeholder in such developments.

### ROLE OF ICID

ICID is a scientific and technical, non-governmental international organisation. Its objectives are to stimulate and promote the development and application of irrigation, drainage, flood control, river training and environmental management in all their technical, economic, social and environmental aspects, as well as the needed research leading to the use of modern techniques. One of the interesting aspects of ICID is that, although it is a non-governmental organisation, there is a very good representation of government officials from ministries of Agriculture, Public Works, or Water Resources, as well as of the multilateral organisations that have programmes or projects in the sector. In this way ICID functions as a forum where representatives of the public and private sector, active in the field of water management and flood protection, can discuss and study subjects of joint interest. In addition to its forum function ICID disseminates its messages through the Journal Irrigation and Drainage, guidelines, books, congresses, conferences and workshops and the new media, like CD-ROM, ICID's website [www.icid.org](http://www.icid.org) and websites of various National Committees and Work Bodies.

In order to show its contribution to water for food and rural development ICID has prepared its Strategy for Action reflecting its specific ideas, position and plans as a key international association of professionals in the sector. Together with the Country Position Papers which were made by the National Committees the draft Strategy for Action was presented during the Second World Water Forum. The Strategy for Action also formulates what ICID considers of importance for guiding decisions and activities by the actors in the sector. In line with that ICID's own contribution has been formulated. The Strategy for Action has been discussed during the ICID Council Meeting in October 2000 in Cape Town, South Africa, where several suggestions for improvement were made and the strategy was approved. Several activities as outlined in the strategy will be described.

ICID is in the privileged position that its National Committees in many countries are very well organised and develop a wide range of activities that contribute to the development of the sector. A few key data on developments and activities are:

- **Meetings and conferences.** The list is impressive and the topics presented and discussed are all very relevant for the sector. In chronological order for this year:



- \* European regional conference on Sustainable Use of Land and Water, 4-8 June 2001, Brno and Prague, Czech Republic
- \* USCID conference on Transbasin Water Transfers, 27-30 June, Denver Colorado
- \* 4<sup>th</sup> IRCEW Competitive Use and Conservation Strategies for Water and Natural Resources, 27-30 August 2001, Fortaleza, Brasilia Brazil
- \* 52<sup>nd</sup> council meeting and 1<sup>st</sup> Asian Regional Conference on Agriculture, Water and Environment, Seoul, Korea

ICID's Congresses and Council Meetings are allocated up to 2006 with themes and topics that are all relevant to the problems of and developments in the sector. An additional service that is now available is that all the papers can be downloaded from ICID's Text Delivery Service at Central Office. This will make all this valuable information much more accessible than could be done in the past;

- ***Irrigation and Drainage***. ICID's scientific Journal that is now being published by John Wiley & Sons under ICID's full editorial responsibility. I sincerely hope that the Journal will have a bright future and encourage potential authors to submit quality papers;
- ***ICID products***. Several of ICID's other products have relevance for the sector and are gaining increasing interest. With respect to this specifically have to be mentioned:
  - \* web site: *www.icid.org*, including the Text Delivery Service;
  - \* multilingual technical dictionary in English and French, which is now also available on CD-ROM;
  - \* *ICID's books*. Reference is made to ICID's web site and to the forthcoming publication on Historical Dams that will be presented in the ICID Council meeting in Seoul, Korea in September;
  - \* *WatSave prices*. These prices focus on the promotion of water saving technologies and activities. This year the prices will be awarded already for the fourth time.
- there is an impressive list of activities that ICID is developing jointly with other organisations. Of special importance in relation to the theme of this conference is the *Dialogue on Water, Food and Environment*. If the International Executive Council meeting approves the proposal ICID will participate in the consortium that will be established for this dialogue. The other partners will be: UNEP, IWMI, FAO, IUCN, WHO, WWF, GWP.

Above are mentioned various specific activities and developments, which will directly, or indirectly contribute to improved water management for increased

agricultural production, poverty alleviation and sustainable development of the rural area. With respect to this I even did not mention all the work that is being done by ICID's working groups. If you are not familiar with this it is recommended to have a careful look at ICID's web site. You will undoubtedly find information that will be of use for you.

### CONCLUSION

There are tremendous challenges for the irrigation and drainage sector. Generally speaking we are prepared to deliver our contribution, but we have to be very keen to maintain and improve our position in light of scarcity and increased competition for water. In this light the theme of this conference is very relevant and has to be dealt with carefully and professionally. When we further develop our profession in a sustainable way we can serve societies in the way they have to be served.

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# **CASE STUDY - THE TRUCKEE CANAL: A TRANSBASIN DIVERSION FROM THE TRUCKEE RIVER BASIN TO THE CARSON RIVER BASIN**

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Michael C. Archer<sup>2</sup>

## **ABSTRACT**

The Truckee Canal, which diverts water from the Truckee River basin to the Carson River basin in Nevada, was constructed in 1905 by the Reclamation Service as a part of the Truckee-Carson Project. The Reclamation Service was the predecessor of today's United States Bureau of Reclamation. The development of a water supply for the Truckee-Carson Project and the operation of the Truckee River system and the Truckee Canal have resulted in almost one hundred years of controversy and litigation.

The Truckee-Carson Project was one of the first projects authorized by the United States government under the 1902 Reclamation Act. At the time of authorization, it was envisioned that 300,000 acres of desert land could be brought under irrigation with the water supply coming from both the Truckee and Carson Rivers. The attempt to develop a water supply for the Truckee-Carson Project and to satisfy the water rights of users upstream of the Truckee Canal diversion has been extremely controversial. Both of the rivers originate in California and flow into Nevada, introducing interstate issues. To further complicate matters, the Truckee River terminates in Pyramid Lake, the home of the Cui-Ui sucker fish, a federally listed endangered species. Pyramid Lake is fully contained within the Pyramid Lake Paiute Indian Reservation. The Truckee River is the primary water supply source for the cities of Reno and Sparks, two rapidly growing cities.

This case study traces the actions taken in the Truckee River basin to meet the Project demand and the resulting impacts on the entire Truckee River system. The demands placed on the Truckee River system have resulted in one of the most litigated and complex operations of any river system in the United States.

## **INTRODUCTION**

The Truckee Canal, completed in 1905, diverts water from the Truckee River basin to the neighboring Carson River basin in the State of Nevada as shown in Figure 1. The Truckee Canal is part of the Truckee-Carson Project, one of the

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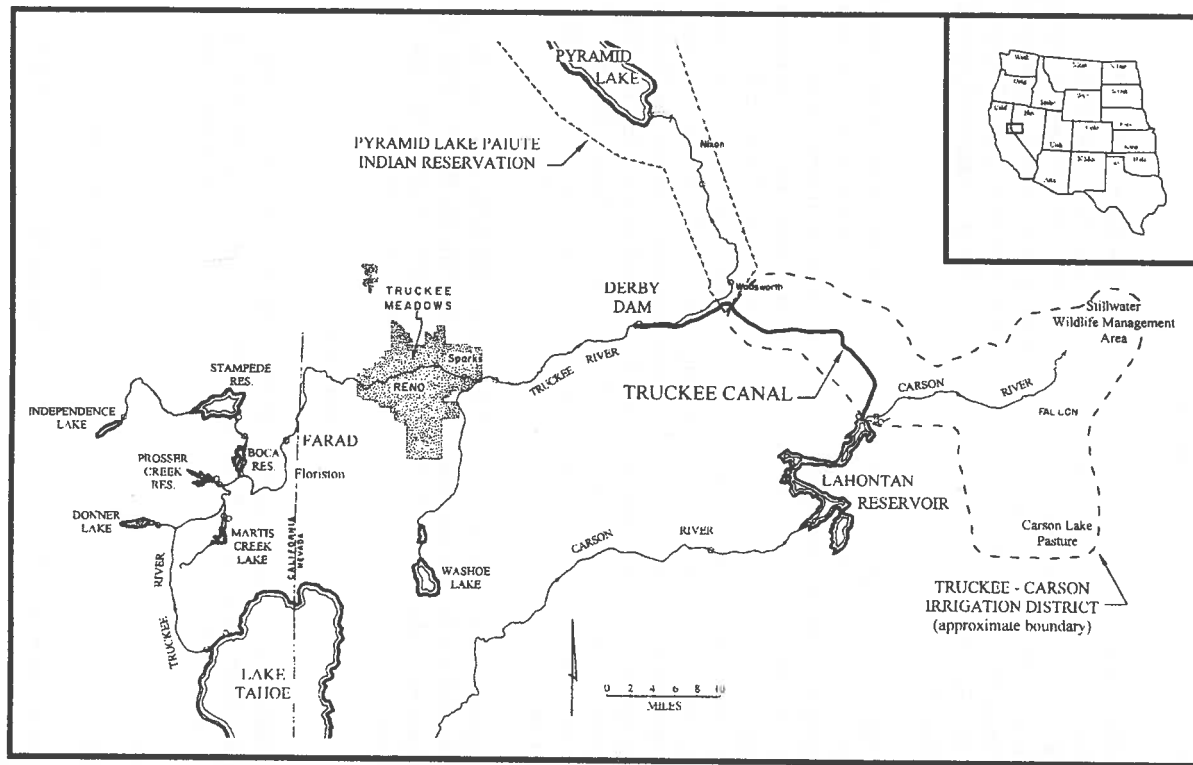


Figure 1. Location Map

first projects constructed by the United States Reclamation Service<sup>3</sup>, and has spawned nearly 100 years of litigation, water rights challenges, interstate interaction, endangered species challenges, Indian water rights claims, and congressional involvement on the Truckee and Carson Rivers. In 1990, the Truckee-Carson-Pyramid Lake Water Settlement Act (Settlement Act) was passed by the United States Congress to “resolve” the many Truckee-Carson interbasin and California-Nevada interstate issues. The Settlement Act is still in the implementation phase and appears to be several years away from finalization.

The Truckee River originates at Lake Tahoe in California and flows northeasterly to the California-Nevada border and continues to its terminus in Pyramid Lake, which is fully contained within the reservation of the Pyramid Lake Paiute Tribe. The Carson River originates in California on the eastern slope of the Sierra Nevada south of Lake Tahoe and flows northeasterly to its terminus in the Carson Sink. The Truckee Canal diverts water from the Truckee River at Derby Dam just upstream from the Pyramid Lake Paiute Indian Reservation and delivers that water to adjacent lands and to the Lahontan Reservoir on the Carson River.

The diversion from the Truckee River was one element in a complicated and ongoing saga involving the Truckee River in California and Nevada and the Carson River in Nevada. This case study outlines the historical sequence of events that has resulted in the Truckee River being perhaps the most litigated, contentious and complex water challenge in the United States.

### THE TRUCKEE-CARSON PROJECT

The Federal Reclamation Act of 1902 authorized the withdrawal of public lands in Nevada for the Truckee-Carson Project (Project). The Project was subsequently renamed the Newlands Project. In 1902 it was envisioned that an additional 300,000 acres of desert land could be irrigated by the waters of the Truckee and Carson Rivers. However, as of today, the Project, operated by the Truckee-Carson Irrigation District (TCID), has only 73,700 acres of water righted lands of which approximately 65,000 acres have been irrigated. Water is delivered directly from the Truckee Canal in the Truckee Division of the TCID and from Lahontan Dam and the Carson River in the Carson Division of the TCID. The Project has about 326 miles of canals. The Fallon Paiute-Shosone Indian Reservation near Fallon contains about 8,000 acres and is supplied irrigation water from the Project. The Carson River and tail-water from the Carson Division flow into two wetland areas: Carson Lake Pasture and the Stillwater Wildlife Management Area.

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<sup>3</sup> In 1923 the Reclamation Service became the United States Bureau of Reclamation.

When the Project was authorized, Reclamation Service engineers recognized that stored water in Lake Tahoe would be required for the Project. The upper seven feet of Lake Tahoe was regulated by a log crib dam at its outlet to the Truckee River, creating over 800,000 acre-feet of usable storage. The dam was owned and operated by the Donner Boom and Logging Company primarily for regulating the flow of the Truckee River to transport logs to downstream saw mills. In 1903 the Reclamation Service posted a notice at the dam claiming a right to store and release 3,000 cubic feet per second (cfs) from Lake Tahoe. In an effort to secure control of the outlet from Lake Tahoe, Reclamation Service purchased 64 acres of land south of the existing dam and in 1905 awarded a contract for the construction of new outlet works. Subsequent litigation by the owners of the dam and others resulted in the cancellation of the construction contract.

In 1905 the Reclamation Service completed the Truckee River Diversion Dam (Derby Dam) and the Truckee Canal to transport Truckee River water 31 miles to the Carson River. In 1915, the 162 foot high Lahontan Dam, which forms the 317,000 acre foot Lahontan Reservoir, was completed at the terminus of the Truckee Canal on the Carson River. The Canal has a capacity of 900 cfs but the Project has the right to discharge from Lake Tahoe an amount of water sufficient to deliver to the head of the Canal, after transportation losses, 1,500 cfs.

### LITIGATION AND NEGOTIATION

Without the benefit of stored water, the Project farmers were struggling to survive with an inadequate water supply. In 1908, The Truckee River General Electric Company (TRGEC) purchased the Lake Tahoe Dam and the adjacent 14 acres from the Floriston Land and Power Company and Floriston Pulp and Paper Company. The TRGEC was the predecessor of the current Sierra Pacific Power Company (SPPCo), the current purveyor of water in the Reno-Sparks metropolitan area<sup>4</sup>. In 1909, the Reclamation Service and the TRGEC jointly initiated reconstruction of the dam and by 1913 the dam, which is in place today, was completed. The dam regulates 6.1 feet of water in Lake Tahoe providing 720,000 acre feet of storage. In the 1908 purchase agreement, the TRGEC agreed to release stored water to maintain Truckee River flows of either 500 cfs or 400 cfs, depending on the time of year, as measured at the Farad Gage near Floriston at the California-Nevada state line. This flow requirement is referred to as the Floriston Rates. The Floriston Rates flow provided power for the pulp and paper company and water for four run-of-the-river power plants owned by the TRGEC. The Floriston Rates requirement also ensured water would be released for

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<sup>4</sup> Sierra Pacific Power Company's interest as purveyor of municipal water in Nevada has been purchased by the Cities of Reno and Sparks and Washoe County and will be managed by the Truckee Meadows Water Authority.

downstream uses and became the cornerstone and the key to potentially settling Truckee River water problems almost 100 years later.

Unable to consummate an operating agreement for the Lake Tahoe dam, the Reclamation Service took two significant steps to ensure a water supply for the Project. In 1913, the United States brought an action in federal court (*The United States of America vs. Orr Water Ditch Company, et al.*) to adjudicate the upstream water rights in Nevada in order to protect the Project's water rights with a priority of 1902. This action was not completed, as will be discussed later, until 1983. The other significant step was taken in 1915 when the United States brought a condemnation suit (*United States of America vs. The Truckee River General Electric Company*) for control of the Lake Tahoe Dam. The suit resulted in a stipulated decree that granted the United States an easement to use the outlet controlling works and the adjacent 14 acres at a cost of \$139,500. In this stipulated decree, the United States agreed to meet the aforementioned Floriston Rates requirement. The TRGEC retained ownership of the dam and surrounding land.

In the Orr Water Ditch Company adjudication, a Special Master for the federal court submitted his findings as to the owners of Truckee River water rights in Nevada which were approved by the Court in a "Temporary Restraining Order" in February 1926. At this time, the United States transferred the care, operation and maintenance of Lake Tahoe Dam to the Truckee-Carson Irrigation District. Although the Restraining Order dealt only with water rights in Nevada, there was concern by Lake Tahoe shore owners about how Lake Tahoe was to be operated, primarily in regards to high water levels. The problems between the States and the federal government were compounded by a severe drought in the early 1930s which lowered the level of Lake Tahoe below its natural rim resulting in limited water supplies for all Truckee River water right holders, including the Project, and severely limiting boating access to piers in Lake Tahoe.

After years of negotiations, the United States, TCID, Washoe County Water Conservation District (Reno-Sparks area), SPPCo and "Other Users of the Waters of the Truckee River" signed the Truckee River Agreement in June 1935. This was in effect an operating agreement, although not signed by California interests, which provided for stabilizing the mean elevation and limiting the maximum elevation of Lake Tahoe, provided for additional storage facilities to benefit the Washoe County Water Conservation District, reduced the flow of winter draft from Lake Tahoe, and served as the basis for entering a final decree in the Truckee River Adjudication suit. The Agreement required that a storage facility of at least 40,000 acre foot be constructed and operated in conformance with this agreement before a final decree could be entered. Boca Reservoir with a capacity of 40,800 acre feet was completed in 1939 and the final decree was entered in 1944. The final decree was challenged by the Pyramid Lake Paiute Tribe in 1975 (United

States of America and Pyramid Lake Paiute Tribe of Indians vs. Truckee-Carson Irrigation District, et al.) but the decree was upheld in 1983 by the United States Supreme Court. The Orr Ditch Decree allocated 30,000 acre feet of water for irrigation on the Pyramid Lake Indian Reservation but allocated no water to sustain the fishery or level of Pyramid Lake.

Throughout these years, the maximum amount of water possible was being diverted from the Truckee River at Derby Dam, not only for irrigation in the Project but also for single purpose power generation in Project facilities. These diversions had disastrous effects on Pyramid Lake as is shown on Figure 2. By the 1940s the lake level had dropped 60 feet and the world famous Lahontan Cutthroat Trout became extinct due to a combination of overfishing and the inability of the fish to migrate upstream to spawn. In 1970, the Cui-Ui, a sucker fish found only in Pyramid Lake and a cultural centerpiece to the Pyramid Lake Paiute Tribe, was designated an endangered species. A reintroduced strain of Lahontan Cutthroat Trout in Pyramid Lake has been listed as a threatened species.

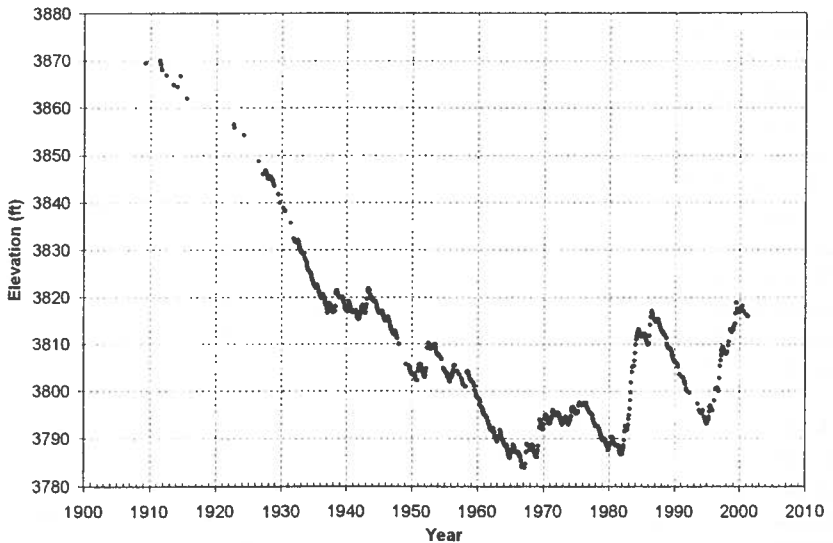


Figure 2. Historical Pyramid Lake Water Surface Elevation

If the water supply for Nevada interests, including the Project, was to be protected, it was imperative that California and Nevada reach agreement on the division of water in Lake Tahoe and the Truckee River Basin. The two states initiated negotiations in the 1950s to develop a compact on the division of the water. By 1970, after 15 years of negotiations, the two state legislatures approved the compact; however, the United States Congress refused to ratify the bi-state



agreement because of objections by the Pyramid Lake Paiute Tribe.

As the Pyramid Lake level continued to drop, litigation increased. In November 1972, and supplemented in 1973, the United States District Court, District of Columbia issued a ruling in Pyramid Lake Paiute Tribe of Indians vs. Rogers C. B. Morton, Secretary of the Interior finding that the Operating Criteria and Procedures (OCAP) for the Truckee and Carson Rivers, which would permit the diversion of 378,000 acre feet of water from the Truckee River at Derby Dam, were arbitrary and not based on the sound exercise of discretion. As a result of this ruling, the diversion in 1974 was not to exceed 288,000 acre feet. Additionally, detailed criteria defining when and how much water could be diverted were spelled out, checks on individual water rights were required, and actions to minimize waste were to be implemented. This action resulted in additional litigation when TCID, which was not a party in the aforementioned action, did not reduce their diversions or implement the court's order resulting in a 1979 order by the court for TCID to "repay" 1,050,000 acre feet to Pyramid Lake. As of this date, the repayment has not been initiated.

The enactment of the Endangered Species Act in 1969, the need to develop a secure water supply for the rapidly growing Reno-Sparks metropolitan area, litigation involving water quality issues, pressure to reduce the dependency of the Project on the Truckee River, and the imperative that California and Nevada reach a Congressionally approved bi-state agreement on the division of waters of Lake Tahoe and the Truckee River, came together with new urgency in the 1970s. Negotiations among the stakeholders resulted in failed attempts to get federal legislation to solve this myriad of outstanding problems.

A breakthrough in solving the impasse came when the President of SPPCo and the Chairman of the Pyramid Lake Paiute Tribe, met in 1988 and concluded that they held the key to providing a basis for settlement of these many issues. The key was the Floriston Rates. SPPCo would agree to forego the requirement that Floriston Rate flows be met at the run-of-the-river power generation plants when all the water was not needed by downstream water right holders. If the water saved by reducing Floriston Rates flow could be held back in upstream reservoirs, it could be stored as an emergency drought supply for the Reno-Sparks metropolitan area. Water stored in excess of the metropolitan area drought needs could be made available for release for fishery purposes when that water would be most beneficial for the endangered and threatened fish in Pyramid Lake. This concept was developed and incorporated into a Preliminary Settlement Agreement signed by Pyramid Lake Paiute Tribe and SPPCo in 1989.

Using the Preliminary Settlement Agreement as a foundation, California, Nevada, SPPCo, the Pyramid Lake Paiute Tribe, the Fallon Paiute Shoshone Indian Tribes and the TCID, under the sponsorship of Nevada's United States Senator Harry

Reid, developed the Negotiated Settlement Act which was adopted into law in 1990 in Public Law 101-618.

The Settlement Act apportions the waters of Lake Tahoe and the Truckee River between California and Nevada; authorizes the coordinated operation of all Truckee Basin Reservoirs and Lake Tahoe to enhance fish and wildlife, recreation and water supply benefits; authorizes the acquisition of water rights for additional water supply to wetlands and wildlife management areas; settles long standing litigation and claims between the stakeholders; provides funds to fulfill the Federal trust obligations to Indian tribes; fulfills the goals of the Endangered Species Act by promoting the enhancement and recovery of the endangered Cui-Ui and threatened Lahontan Cutthroat Trout; and protects significant wetlands from further degradation and enhances the habitat of many species of wildlife which depend on those wetlands.

Today diversion from the Truckee River, limited by the current OCAP and by acquisition of agricultural water rights for use in instream flow enhancement and for water quality improvement and protection of the endangered species, has resulted in reversing the decline in Pyramid Lake levels. With a repeat of the hydrology of the last 100 years and the implementation of the Negotiated Settlement, it is estimated that Pyramid Lake will rise over 60 feet.

To implement the Settlement Act, a Truckee River Operating Agreement (TROA) was to be negotiated for the operation of the Truckee River System. Although the Settlement Act was specific in many areas, the very detailed operating criteria required to carry out the mandate to coordinate the operation of all the Truckee River Reservoirs, to protect the existing water right holders and to meet newly defined environmental objectives, has resulted in eleven years of negotiations. These eleven years have demonstrated the axiom that the "devil is in the details". It is anticipated, or hoped, that the TROA will be signed this year and that the environmental documentation will be completed in two years. Subsequently, federal courts in Nevada and California will have to approve required modifications to the Orr Ditch Decree and the 1915 Lake Tahoe Decree.

### CONCLUSION

It will have been just over 100 years since the Truckee River transbasin diversion was implemented that the repercussions of that diversion may yet be "settled". However, that is dependent on the TROA being completed and signed by all necessary parties. If not, the litigation and/or negotiations may still go on - for another 100 years? Perhaps.

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# FIRMING OF M&I WATER RELIABILITY THROUGH THE USE OF UNDERGROUND WATER BANKING

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## ABSTRACT

The Central Arizona Project (CAP) transfers water from the Colorado River into the Salt, Gila and Santa Cruz River Basins in central and southern Arizona. The water entitlement for the CAP is one of the lowest priorities on the Colorado River. Due to political agreements between Arizona and California, the CAP essentially bears all shortages on the lower Colorado River. Hence, the CAP water supply is expected to be highly variable from year to year with shortages becoming more frequent as water depletions increase in the Upper Division States. Demand for M&I water for specific areas in central and southern Arizona is relatively constant from year to year and is inconsistent with a highly variable natural supply. The mechanism of banking of water in underground aquifers appears to be a very feasible method of smoothing out the variability in surface water supplies. This paper shows example applications for underground storage in central Arizona and presents some associated costs.

## INTRODUCTION

Traditional water storage projects have focused on placing dams on natural streams to form storage reservoirs. Only limited attention has been given to alternative storage in natural underground aquifers. CAP customers and water users have been experimenting with storage of water underground. The United States, on behalf of Indian tribes in central Arizona, is evaluating alternative schemes for underground storage and recovery to increase the reliability of water rights held by the Indians. We will briefly examine both the hydrologic and economic considerations involved in transfers and storage between basins in Arizona.

## COLORADO RIVER WATER PRIORITIES

Rights to use Colorado River Water are shared by seven Colorado River Basin States and Mexico, through a multitude of Federal and state statutes, interstate

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<sup>2</sup>Economist, Reclamation.

compacts, court decisions and decrees, an international treaty, operating criteria, regulations, administrative decisions, and contracts with the Secretary of the Interior (Secretary) collectively known as the *Law of the River*.<sup>3</sup> The Colorado River Basin is divided into the Upper Basin and the Lower Basin, each of which is entitled to 7.5 million acre feet of Colorado River water annually. The division point between the Upper and Lower Basins is Lee Ferry on the Colorado River, about 18 miles downstream of Glen Canyon Dam.<sup>4</sup> By treaty, Mexico is also entitled to 1.5 million acre feet annually.<sup>5</sup>

The Boulder Canyon Project Act of 1928 (Public Law 70-642) apportioned Arizona 2.8 million acre feet out the 7.5 million acre feet of Colorado River water apportioned to the Lower Basin.<sup>6</sup> The Colorado River Basin Project Act of 1968 (Public Law 90-537) authorized the Secretary to build, operate, and maintain the CAP. Under the *Law of the River*, unused apportionment remains as Colorado River or system water. Even though the Upper Basin is entitled to utilization of 7.5 million acre feet annually, development and utilization in the Upper Basin are far short of its right. Since CAP is the residual claimant in the Lower Basin, any under utilization in the Upper Basin enhances the projected possible diversions of Colorado River water into central Arizona. Presently, Upper Basin developments are depleting Colorado River flows by about 4.8 million acre feet per year. Projected Upper Basin depletions are shown on Figure 1. Full development is not expected to occur until about 2050. Total depletions are then estimated to be about 5.9 million acre-feet. Before full development is achieved in the Upper Basin, the unused water is assumed to be part of the CAP water supply.

### THE CAP

The CAP provides delivery facilities to move water from the Colorado River into central and south-central Arizona. Water is delivered to augment existing supplies in the Salt River, Gila River, and Santa Cruz River Basins. In addition to existing local surface supplies, alluvial ground water reserves have been widely developed to meet existing water demands.

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<sup>3</sup>Upper Division States are Colorado, New Mexico, Wyoming, and Utah. Lower Division States are Nevada, Arizona, and California. Collectively the seven states are known as the Colorado River Basin States or Basin States.

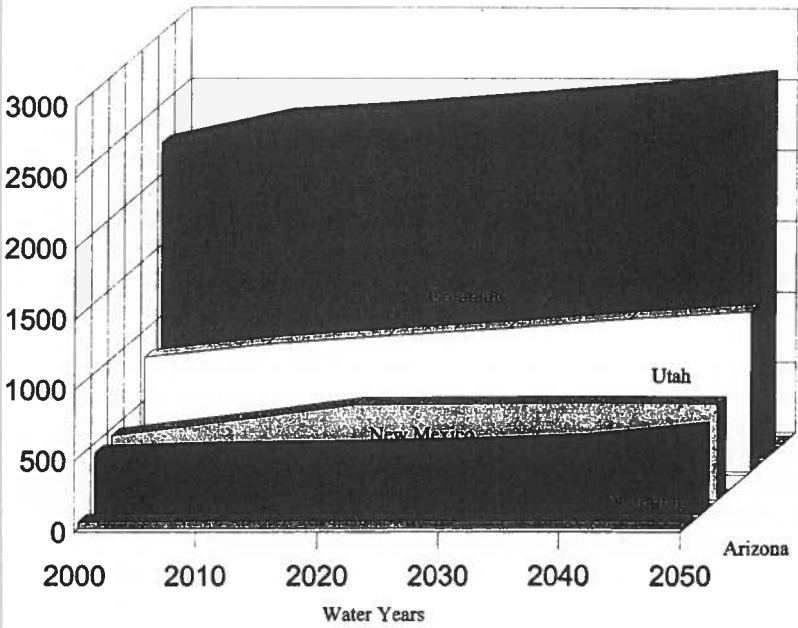
<sup>4</sup>The Colorado River Compact of 1922 apportioned water to the Upper and Lower Basins.

<sup>5</sup>United States – Mexico Water Treaty of February 3, 1944.

<sup>6</sup>The Lower Division states' apportionments are expressed in terms of a fixed amount of consumptive use for each state, subject to varying provisions at times of surpluses or shortages. These apportionments are: California 4.4 million acre feet, Arizona 2.8 million acre feet, and Nevada 0.3 million acre feet.

Figure 1. Upper Basin Depletion Projects  
(Based on 1998 Depletion Schedule)

Thousands  
of acre-feet



Note: Arizona has a 50,000 acre-foot apportionment from the Upper Division.

The CAP began limited deliveries of water in 1985. The physical system consists of a series of pumping plants, aqueducts, dams and reservoirs, which extend approximately 336 miles into central Arizona. The geography of the system is shown on Figure 2. The CAP system has the physical capacity to deliver up to 2.2 million acre feet of Colorado River water annually. However, operational limitations reduce the actual annual amount that can be delivered to a range of between 1.6 and 1.8 million acre feet.

### CAP WATER PRIORITIES

CAP water rights are a relatively low priority compared to rights held by other Lower Basin users. When less than 7.5 million acre feet is available in the Lower Basin, California receives its full 4.4 million acre foot entitlement, while Arizona and Nevada take reduced quantities. CAP also has a priority junior to most users in Arizona along the Colorado River.<sup>7</sup> Based upon current trends regarding Arizona's use of Colorado River water along the mainstem, the long-term consumptive use along the mainstem in Arizona is estimated to be 1.3 million acre feet, leaving 1.5 million acre feet available for diversion by CAP in a normal year (ADWR 1993).<sup>8</sup> The CAP was historically conceived to provide replacement water for local ground water sources that are over drafted.

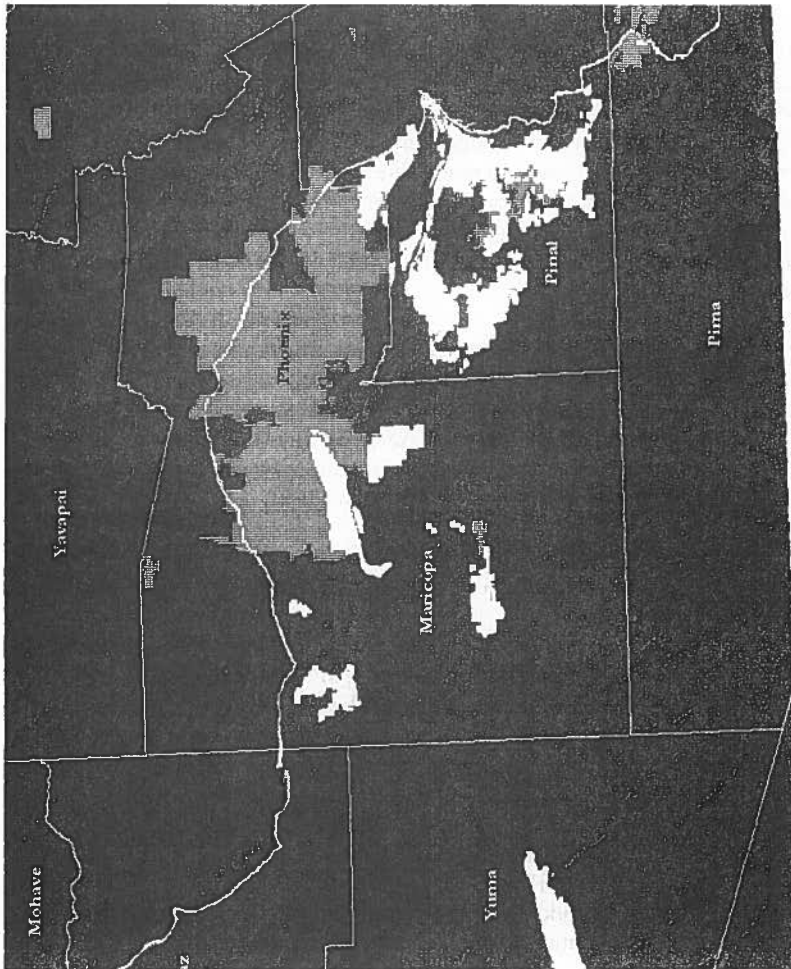
In accordance with Federal Reclamation law, uses of CAP water are divided into three major sectors: municipal and industrial (M&I), non-Indian agriculture, and Indian. Originally conceived as essentially an irrigation water replacement project, the CAP has evolved over time to reflect the rapid urban growth in central Arizona and increased awareness of Indian water rights and needs. CAP now has a greater emphasis on water uses for M&I and Indian purposes; non-Indian agricultural water deliveries have become almost incidental. Originally the CAP allocations were composed of 640,000 acre feet for M&I, 310,000 acre feet for Indians, with the residual (about 465,000 acre feet), after accounting for CAP system losses, available for non-Indian agricultural use. Currently, agreement between the United States and Arizona results in 603,678

<sup>7</sup> Rights established prior to September 1968.

<sup>8</sup> The Secretary is required to determine when normal, surplus, or shortage conditions occur in the lower Colorado River. Normal conditions exist when the Secretary determines that sufficient mainstream water is available for release to satisfy 7.5 million acre feet of annual consumptive use in the Lower Division states. Surplus conditions exist when the Secretary determines that sufficient mainstream water is available for release to satisfy consumptive use in the Lower Division states in excess of 7.5 million acre feet annually. Shortage conditions exist when the Secretary determines that insufficient mainstream water is available to satisfy 7.5 million acre feet of annual consumptive use in the Lower Division states.



Figure 2: Central Arizona Project Service Area



acre feet allocated to M&I purposes, 670,224 acre feet allocated to Indian purposes, and 141,098 acre feet available for agricultural deliveries. A significant portion of the Indian allocation will be utilized by M&I entities under long-term leases. The approximately 140,000 acre feet available for agricultural deliveries in the short-run is projected to be utilized for delivery to M&I users in future years.

Historically, in central Arizona, essentially all M&I and agricultural water supplies were extracted from underground aquifers. Enormous reserves of ground water continue to exist in various aquifers underlying Maricopa, Pinal and Pima Counties. Arizona water management policy dictates that M&I users shift their reliance from ground water to renewable surface water supplies. When the goal of "safe yield" is achieved, the ground water reserves will be utilized only in emergencies such as severe drought situations.<sup>9</sup> In the Lower Basin, central Arizona is in a somewhat unique situation of having a "back-up" supply of ground water to utilize as needed.

Water users in Arizona have been replenishing groundwater aquifers through both direct and indirect recharge projects. Indirect recharge is authorized as a beneficial use under Arizona law and is more commonly referred to as in-lieu recharge. Water users that have a ground water right take delivery of CAP surface water in-lieu of pumping ground water. Ground water credits may be earned from both direct and in-lieu recharge of an aquifer.

### THE BASIC CAP PROBLEM

Non-Indian agricultural water users have long relied upon ground water as the primary source for irrigation of crops. Shortages of CAP water simply force irrigators to recommence the pumping of ground water. Ground water pumping may occur fairly easily on a yearly basis as well as on a seasonal basis because the ground water extraction facilities and infrastructure have been in place for a long time. The Arizona ground water code continues to respect ground water rights that are associated with agricultural lands. The CAP water, upon which agriculture relies, was always intended to be a diminishing water supply. As development in the Colorado River Basin continues and increasing pressure is placed upon existing Colorado River water supplies, the amount of water available for CAP agricultural use will decrease.

M&I users have also long relied upon under ground aquifers as their primary source of water for delivery. However, with the completion of the CAP and enactment of the Arizona State ground water code, municipalities have been required to shift their reliance upon ground water to renewable surface water

<sup>9</sup> Safe yield means that over time extraction does not exceed the rate of natural, incidental, and direct recharge.

supplies. M&I demand is fairly uniform throughout each calendar year; therefore, any interruption in M&I supplies is more serious than interruptions in agricultural supplies. The overall goal for the municipalities that overlie ground water aquifers is to achieve safe yield. Natural recharge in many basins within the CAP service area of Maricopa, Pinal, and Pima Counties is on the order of 10,000 to 20,000 acre feet annually in each county as compared with M&I demands of 400,000 to 500,000 acre feet per year.

CAP M&I allocations are fairly firm; only minor cutbacks in supply are expected over the next 100 years. In contrast, CAP agricultural water allocations are increasingly being targeted for use for M&I purposes. CAP agricultural water that is used to satisfy M&I purposes retains its CAP agricultural priority and is less firm than CAP water carrying an M&I priority. In the future, during certain years, CAP agricultural priority water may be unavailable.

The classical approach to solving this dilemma is to build more reservoir storage in order to increase the firm supply of the Colorado River and even out supplies on a yearly basis. However, a host of political, environmental and economic concerns have combined to essentially preclude any future reservoir construction. Furthermore, in some instances, the total firm yield of the Colorado River has already been maximized since additional water cannot be stored in existing reservoirs on the mainstream without a high risk of spills.

After deducting system losses of the CAP, about 1.415 million acre feet of Colorado River water are available for delivery into central Arizona. Direct use demands are currently less than 1 million acre feet per year. The Colorado River system has been in a surplus condition for the last few years. Projections of normal runoff and expected demands indicate that surplus conditions may continue for the next 10 to 15 years. However, additional storage space in reservoirs is unavailable due to the high risk of spills.

### **POSSIBLE SOLUTION**

Arizona State law and water users have implemented a storage strategy in the short-run to firm-up CAP water supplies for a 100-year period. This strategy involves the storage of water in under ground aquifers, for future withdrawal, instead of storage in above ground reservoirs. Water is placed in storage either by direct injection into aquifers or by in-lieu utilization of surface water and reduction of ground water pumping. The primary advantages of underground storage are the elimination of reservoir evaporation losses and substantially reduced capital expenditures. Possible disadvantages include contamination of stored water by existing groundwater and the need to leave a "cut for the aquifer." Under Arizona law, 5 percent of the water stored under ground must be left in the aquifer to enhance the long-term reserves. In addition, when the stored water is

needed for use, recovery costs are substantial compared to the usual reservoir scheme involving gravity flow of stored water into the delivery system.

An important requirement for implementation of an under ground storage scheme is the estimation of the amount of water which must be stored for later use in order to firm-up CAP agricultural water supplies that will serve M&I demand to equal M&I reliability.

#### **STORAGE OF WATER IN ONE BASIN FOR USE IN THE SAME OR ANOTHER BASIN**

The intent is to utilize CAP agricultural priority water for M&I use, but firm-up the agricultural water to M&I water reliability levels. Presented below are the assumptions and methodology employed to achieve a 100-year M&I equivalent water supply.

The estimated CAP water supply is based upon a 17-trace simulation over a 100-year period. Assuming that all shortages are borne by non-Indian agriculture water users, approximately 17 years of shortage occur during the first 50 years. For the next 10 to 15 years, surpluses are expected on the Colorado River system. The probability of shortage in the Lower Basin is shown on Table 1 on an annual basis. Table 1 reflects that the probability of shortage increases to about 62 percent by year 2050. Beyond 2050, the probability of shortage remains constant.

Table 1. Probability of Lower Basin Shortage

Dec-00	0.0000	Dec-19	0.2706	Dec-38	0.5765
Dec-01	0.0000	Dec-20	0.2824	Dec-39	0.5765
Dec-02	0.0000	Dec-21	0.3294	Dec-40	0.5765
Dec-03	0.0000	Dec-22	0.3647	Dec-41	0.5765
Dec-04	0.0000	Dec-23	0.3882	Dec-42	0.5765
Dec-05	0.0000	Dec-24	0.3765	Dec-43	0.5765
Dec-06	0.0000	Dec-25	0.4235	Dec-44	0.5882
Dec-07	0.0000	Dec-26	0.4824	Dec-45	0.5882
Dec-08	0.0000	Dec-27	0.5059	Dec-46	0.6118
Dec-09	0.0000	Dec-28	0.5059	Dec-47	0.6118
Dec-10	0.0000	Dec-29	0.5294	Dec-48	0.6235
Dec-11	0.0118	Dec-30	0.5294	Dec-49	0.6235
Dec-12	0.0588	Dec-31	0.5294	Dec-50	0.6235
Dec-13	0.0824	Dec-32	0.5412		
Dec-14	0.1294	Dec-33	0.5412	Average	0.375
Dec-15	0.1294	Dec-34	0.5529		
Dec-16	0.1294	Dec-35	0.5529	Years of Short.	17.5
Dec-17	0.1647	Dec-36	0.5529		
Dec-18	0.2000	Dec-37	0.5765		

**Water Storage Requirements for Firming.**

The first task is to ascertain the quantity of water that needs to be stored during surplus and normal years to provide a reserve that can be drawn upon during shortage years. A simple formula has been developed to ascertain the storage quantity. The formula is applicable to any quantity of water for which firming is desired. The example illustration will calculate the amount based on a single acre foot. The results can then be multiplied by the actual quantities of concern. The formula proposed for utilization is:

$$AS = \frac{(D * MI * \% ) 1.05}{(1 - \%)}$$

where: AS = annual amount of storage required in a non-shortage year

D = target amount to be delivered in a shortage year

MI = % of reliability of M & I desired

% = percent of shortage years

1.05 = cut for the aquifer

(1-%) = percent of normal and surplus years

With the following assumptions,

D = 1, MI = 98 percent, and % = 35.7

the quantity to be stored totals 18.57 acre feet for each acre foot of water requiring firming over the next 50 years. For the second 50 years the amount of storage would be 64.16 acre feet for each acre foot requiring

firring. For the full 100-year period the amount of required storage would total 82.73 acre feet for each acre foot to be firred. Detailed calculations both with and without storage recovery costs as shown on Table 2 and 3. These two tables show results for the full range of M&I reliability that could be considered.

Table 2. Analysis of Stored Water and Costs Needed to Firm CAP Non-Indian Agricultural Water to M&I Reliability  
(All values are on one acre foot basis)

$$\text{Equation: } \frac{(D * MI * \%)}{(1-\%)} * 1.05$$

where: D = 1 acre foot being firred

MI = % of reliability (expected is 98%)

% = percent of shortage years

1.05 = cut for the aquifer

Assumptions of water cost: Water cost escalates 3 percent annually  
Discounting of future costs at 6 percent  
Variable cost of CAP water is \$29 per acre foot  
Fixed cost of CAP water is \$29 per acre foot  
Cost of groundwater recovery is \$30 per acre foot  
(95% of stored is recovered)

Assumptions for calculations: 50 year costs based on storage in first 15 years and recovery in last 10 years  
51 to 100 year costs based on storage and recovery every year

M&I Reliability	1 <sup>st</sup> 50 year Required Annual Storage (note 1)	1 <sup>st</sup> 50 year Additional Water	P.V. Added Cost per Acre foot	2 <sup>nd</sup> 50 year Required Annual Storage (note 2)	2 <sup>nd</sup> 50 year Additional Water	P.V. Added Cost per Acre foot
100%	0.5830	18.95	\$640	1.834	65.47	\$1,075
98%	0.5713	18.57	\$628	1.797	64.16	\$1,055
90%	0.5247	17.05	\$584	1.650	58.92	\$976
85%	0.4955	16.10	\$556	1.559	55.65	\$926
80%	0.4664	15.16	\$528	1.467	52.37	\$876
75%	0.4372	14.21	\$500	1.375	49.10	\$826
70%	0.4081	13.26	\$471	1.284	45.83	\$776
65%	0.3789	12.32	\$444	1.192	42.55	\$727

Note 1: Based on average of 35.7 percent shortage during next 50 years. This is the amount (in acre-feet) of water required to be stored each year during normal and surplus flows in order to firm up 1 acre foot.

Note 2: Based on average of 62.35 percent shortage in years 51 through 100. This is the amount (in acre-feet) of water required to be stored each year during normal and surplus flows in order to firm up 1 acre foot.

Table 3. Analysis of Stored Water and Costs Needed to Firm CAP Non-Indian Agricultural Water to M&I Reliability

(all values are on one acre foot basis)  
(no costs are included for groundwater recovery)

Equation: 
$$\frac{(D * MI * \%)*1.05}{(1-\%)}$$

where: D = 1 = acre foot being firmed  
MI = % of reliability (expected is 98 %)  
% = percent of shortage years  
1.05 = cut for the aquifer

solving for additional quantity of water needed to firm an acre foot of right

Assumptions of water cost: Water cost escalates 3 percent annually  
Discounting of future costs at 6 percent  
Variable cost of CAP water is \$29 per acre foot  
Fixed cost of CAP water is \$29 per acre foot  
No cost of groundwater recovery

Assumptions for calculations: 50 year costs based on storage in first 15 years and recovery in last 10 years  
51 to 100 year costs based on storage every year

M & I Reliability	1st 50 year Required Annual Storage (note 1)	1st 50 year Additional Water	P. V. Added Cost per Acre foot	2nd 50 year Required Annual Storage (note 2)	2nd 50 year Additional Water	P. V. Added Cost per Acre foot
100%	0.5830	20.81	\$560	1.739	65.21	\$801
98%	0.5713	20.40	\$549	1.704	63.90	<b>\$786</b>
90%	0.5247	18.73	\$504	1.565	58.69	\$721
85%	0.4955	17.69	\$477	1.478	55.43	\$682
80%	0.4664	16.65	\$448	1.391	52.17	\$641
75%	0.4372	15.61	\$421	1.304	48.91	\$602
70%	0.4081	14.57	\$392	1.217	45.64	\$561
65%	0.3789	13.53	\$365	1.130	42.38	\$522

Note 1: Based on average of 35.7 percent shortage during next 50 years

Note 2: Based on average of 62.35 percent shortage in years 51 through 100

### Cost of Water Storage Program.

The second concern is the cost of the water storage program. The cost will vary depending upon whether the storage is direct or indirect (in-lieu). Calculated costs for direct storage are shown on Tables 2 and 3. All costs, delivery, direct recharge, and recovery, are expected to escalate 3 percent annually.

The cost of delivery is based upon the total of fixed and variable operations and maintenance costs associated with CAP water in 2001. That cost is currently \$58 per acre foot. The cost of direct recharge is estimated to average about \$20 per acre foot. Future recovery cost is estimated to be \$30 per acre foot. Future costs are discounted to the present at a 6 percent rate. Fifty year costs are based upon storage in the first 15 years and recovery in the last 17 years of the period. The second 50-year costs are based upon storage and recovery every year.

Direct Storage: Given the above assumptions, the present value of the added cost for water storage for 50 years is about \$628 per acre foot using a 6 percent discount factor. For the second 50 years the added cost would total about \$1,055 per acre foot. The total cost for 100 years would be about \$1,683 per acre foot for both storage and recovery.

In-direct Storage: Irrigation partners that would pay \$21 per acre foot are assumed to be obtained. This credit, \$21, plus the elimination of the \$20 per acre foot direct recharge cost, would lower costs by over \$40 per acre foot. The resulting cost of storage for the first 50 years would total about \$549 per acre foot. For the second 50 years, the added cost would total about \$786 per acre foot. Total cost to firm up water for a 100-year period would be about \$1,335 per acre foot.

### Indian Water Storage Possibilities.

The Gila River Indian Community (GRIC) has water rights from the San Carlos Project. Gila River water is impounded in San Carlos Lake behind Coolidge Dam. The hydrology is such that the reservoir has rarely been filled. The San Carlos Apache Tribe (SCAT) derives fishery benefits from the reservoir. During drought periods the fishery has been in danger of disappearing completely. Temporary exchanges of CAP water for stored Gila River water has kept the fishery alive to the present.

The concept of a Federal water bank has been explored which would have significant benefits to both SCAT and GRIC. Table 4 shows the water budget possibilities associated with such a water bank. CAP surface water deliveries would substitute for Gila River surface deliveries and for groundwater pumping. About 180,000 acre feet annually could be stored underground and in San Carlos



Lake. Based upon CAP water availability, more than 2.5 million acre feet could be stored over the next 20 years. In addition to the significant fishery benefit, an increase in head at Coolidge Dam may result in an important power benefit. About 800,000 acre feet could be stored in San Carlos Lake for a number of years resulting in greatly enhanced recreation benefits. About 1.8 million acre feet could be stored beneath the Gila River Reservation for future use during dry periods.

Table 4. Federal Water Bank Data for Gila River Indian Reservation with CAP Water

Assume:	<p>Surface water, about 800,000 acre feet, could be left in the San Carlos Reservoir (actual capacity is 867,400 af)</p> <p>Groundwater, about 1.8 million acre feet, could be left in the aquifer without adverse effects</p> <p>Storage would not begin before GRIC settlement is final -- 2003</p> <p>GRIC could maintain rights to its unused stored water in San Carlos Reservoir without loss to SCIDD</p> <p>GRIC could secure groundwater credits in its aquifer and would have capability to extract in future (current capacity is about 223,000 af/yr)</p> <p>GRIC could secure groundwater recovery rights of its accrued credits which would total about 1.7 million acre feet</p> <p>Storage in, and non-delivery of SCIIP water from the San Carlos Reservoir needs no State approval, only agreement with SCIDD</p> <p>CAP water can be delivered to most currently irrigated lands on GRIC (can currently deliver to about 85 percent of irrigated lands)</p> <p>CAP water could be delivered through RWCD and SRP system, in addition to SCIIP system</p>
Concl.:	<p>Over 71,500 acre feet could be "firmed", leaving a 5 % "aquifer cut"</p> <p>About 80 percent of the interim excess CAP water could be "in-lieu" recharged</p> <p>The GRIC aquifer would have a long-term permanent gain of about 130,000 acre feet due to the "cut"</p> <p>Significant fishery benefit to San Carlos Apache Tribe</p> <p>Improved power generation head may be an important benefit to SCIIP.</p>

## Transbasin Water Transfers

Table 4. Federal Water Bank Data for Gila River Indian Reservation with CAP Water (cont.)

All tabular values in acre feet, unless noted otherwise.								
Present Water Supplies which could be replaced with CAP Water								
Year	Projected On-Res. Direct Use	GRIC CAP Interim Excess (note)	SCIIP Pumped Water (58 yr. ave.)	SCIIP Surface Water (58 yr. ave.)	GRIC Pumped Water (58 yr. ave.)	Maximum Potential Total	Available CAP water Constrained Total	Delivery System Constrained Total
2000	0	328,500						
2001	0	328,500						
2002	0	328,500						
2003	0	328,500	79,609	90,157	41,713	211,479	211,479	179,757
2004	0	328,500	79,609	90,157	41,713	211,479	211,479	179,757
2005	56,000	272,500	79,609	90,157	41,713	211,479	211,479	179,757
2006	71,000	257,500	79,609	90,157	41,713	211,479	211,479	179,757
2007	86,000	242,500	79,609	90,157	41,713	211,479	211,479	179,757
2008	101,000	227,500	79,609	90,157	41,713	211,479	211,479	179,757
2009	116,000	212,500	79,609	90,157	41,713	211,479	211,479	179,757
2010	131,000	197,500	79,609	90,157	41,713	211,479	197,500	179,757
2011	146,000	182,500	79,609	90,157	41,713	211,479	182,500	179,757
2012	161,000	167,500	79,609	90,157	41,713	211,479	167,500	167,500
2013	176,000	152,500	79,609	90,157	41,713	211,479	152,500	152,500
2014	191,000	137,500	79,609	90,157	41,713	211,479	137,500	137,500
2015	206,000	122,500	79,609	90,157	41,713	211,479	122,500	122,500
2016	221,000	107,500	79,609	90,157	41,713	211,479	107,500	107,500
2017	236,000	92,500	79,609	90,157	41,713	211,479	92,500	92,500
2018	251,000	77,500	79,609	90,157	41,713	211,479	77,500	77,500
2019	266,000	62,500	79,609	90,157	41,713	211,479	62,500	62,500
2020	281,000	47,500	79,609	90,157	41,713	211,479	47,500	47,500
2021	296,000	32,500	79,609	90,157	41,713	211,479	32,500	32,500
2022	311,000	17,500	79,609	90,157	41,713	211,479	17,500	17,500
2023	326,000	2,500	79,609	90,157	41,713	211,479	2,500	2,500
2024	328,500	0	79,609	90,157	41,713	211,479	0	0
2025	328,500	0	79,609	90,157	41,713	211,479	0	0
Totals	4,286,000	4,286,000	1,831,007	2,073,611	959,399	4,864,017	2,880,353	2,637,814
Note: Excess values for 2000, 2001, and 2002 are not included in totals								

GRIC - Gila River Indian Community

SCIDD - San Carlos Irrigation and Drainage District

SCIIP - San Carlos Indian Irrigation Project

RWCD - Roosevelt Water Conservation District

SRP - Salt River Project

**SUMMARY AND CONCLUSIONS**

Storage of excess Colorado River flows which exceed current demand in underground basins in central Arizona appears to be both hydrologically and economically feasible. Arizona law has authorized underground storage as a beneficial use of water. Water users have begun to store water in the Phoenix and Tucson aquifers. Current market values of water indicate a price of about \$1,500 to \$2,000 per acre foot, resulting in an excess of benefits over costs. The requirement by the State of Arizona to leave an aquifer cut promises at least partial restoration of depleted aquifers.

Current direct demand for CAP surface water in Arizona is less than 1 million acre feet annually. Given an entitlement of about 1.5 million acre feet, transfer and storage of the excess water supplies over the next 20 years appears to be an excellent management strategy in planning for future water needs.



**TRANSBASIN WATER TRANSFER  
DOLORES RIVER  
SOUTHWESTERN COLORADO**

**John Porter<sup>1</sup>**

**ABSTRACT**

Transbasin diversions historically have facilitated settlement of the West, an inhospitable land without the development of water. Given that water is a finite resource, new competing environmental / recreational demands set the stage for increased motivation for efficient water management, controversy and finally litigation.

Regarding the Dolores River, two diversions, primarily for agriculture, began with private development in 1886. Within a short period of time, the River below the point of the two diversion was a dry - dead river during the annual irrigation season.

One of the components of the Bureau of Reclamation's Dolores Project, which was constructed, beginning in 1979 and completed in 1999, was to re-water the river during irrigation season. The second largest user of the new McPhee Reservoir, an on-stream impoundment facility, is the water (33,200 acre feet) released to resurrect the river below McPhee to create habitat for a quality fishery.

A controversy erupted during the five year drought of 1988-1992. It focused on the pattern of the release. It was determined that management of a "pool" of water, where less water would be released during the cold winter months and greater flows during the hot summer months would be advantageous. It took five years to agree, and implement that change. The controversy now focuses on the fact that the "pool" is not big enough.

Last fall the Dolores Water Conservancy District finished a feasibility study, with CWCB funding, of a project called WETPACK (Water for Everyone Tomorrow PACKage). WETPACK's purpose is two fold. First, it explored ways to obtain / develop more water for the fishery. Second, it moves water, that Montezuma Valley Irrigation Company is not presently using, to the Dove Creek area of the Dolores Project to develop 4,000 acres of added irrigation. The District recently obtained a loan from CWCB to begin the agriculture portion of WETPACK.

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## INTRODUCTION

The Dolores River originates in the San Juan Mountains, fifty miles northeast of the Town of Dolores, in Southwestern Colorado.

For those who are not familiar with the Dolores River System, the head waters are above Dunton on the West Fork and Rico on the East Fork, south west of Telluride, south-east of Norwood, north-west of Durango and north-east of Cortez. From Lizard Head Pass, the river flows in a southwesterly direction to the Town of Dolores. There it does an about face, heads northwest, then joins the San Miguel just west of Naturita, then to the Colorado River half way between Grand Junction, Colorado and Moab, Utah.

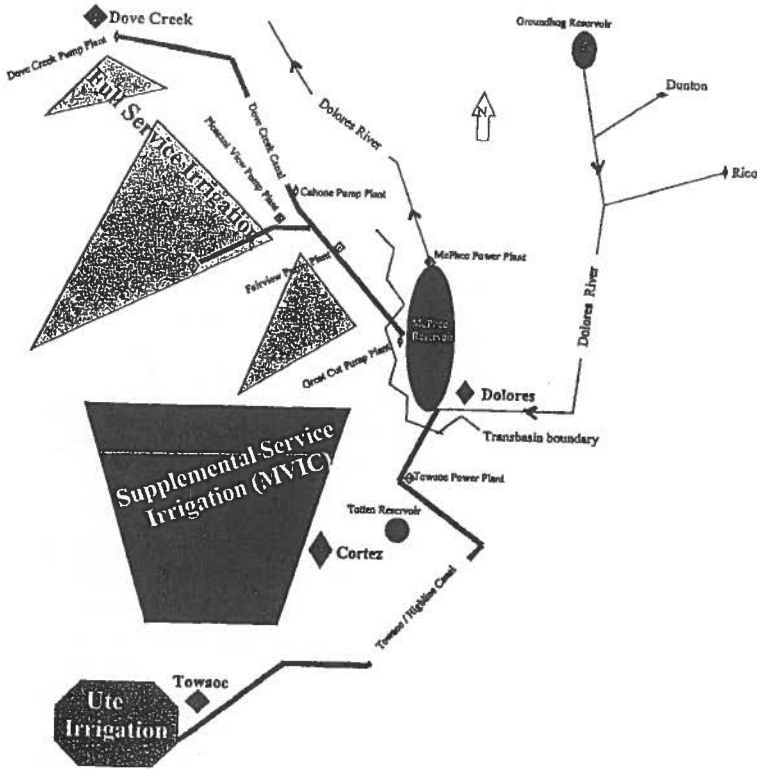
In 1776 the Fathers Dominguez and Escalante came through the area, looking for a shorter route to California. As they camped on a bluff overlooking the Dolores River to the east and the vast expanse of land in the San Juan drainage to the west, they observed that, "If the river's water supply could be brought to the land, it could sustain a culture." One hundred ten years later (1886) this came to pass, when a private ditch Company constructed two transbasin diversions, a tunnel and a canal from the Dolores River to the Montezuma Valley / San Juan Basin. From that point until 100 years later (in 1986) the first year water was used from McPhee Reservoir, the Dolores River was a dry / dead River, downstream of the two transbasin diversions during the irrigation season, from mid June to mid October.

Except for relatively small amounts of consumptive use upstream of the Town of Dolores, all of the traditional use of the Dolores River is a transbasin diversion, into the San Juan River drainage. Fortunately there is very little development / use of the Dolores River downstream of the transbasin diversion – in fact only 3,900 AF ("AF") or 9.2 cubic feet per second ("cfs") to satisfy private senior water rights below McPhee Dam. Since the first diversion in 1886, an entire economy, supporting a population of 17,000, has built itself upon transbasin diversion of water from the Dolores River. That is until the "New West" came to pass, where instream flow, fish habitat and recreation also need water.

## THE STORY

THIS STORY, THEN, IS, there is not enough water to go around; THE STORY IS, Old West meets New West; THE STORY IS, The Old Bureau gives way to New Bureau; THE STORY IS, will Irrigators and Fishermen compromise; OR will they continue to fight? THE STORY IS, the Dolores Project DOES satisfy both Old and New needs.

This story has most of the classic components of why water is so controversial. First and foremost, it is about a trans-basin diversion, in addition it is about senior private in-basin water rights, it is about endangered fish in one basin and



A graphic illustration of the Dolores Project  
Southwest Colorado

depletion of traditional return flows, it is about Colorado's allocation to the Colorado River, per the 1922 Compact, it is about the Upper Colorado River Basin Salinity Control Program, specifically the McElmo Unit, it is about Colorado law as it applies to "saved water" vs. contractual provisions concerning that saved water, it is about a carriage contract with the federal government to transport non-project water through federal facilities, it is about the local community's desire to preserve agriculture vs. recreation's desire for more in-stream flow, it is about the recreational boaters perception that cloud seeding will not mitigate new storage depletion, it is about U S Forest Service Federal Reserved Rights for in-stream flow in the Dolores Basin below McPhee Dam, and finally it is about settlement of Winters Doctrine Indian water claims to the neighboring Mancos River.

### **Dolores Project Planning**

During the 1970s planning for the water needs for the multi-purpose Dolores Project, the Bureau of Reclamation ("BOR"), not only planned for the traditional uses of a project, but had to plan for two unique / non-traditional needs. One, the Dolores Project could be the means for satisfying Ute Mountain Ute Indian Tribe's ("UMUT") winters doctrine claims to the Mancos River and Two, a bypass flow for a fishery below McPhee Dam, which required re-watering the river during irrigation season. Incidentally, the fishery release is the second largest user of McPhee Reservoir (33,200 AF). These two uses define the Dolores Project as a model for the "New West" era.

To get the water for these, up till then, non-traditional needs the BOR converted the design of non-Indian Full Service irrigation features of the Project from an "open ditch surface delivery" system to an "underground pressurized pipeline" system. Doing so saved enough water for those two unique purposes. One, it provided 23,200 AF of water for the UMUT to irrigate 7,500 acres of land, which was pure desert. Also the water became the basis for settlement of their claim to the Mancos River. It provided 25,400 AF (which has now been expanded) of water for a stocked, quality, year around fishery below McPhee Dam. Since there are no other users below that point the release amounts to a 100% consumptive use of water as far as users in the State of Colorado are concerned.

### **Project's EIS Planned A 20-50-78 Cfs "Flow"**

Specifically, for the creation of what is now called the "downstream fishery, or just Fishery" the BOR realized that without being able to develop all of the flow of the Dolores River (to do so meant flooding the town of Dolores) the Fishery would have to share shortages commensurate with other users, specifically irrigators. The method the BOR chose to administer such a shortage was to incorporate into the final Environmental Impact Statement ("EIS") a mechanism whereby the release below McPhee would be either 20 cfs, 50 cfs, or 78 cfs, depending on whether it was a dry, normal or wet year. The type of year was to



be determined on March 1st of each year based on the content of the reservoir and the relative amount of snow pack. If those two criteria established a "dry" year then 20 cfs would be released for the next 365 days. If the formula determined a "normal" year then 50 cfs would be the next years release and if it was a "wet" year, then 78 cfs was the annual release.

Construction of McPhee Dam was completed in the fall of 1983. Filling began in the spring of 1984. Filling of the reservoir was completed in 1987. Very few irrigation users were on line, so there was plenty of water for the Fishery during filling. The release was set at 150 cfs until the drought of 1988 THROUGH 1992. The Colorado Division of Wildlife ("DOW") began a fish-stocking program below the dam in the fall 1983 and continued throughout the filling of the reservoir and beyond. A grand fishery was established.

### Test Of Environmental Impact Statement

THEN the drought of 1988 through 1992 hit! In accordance with the Project's EIS, the March 1, 1990 content of the reservoir and the snow pack dictated a "dry" year - 20 cfs release to the Fishery. The release was decreased from 78 cfs to 20 cfs. Contrary to the Environmental Impact Statement ("EIS") guidelines, the Dolores Water Conservancy District ("District" or "DWCD") & BOR agreed to re-evaluate the criteria on May 1st. As a result of April precipitation, the calculation was much nearer being a "normal" year with a 50 cfs release. In fact had the calculation been redone on May 5th it would have clearly been a normal year. The District and the BOR abided by the EIS guidelines. "We were obeying the environmental edict to the letter of the law". Recreationalists expect administrators to follow an EIS when it was in their favor, so we gleefully followed it when we perceived it to be in traditional users favor.

In March, the Five Rivers Chapter of Trout Unlimited ("TU"), wrote "arbitrary selection of water use and management by DWCD is offensive and wrong". Naturally, the District responded with a defensive retort as follows: "More water for the Fishery hurts all the other users. NO WAY". By June 10th the 20 cfs was clearly having a negative effect on the Fishery. I don't know that anyone ever saw a dead fish floating along the bank but the word on the street and in the State's newspapers was, "Dolores means river of sorrow" - "The river will die" - "lawsuit in works". On June 12th I got a call from the BOR in Washington - ordering that the gates below McPhee be opened - that the flow be increased back to 78 cfs. Obviously the District's response was, "We are abiding by the EIS, so by what authority do you make such a request?" I gather, somewhat uniquely, DWCD owns the projects water rights, rather than the Federal Government.

### Classic "water war"

SOOO! The stage was set for a classic "water war", wouldn't you agree? In many cases the better way to manage water is obvious. It is the "misses" that get in the

way – the mis-understandings, the mis-trust, the mis-communications, the mis-conceptions, the mis-directions, and of course the other influences – the institutions, the people, the traditions, the politics, and finally the well-intentioned (or in some cases the not so well intentioned) self interests. In this case it was clear that if a way could be found to manage the Fishery release in such a manner that water could be saved during the winter season for higher flows during the summer (a “pool” concept) the Fishery would greatly benefit. However, the irrigators would suffer greater shortages during consecutive drought years.

Changing from a “flow” to a “pool” release was a process that is worthy of a story all its own. Suffice it to say, after 210 meetings, 1346 telephone calls and 9286 pages of written text and documentation, finally, seven years later, an Environmental Assessment was issued, with a Finding of No Significant Impact (“FONSI”), which officially changed the release below McPhee Dam from an “annual flow” to a “managed pool”. In addition the parties agreed to work together to create a pool of 36,500 AF, instead of 29,300 AF of water for the Fishery.

In July of 1997, I reported this process to the Colorado Water Workshop in Gunnison. At that time, I was very optimistic about our efforts to collaborate.

#### **Since 1997 – The Saga Continues.**

More than two years were spent in the transition from the Bush Administration (BOR Commissioner, Dennis Underwood) to the Clinton Administration (with Commissioner Dan Beard). The focus went from one of “purchase water” to one of “take water”. The issue came to a head with a visit from Assistant Commissioner, Ed Osan. He was the catalyst that convinced the local diverse entities to cooperate and work with each other.

SOOO -- an adhoc organization called the Dolores River Instream-flow Partnership (“DRIP”) was formed. That Committee is composed of eight organizations - Dolores Water Conservancy District, Bureau of Reclamation, Trout Unlimited, Division Of Wildlife, U S Forest Service, Bureau of Land Management, Colorado River Outfitters, and an interested coalition called the Friends of the Dolores.

Early in 1997, the District began an exploratory Long Range Water Plan (“LRWP”) to study, all the sources and all of the demands of water in the area. This preliminary study was later dubbed WETPACK (Water for Everyone Tomorrow PACKage). The reason for the term “package” is because of the District’s effort to collaborate with instream flow advocates for more water below McPhee along with use of pre-developed Montezuma Valley Irrigation Company (“MVIC”) water for additional irrigated acres.

The reasons for the agriculture portion of WETPACK are: 1) to expand the Projects success, as evidenced by the fact that owners of 16,000 acres requested water, when only 4,000 acres are available; 2) to mitigate damage caused to irrigators by changing the Fishery release from the "flow" to the "pool" (it spreads the fixed costs of O&M to a broader base – 32,000 acres instead of 28,000); 3) efficiently use and provide that MVIC's developed water remain in the community; and 4) it adheres to the local land use committee's desire to preserve the community's agriculture base.

The reasons for the Fishery portion of WETPACK are: 1) to create an adequate "pool" of water in McPhee as result of changing from the "flow" to the "pool". The present pool is 33,200 AF. Its components are the original 25,400, 3,900 purchased from DWCD, and 3,900 AF of senior water; 2) according to local fishery biologists, a minimum "pool" of 36,500 AF is needed to protect the fish and wildlife habitat below McPhee Dam. This means that an additional 3,300 AF is needed; and 3) there are many benefits to the establishment of a quality sports fishery.

### **Recent Developments**

To date the District has spent \$130,000 in completing a WETPACK feasibility study.

WETPACK identified sources of water for both the agriculture and the fishery parts of the "package". For the agricultural portion the source is "saved water" which heretofore has been diverted by MVIC, a private, non-profit irrigation company. The "saved water" is due to better water management, urbanization of area and implementation of the McElmo Salinity Control Unit. The salinity unit abandoned two old leaky canals and constructed one new Federal Canal to deliver irrigation water to both Non-Indian irrigators and the Ute Indian Tribe.

WETPACK identified new storage as the source of water for the Fishery. Trout Unlimited's independent study concluded that McPhee Reservoir has enough storage capacity, even though it is all allocated, to give the Fishery the additional water they want. DWCD's opinion, based on all the District's studies, show that the only way to get more water for the Fishery, without damage to present Project users, is to construct additional storage upstream of McPhee Reservoir. The other members of DRIP view new construction with skepticism. My perception is that those individuals think that McPhee, with its 381,000 AF of water, is so large it must have extra water for allocation.

In an effort to obtain funds to develop / acquire water for the Fishery, the Dolores River Instream flow Partnership submitted two successive applications to GOCO (which is Colorado's lottery fund) for purchase of 570 AF of the District's Municipal and Industrial water. Both applications were denied, primarily because

there was no organized collaborative support effort. In fact the rafting community openly opposed the second attempt.

It was determined that due to the failure of the two GOCO applications, the phasing of WETPACK study should be divided into Phases. Phase I should focus on the agricultural portion and move ahead as soon as possible. Phase II, should focus on the fishery portion, which would be delayed until a course of action can be collaboratively agreed to.

Regarding Phase I, the District formally requested a "carriage contract" from the BOR to carry the non-project water (the water purchased from MVIC) to new lands in the Dove Creek area through federal facilities. That contract will be signed within one month.

The District completed Phase I of the WETPACK feasibility study. It then applied to the Colorado Water Conservation Board ("CWCB") for a \$7,200,000 loan to construct the pump plants and pipelines needed to deliver water to the 4,000 acres of additional land.

The day the loan application was presented to CWCB, November 20, 2000, Trout Unlimited asked CWCB to delay approval of the WETPACK loan until the District included an additional allocation of water from McPhee for the Fishery. CWCB denied the request. Since then TU has focused its efforts on blocking the Bureau's issuance of a carriage contract to the District.

On the other side of the coin, DWCD has threatened that if TU is successful in delaying the issuance of the carriage contract, to the extent that if construction of WETPACK Phase I, is delayed, DWCD will discontinue adding the 3,900 AF of senior water rights to the Fishery "pool", as previously explained. DWCD's perspective is that TU has more to lose than it has to gain, if confrontation is pursued.

However, to keep the dialogue open and because DWCD has invested much time and resources toward solution of the fishery release, DWCD initiated meetings with fishery interests. At the time of the submittal of this presentation DWCD's perception is that a comprehensive collaborative feasibility study is needed to identify the solution for the Fishery's supply of water. DRIP has proposed that DWCD sell 800 AF of Municipal and Industrial water to the Fishery and give them eighteen months to find funds for such a purchase.

At this moment, there is strong potential that a solution will be found. However, realism, and history tempers ones optimism.

#### **"Train Wreck" Or Collaboration**

I think this story clearly illustrates the problems, trials, and tribulations that irrigators and water managers are faced with, especially in an environment of

transbasin diversion. It simply is "today's world", in the era of the "New West". The reality is that all parties with a vested interest in the a river system must realize that the only way the system can be optimally used is through an unqualified cooperative effort. Neither developing / acquiring water to increase the Fishery pool, nor water to preserve agriculture's base can ever be achieved without actions that are of mutual benefit or have appropriate "trade offs". Much has already been done to meet "Old needs and New needs". In fact that is what the Dolores Project is all about.

Looking back since 1990 "we have come a long way". Cooperative effort has begun: To manage the "pool" release and to manage reservoir spills to benefit the Fishery. There has to be a basis of common trust between the parties (that trust comes and goes – the problem is that many faces periodically change, especially within bureaucratic agencies). There is a willingness to negotiate - a willingness to work together. But even with an honest desire to negotiate there can be NO hidden agendas, there has to be an honest two-way communication. Hopefully the parties realize that any effort to out-maneuver / manipulate each others' interests would be counter productive and would eventually "back fire". The effort requires that priorities and bottom lines must be jointly established, demands have to be realistic, all cards have be on the table, and finally, there has to be unbiased assessment of others proposals.

While I offered this assessment in 1997, I believe the basic principles are still in place among most of the parties. They are just being tested. These issues may be never ending. "We have come a long way but we still have a long way to go".

### Summary

Transbasin diversions historically have facilitated settlement of the West, which is an inhospitable land without the development of water. Given that water is a finite resource, new competing environmental / recreational demands set the stage for continued demand for more efficient water management, controversy and finally litigation.



**EXTENDING PUBLIC BENEFITS:  
RETIRING THE DANIEL IRRIGATION COMPANY TRANSBASIN  
DIVERSION FACILITIES**

Ralph G. Swanson<sup>1</sup>

Barbara Blackshear<sup>2</sup>

**ABSTRACT**

The Daniel Irrigation Company (DIC) transbasin irrigation facilities in Wasatch County, Utah (USA) will be retired in 2001 after nearly 120 years of continuous service delivering irrigation water from the Colorado River basin to the Provo River basin. Constructed in the late 1800's, the DIC facilities were the first transbasin irrigation diversion facilities in Utah and among the earliest in the entire western United States. Fortunately, termination offers continued opportunities for public benefit. First, the historic nature of the design and construction of these facilities will be documented, and significant portions preserved intact and interpreted for future study and public enjoyment. Federal requirements for the identification and preservation of historic facilities, as mandated by the National Historic Preservation Act *16 U.S.C. 470f*, are reviewed. Specific plans for preservation and interpretation of the colorful history of the DIC facilities are described. Second, upon termination of diversions, 2,900 acre-feet (3.5 million m<sup>3</sup>) of additional water (annual average) will be available in the upper Strawberry River basin of Utah. Restoration of heretofore diverted streamflows will improve aquatic habitats, increase resident fish populations, and public recreational fishing opportunities in 35 miles (56 Km) of the upper Strawberry River and its formerly affected tributaries. Trout biomass is expected to increase 914% resulting in 10,000 angler-days per year of additional recreational fishing. Re-regulation of 2,900 acre-feet of water to other streams in the Uinta Basin will result in 1,914 angler-days and \$35,218 (1997 \$US) of benefit. Restored natural trout production will allow reallocation of hatchery-reared fish, formerly stocked in upper Strawberry basin waters, to other Utah waters, resulting in 201,946 annual angler-days of increased fishing and \$3.7 million (1997 \$US) in annual economic benefits. Conversely, a reduction of transbasin deliveries to the Provo River basin, will decrease trout biomass in Daniels Creek approximately 713 pounds (323 Kg) annually (81-96% of existing biomass).

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## INTRODUCTION

Recent Federal legislation provides new emphasis, and additional funding, for environmental enhancement in conjunction with water resource development in Utah (USA). The Wasatch County Water Efficiency Project (WCWEP) (Section 202(a)(3) of the Central Utah Project (CUP) Completion Act (Public Law 102-575; *106 Stat. 4600*)), allocates funds to end the historic transbasin irrigation diversions of the Daniel Irrigation Company (DIC). Replacement irrigation water will be provided to the company via new pipeline facilities from sources within the Provo River basin. With completion of WCWEP in 2001, DIC transbasin diversions will end after nearly 120 years of continuous service delivering irrigation water from the Strawberry River (Colorado River basin) to the Provo River basin. Termination will effect the "Strawberry Exchange", a long-standing environmental commitment of the CUP to restore natural flow regimes and natural aquatic productivity in streams of the upper Strawberry River basin. Completed in 1882, the DIC facility was the first transbasin irrigation diversion in Utah and among the earliest in the entire western United States. It is our position that irrigation facilities retired from service, or replaced by modern facilities, can yield new opportunities for public benefits if planners give creative thought to a full range of public needs.

## PROJECT HISTORY

The DIC facilities are at 8,200-8,450 feet (2,499-2,576 m) in the upper Strawberry River basin (Colorado River basin) of the Wasatch Mountain Range in north-central Utah, approximately 15 miles (24Km) southeast of Heber, Utah. Project features lie within north/south oriented mountains characterized by steep slopes leading upward from creek bottoms with narrow ridges at the highest elevations. Daniels Creek (Provo River basin) flows west into the Heber Valley from the mouth of Daniels Canyon south and west of Heber City. Historic annual diversions have averaged 2,900 acre-feet (3,577,092 m<sup>3</sup>) from 1950-1991. The maximum diversion during the period was 5,423 acre-feet (6,689,162 m<sup>3</sup>); the minimum was 707 acre-feet (872,070 m<sup>3</sup>) (CUWCD 1996b). For purposes of this analysis, the annual average diversion of 2,900 acre-feet is recognized.

The Strawberry River drains southeast via the Duchesne and Green Rivers. The DIC diversion facilities operate on a permit from the U.S. Forest Service, Uinta National Forest. The water collection and delivery system consists of a series of dams, canals, diversion structures, a tunnel and a siphon which collect water from the upper Strawberry tributaries and transfers it to Daniels Creek in the Provo River basin for irrigation in the Heber Valley.



### **The First Years: Water Systems and Indian Wars**

The first pioneers arrived in Utah in 1847; just 11 years later, in 1858, settlement of the Heber Valley began. By 1862, the original 19-family settlement expanded to approximately 1,000 residents, nearly all farmers, thus increasing water demands. The early pioneer settlements of Buysville and Daniel were located along Daniels Creek on the edge of the Heber Valley. For irrigators in the Heber Valley, the small streams in the immediate area proved insufficient. Soon farmers were exploring for other water sources eastward across the Wasatch Mountain range in the Strawberry River drainage. A drought in 1879 hastened the search.

Disputes with the Ute Indian tribe resulted in the "Black Hawk War" which started in the early 1860's and ended in 1867. Life in the Heber Valley became more complex and work on water systems took a hiatus while the settlers' presence in the area was being challenged by Chief Black Hawk. Indian agent Burns of White Rocks, Utah, asked for protection from white settlement of the Ute Indian Reservation lands including the Strawberry River Valley, and soldiers from three forts were sent into the area in 1871, but there is no specific historic record of dispute over the first systems constructed several years later which brought Strawberry River water into the Heber Valley (Weicks 2001).

### **Daniels Creek Irrigation Company: The First Trans-Basin Diversion**

Surviving the war and under the authority of several Federal laws, including the Federal Water Rights Act of 1866 (*30 U.S.C. § 51*), the people along Daniels Creek first formed their own small water association. In 1879 three local farmers formed the Daniels Creek Irrigation Company (DCIC) and bought out or traded for all of the water rights of earlier claimants on Daniels Creek. They also began construction of what would be known as the Strawberry Ditch, the first transbasin water diversion.

Fortunately, geographic and geologic formations suited the project, and the distance between the two drainages was relatively short. With amazing survey accuracy for 1879, the proper grade was achieved. Work was undoubtedly completed using hand tools common on the farm, manual labor and horse-drawn implements. Due to the lack of records, the use of early engineering tools such as levels, and land survey equipment can only be assumed. In many cases the men "got down on their knees and sighted along the ground to construct the ditches" (Fern Carter, pers. comm.). In 1882, upon completion of the ditch, the Strawberry Canal Company was organized, separately from the DCIC, to operate this first transbasin diversion. The system diverted the Strawberry River from a dam at Mill B canyon, delivered it to the head of McGuire Canyon and, via Daniels Creek, to the Heber Valley (Figure 1). The Strawberry Canal Company operated this ditch until 1888.

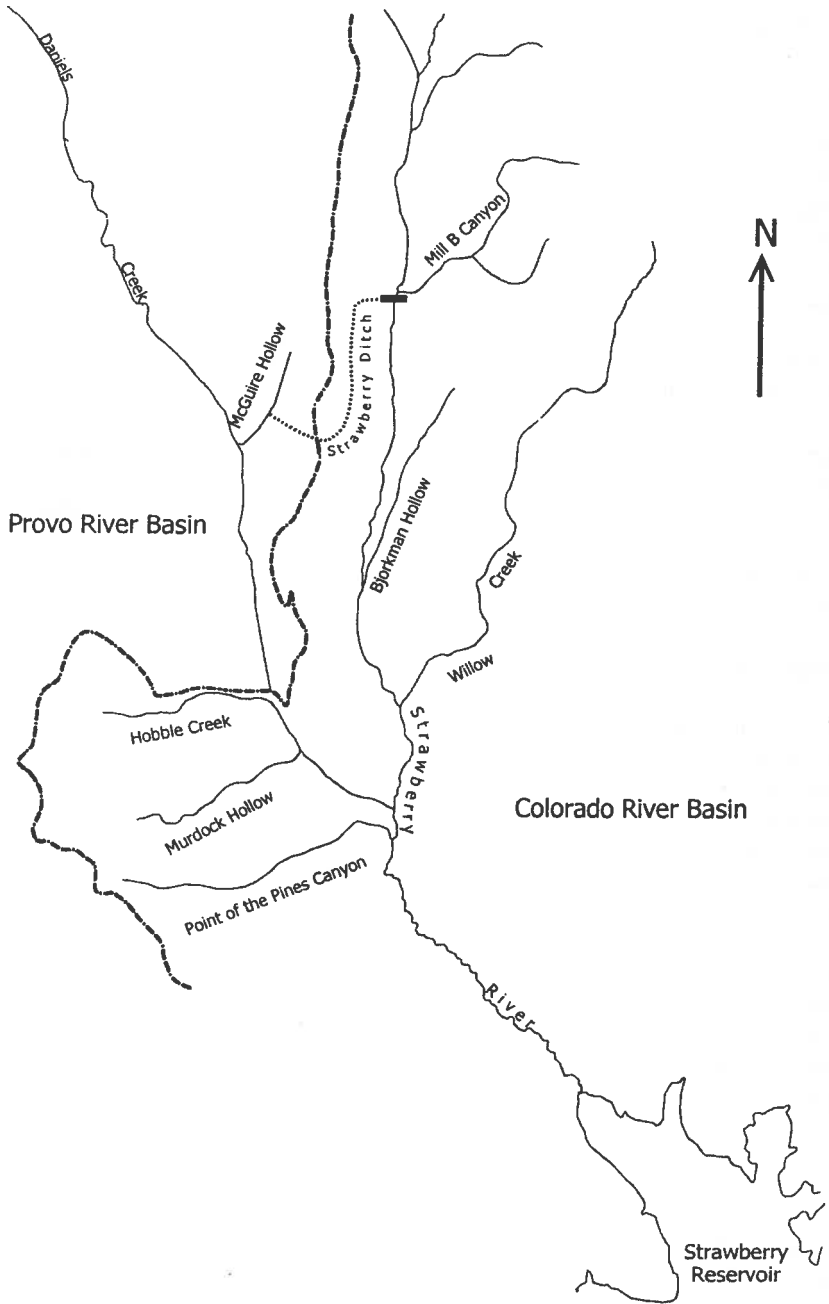


Figure 1. The First Transbasin Diversion via Strawberry Ditch - 1882

The ditches of the first diversion are still visible on the landscape, although the system has long been replaced by a second, more sophisticated, diversion represented by the currently operating facilities.

### The Second Trans-Basin Diversion

The technological success of the first diversion led to additional attempts to divert Colorado River basin water into the Heber Valley. Excavation of a second ditch began in 1890 and was completed by late 1892 (Figure 2). This system originated on Willow Creek, crossing both Bjorkman Creek and the Strawberry River in wooden flumes. However, just before the Willow Creek Canal reached McGuire Canyon, builders realized it was 250 feet (76.2 m) short of clearing the summit. The need for water, and stubborn determination, led these farmers to dig a tunnel through the mountain. The McGuire Tunnel was 1,000 feet (304.8 m) long and "tall enough for a man to walk through" (Polk, et. al. 1995). The Willow Creek Canal Company formed in February 1892 to operate these facilities. This ambitious company also built reservoirs and more ditches, negotiating with other local water companies to utilize existing water systems to distribute transbasin water on the west side of the mountain.

Through time, water development and conveyance became more complex and expensive. Farmers turned to the Federal government for help, and in 1902, the Reclamation Act (32 Stat. 388) authorized construction of dams, reservoirs, and ditches; it also created the U.S. Bureau of Reclamation to construct water projects and oversee distribution. Thus, the pioneer transbasin diversion of the DIC predated organized Federal efforts by 20 years.

Disputes over rights to the Strawberry River and Willow Creek water between the Ute Tribe and the Heber Valley settlers were finally resolved in 1905 when, under the authority of the General Allotment Act of 1887 (25 U.S.C. Section 331), President Theodore Roosevelt authorized the opening of the Ute reservation lands to white settlement (Polk, et. al. 1995). This included tacit approval for transbasin diversion and use of Strawberry River water.

By the early twentieth century more transbasin canal systems were bringing water from the Strawberry River area into the Heber Valley. Point-of-the-Pines, Murdock Hollow, and Hobble Creek diversions were operating several miles to the south. In 1922, the Daniel Irrigation Company (DIC) was formed by combining the Strawberry Canal, the Willow Creek Canal, and the Daniels Creek Irrigation Companies. Their united efforts have served irrigation water needs in the Heber Valley since that time.

Significant changes and modernization of the DIC facilities began in 1953. Unfortunately for historic preservation, the diversion dam at Mill B and the

wooden flumes that conveyed water over the Strawberry River and Bjorkman Creek were replaced without benefit of any documentation. Other features have been added, replaced, redesigned, and removed as the water companies found necessary. Now, the WCWEP will result in the abandonment of the entire system.

The present DIC facilities are:

Willow Creek Canal: originally crossed over Bjorkman Creek and the Strawberry River in wooden flumes. Since 1953, this canal starts at the concrete diversion in Willow Creek and carries water west to the Bjorkman-Willow Creek divide where it is released into the natural channel of Bjorkman Creek. The water follows the natural channel for one half mile then is diverted into a canal that transports it to the siphon.

Strawberry River Diversion Dam: approximately 40 feet (12.2 m) long and 10 feet high (3 m) on the Strawberry River about 1 mile (1.6 Km) downstream from Mill B. The head gate is a 4-foot (1.2 m) metal gate set in concrete abutments on the east side of the river bottom. The dam and the head gate are connected by an earth dike approximately 8 feet high (2.4 m) and 200 feet (61 m) long. Water from the upper Strawberry River is diverted via the headgate into McGuire Canal and, hence, to the siphon.

McGuire Canal: starts at the Strawberry River diversion dam headgate and takes water south along the east side of the river valley to the siphon. At the siphon, the water joins Willow Creek Canal and crosses the valley to the west side. Once out of the siphon, water continues in the McGuire Canal to the McGuire Tunnel.

Siphon: an underground pipe 2.5 feet (0.08 m) in diameter and ½ mile (0.8 Km) long that takes Strawberry River water to the west side of the Strawberry River valley.

McGuire Tunnel: approximately 200 feet (60.96 m) of concrete canal, an iron debris rack, a concrete overflow spillway to divert excess water, and a tunnel 1,000 feet (304.8 m) long and 4 feet (1.22 m) in diameter. The tunnel takes the water through the mountain and releases it into the natural channel of McGuire Canyon, and hence to Daniels Creek.

Point of the Pines, Murdock, Hobble Creek Canals: starts at the concrete diversion in Point of the Pines stream, intercepts Murdock Hollow and Hobble Creek before preceding to the head of Daniels Canyon.

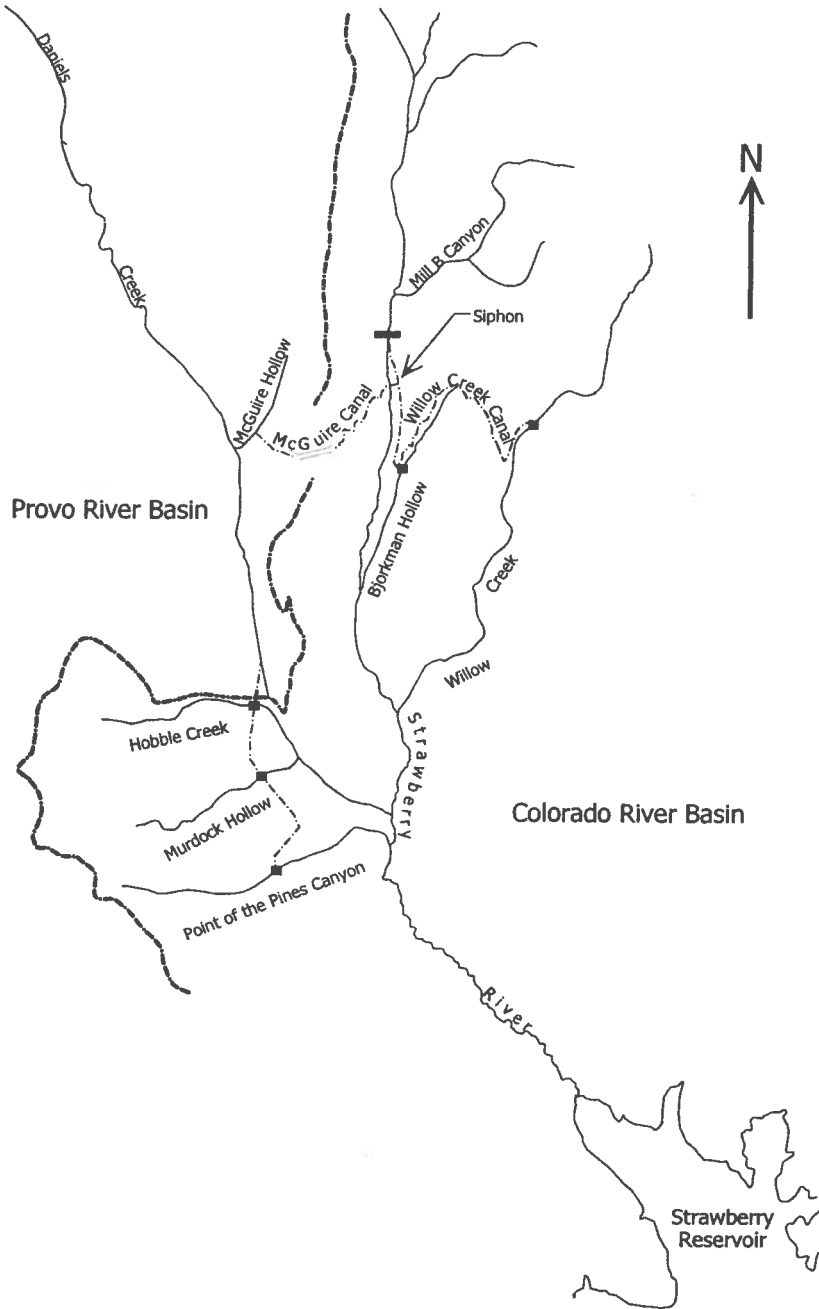


Figure 2. Second Transbasin Diversion via McGuire Canal and Tunnel-1892

## HISTORICAL AND CONTEMPORARY PERSPECTIVES

In the early 1900's there were no U.S. laws protecting archaeological/historical properties. The first law--the Antiquities Act--was not established until 1906 (*16 U.S.C. 431*). This law prohibits primarily vandalism and theft of artifacts; it does not address preservation, interpretation, and documentation requirements that Federal agencies must comply with today. Because of the lack of preservation laws, the costs to the American public and the historic record have been both direct and cumulative. For the original transbasin facilities, the who, how, when, where, and what of the historic engineering information, that would be so interesting and perhaps valuable today, was never formally recorded. Not until 1994, long after the earliest facilities were destroyed or replaced, was any documentation attempted (Polk, et. al. 1995).

The value of history is that it reminds us of where we come from, what we have achieved, and what we may have lost along the way (Peterson 2001). Tangible reminders of the past help set the future. For the original transbasin facilities, most of that historic record is lost. We have no design or construction details of the original Strawberry River diversion dam (First Diversion), or the cross-valley wooden flume system or original McGuire Tunnel (Second Diversion).

## NATIONAL HISTORIC PRESERVATION ACT

Today there are at least ten Federal laws, executive orders, and regulations that seek to protect or otherwise deal with cultural resources of various kinds (King 2000). The historic preservation portion of this paper will emphasize the requirements of the National Historic Preservation Act of 1966 (NHPA) (*16 U.S.C. 470*).

The NHPA is among the most important Federal antiquities laws, requiring all Federal agencies to accommodate historic preservation within their actions. Agencies must make systematic efforts to identify, evaluate and minimize the adverse impacts of their actions on significant historical resources (King 1998).

Briefly, the NHPA:

- ◆ Created the National Register of Historic Places<sup>3</sup> (NRHP)

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<sup>3</sup> Districts, sites, buildings, structures, and objects significant in American history, architecture, engineering, archaeology, and culture (Sec.101.a(2)(A)). Historic properties are researched in the available literature, documented, mapped, photographed, and reported to the State Historic Preservation Office (SHPO), which performs quality control and record keeping.

- ◆ Created State Historic Preservation Offices and Officers (SHPO)
- ◆ Created the Advisory Council on Historic Preservation (ACHP)
- ◆ Required consultation among the action Federal agency, SHPO, and, Native Americans (Indian tribes, native Hawaiians)
- ◆ Required Federal agencies to establish a comprehensive cultural resources program

The significant section of the NHPA is Section 106, which mandates that Federal agencies must assess the effects of their actions on any "historic property"<sup>4</sup> included in, or eligible for inclusion in, the National Register of Historic Places. Strict criteria define eligibility for inclusion on the National Register at 36 CFR 60.4.<sup>5</sup> Literally, no Federal action is exempt from Section 106.<sup>6</sup>

Section 106, in turn, requires that Federal agencies make professional efforts to:

- ◆ Identify historic properties that may be affected by their actions
- ◆ Assess the adverse effects of their actions on those properties; and
- ◆ Resolve adverse effects

The SHPO and ACHP assist and monitor Federal agency compliance with Section 106. Historic properties which are eligible for listing are treated, under Section

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<sup>4</sup> "Historic properties" are sites, structures, districts and objects with archeological, historical, architectural, engineering or cultural value. These are commonly understood as prehistoric or historic sites, but can also include traditional cultural properties, sacred sites, artifacts or other materials or areas of cultural importance regardless of age.

<sup>5</sup> Historic properties can be added to the NRHP based on any of four criteria: (a) association with events making a significant contribution to the broad patterns of our history, (b) association with the lives of persons significant in our past; (c) embody the distinctive characteristics of a type, period, or method of construction, represent the work of a master, possess high artistic value, or represent a significant and distinguishable entity whose components may lack individual distinction; or (d) have yielded, or may yield, information important in prehistory or history.

<sup>6</sup> Federal actions are known as "undertakings," meaning a project, activity, or program that can result in changes in the character or use of historic properties located in the area of potential effects. The project, activity, or program must be under the direct or indirect jurisdiction of a Federal agency or licensed or assisted by a Federal agency. Undertakings include new and continuing projects, or program elements not previously considered under Section 106.

106, identically to those actually listed on the NRHP.

It is important to understand that a property, site or artifact is not eligible for inclusion on the NRHP simply because it is old, and not every property included (or eligible for inclusion) is inviolate, to be preserved or protected from all harm from any Federal undertaking.

The DIC water conveyance system was recorded as an historic property (42WA176) in 1994 and is eligible for listing on the NRHP. Section 106 requires Federal agencies to search for, identify and evaluate whether any properties affected are eligible for nomination to the NRHP before taking actions that damage or destroy properties that embody valued pieces of history. Agencies must decide if listed, or eligible, properties will be adversely affected by their actions and seek ways to avoid, minimize or mitigate the adverse effects of their actions in a manner that accommodates historic preservation within the context of its undertaking. If avoidance or protection-in-place is not feasible, then "mitigation," such as documentation prior to excavation and removal, is acceptable. All protection/mitigation plans are coordinated with the SHPO.

The DIC facilities were deemed eligible for the NRHP under criteria (a) and (c) (Footnote 5) because they embody the importance of water to the subsistence/settlement patterns of the late 1800's in the Heber and Strawberry Valleys of Utah and because (part of) the system was the first transbasin water system in the state (Polk, et. al. 1995). Abandonment of the system and restoration of the land will constitute an "adverse effect" to this historic property. Those effects will be mitigated by a documentation report, including maps and photos, filed with the Utah SHPO as a permanent historic record.

### **HISTORIC PRESERVATION OF DIC FACILITIES**

In addition to documentation, the U.S. Forest Service will implement a public education/interpretation plan to include partial preservation of the historic structures and removal or restoration of remaining DIC facilities (Charmaine Thompson, pers. comm). Key planning considerations will focus on the most historically important and interesting features, be designed to fit the overall recreation/interpretation plans for the National Forest, consider effects on other land uses such as recreation, livestock/agricultural uses, and accommodate public safety.

Although the first Strawberry diversion dam was destroyed long ago, the original Strawberry Ditch will remain in place as a hiking/biking trail with interpretative signing to document its historic importance to irrigated agriculture and pioneer subsistence patterns in the Heber Valley. People will walk the entire length of the original ditch and learn how Utah's first trans-basin water was delivered.



All diversion structures in the second transbasin system will be removed with the exception of the present Strawberry River diversion dam, the siphon, and the McGuire tunnel. The Strawberry diversion dam will be modified by removing some concrete and the earthen dike. The dam will no longer impede the Strawberry River or fish movements. Together with the remaining portions of the dam, the head gate will be preserved with interpretative signing.

The siphon inlet will be plugged and covered for safety, but otherwise preserved intact. Cautionary and interpretative signing will be erected.

The inlet of the McGuire Tunnel will be plugged with concrete, but left intact along with its associated structures, water gauge, overflow sill, debris gate and at least a remnant of the concrete delivery canal. The outlet will be plugged just inside the tunnel for public safety.

All remaining portions of the canal system will be removed and restored to pre-project contours and revegetated. Lands otherwise damaged by the project will be stabilized by reshaping and restoring soil and vegetation.

### **BENEFITS ANALYSIS OF THE STRAWBERRY EXCHANGE**

The Strawberry Exchange has long been an important fish and wildlife enhancement priority for State and Federal resource agencies in Utah (USFWS 1984, IBAT 1988, Mills 1984, Johnson 1987, USDA 1990). The Strawberry Exchange was initially described by Geer (1978) as a means to restore natural streamflows in the upper Strawberry River, Bjorkman Hollow, Hobble Creek, and Willow Creek. Elimination of the transbasin diversion and restoration of natural steam flows would benefit riparian (streamside) and aquatic resources and enhance habitat for the salmonid and non-game species. Increases in sport fish (trout) production in the upper Strawberry River basin are anticipated to be substantial (USFWS, 1997). The Strawberry Exchange will restore natural trout spawning habitat in partial compensation for loss of spawning habitat in streams inundated by Strawberry Reservoir, a major component of the CUP.

The following streams of the upper Strawberry River basin, comprising approximately 35 miles (56 Km) will be enhanced by restoration of natural historic flows: ( Figure 1)

- Strawberry River from the diversion dam downstream to the Reservoir
- Willow Creek
- Stream in Bjorkman Hollow
- Hobble Creek
- Stream in Point of the Pines Canyon
- Stream in Murdock Hollow

Game fish species in upper Strawberry River basin include: brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), cutthroat trout (*Oncorhynchus clarki*), rainbow trout (*Oncorhynchus mykiss*) and mountain whitefish (*Prosopium williamsoni*). Non-game species include leatherside chub (*Rhinichthys osculus*), reidside shiner (*Richardsonius balteatus*), mountain sucker (*Catostomus platyrhynchus*), Utah sucker (*Catostomus ardens*) and sculpin (*Cottus sp.*)

Daniels Creek supports rainbow trout, brown trout, brook trout, cutthroat trout and sculpin.

Potential impacts on game fishes were analyzed by using methods of Binns (1982), an accepted tool to estimate trout standing crop and biomass in western USA coldwater streams. The model produces a Habitat Quality Index (HQI) to predict trout populations in a given stream. Parameters of input to the Binns' Model are late summer stream flow, annual stream flow variation, water velocity, trout cover, stream width, eroding stream banks, stream substrate, nitrate nitrogen concentrations, and maximum summer stream temperatures. See Appendix A.

Table 1 displays the predicted increases in trout standing crop (pounds/acre) and biomass (total pounds) from implementation of the Strawberry Exchange. An overall increase in biomass of 914% is expected.

Conversely, the elimination of DIC diversions would reduce flows in Daniels Creek thereby decreasing habitat for game fish and other aquatic organisms. Losses in Daniels Creek would adversely impact natural trout reproduction and standing crop of non-stocked trout in that stream by 81% and 96% respectively in two upper reaches surveyed (Table 1).

Stream / Reach	Predicted Trout Standing Crop			Trout Biomass			Percent Change from Baseline (%)
	Baseline (lb/acre)	Proposed Action (lb/acre)	Change from Baseline (lb/acre)	Baseline (lbs)	Proposed Action (lbs)	Change from Baseline (lbs.)	
Daniels Creek Upper Daniels Diversion to McGuire Can.	45.37	8.52	-36.85	744.07	139.73	-604.34	-81
Daniels Creek McGuire Can. to Headwaters	40.71	1.78	-38.93	113.99	4.98	-109.01	-96

Upper Strawberry River <sup>a</sup>	n/a <sup>b</sup>	n/a	n/a	1,819	18,437	16,618	914
<b>Notes:</b> <sup>a</sup> Data from Mills (1984) for upper Strawberry River and its tributaries above Strawberry Reservoir. <sup>b</sup> n/a - not available Source: CUWCD, 1996a							

To offset losses, the Utah Division of Wildlife Resources (UDWR) will stock 1,500 catchable-size rainbow trout (500 pounds (227 Kg) at 3 fish per pound) per year in Daniels Creek to support a public trout fishery (Charlie Thompson, pers. comm.).

Direct fishing benefits from eliminating the DIC diversions are estimated at 10,000 angler-days of public fishing opportunity in the upper Strawberry basin (IBAT 1988). These expected increases replace fish production and angler opportunity lost due to inundation of Strawberry River basin streams by the Strawberry Reservoir of the CUP. Because it restores (in part) what was lost by the CUP, the Strawberry Exchange itself receives no monetary benefit. Secondary benefits are, however, quantified and credited.

Streams will require a number of years of successful trout reproduction and recruitment to reach the predicted levels of production. Implementation of other management activities in the upper Strawberry River basin such as stream rehabilitation and riparian revegetation are desirable to assist trout habitat improvements (Mills 1984). It may still take 15 to 20 years for natural trout production to reach full potential in the upper Strawberry River basin (USFS 1990).

Beyond natural restoration of upper Strawberry basin streams, the Strawberry Exchange allows changes in the fishery management directions of the UDWR and are properly calculated as a monetary benefit as discussed below.

Because of dewatering during the irrigation season (June-October) the Strawberry River is inhibited from meeting its potential for contributing spawning/rearing habitat for trout. As a result, the river does not provide the potential number of young-of-the-year juvenile fish to meet management objectives for Strawberry Reservoir to be a self sustaining fishery. The upper Strawberry River basin could produce more than 4.8 million wild, young-of-the-year (YOY) salmonids each year (UDWR, 1995). Presently, the Strawberry River is producing well below this potential due to flow limitation, dewatered stream reaches, unstable banks, high concentration of fine sediments in the gravels, high summer water temperatures, all of which can be corrected by return of natural, undiminished flows and other restoration activities. The Strawberry River affected by the DIC diversions can potentially produce 48% of the salmonids produced in the entire Strawberry

Valley as depicted in Table 2.

Stream / Reach	1984 Estimate (lbs.)	Calculated Potential (lbs.)	Potential Increase (lbs.)
Strawberry River			
Res. to Willow Cr. Confl.	174	8,732	8,558
Willow Cr. to Daniels Div.	0	4,046	4,046
Diversion to FFMP <sup>a</sup>	347	1,253	906
West Fk., Wide Hollow, Trail Hol.	17	132	115
Willow Creek	205	1,252	1,047
Bjorkman Hollow	201	568	367
Mill-B	145	892	747
Hobble Creek			
Straw. Res. to Murdock Hollow	348	572	224
Murdock Hol. To FFMP <sup>a</sup>	210	342	132
<b>TOTAL for Affected Streams</b>	<b>1,647</b>	<b>17,789</b>	<b>16,142</b>
<b>TOTAL (Valley-wide)</b>	<b>5,445</b>	<b>38,524</b>	<b>33,079</b>
<b>Affected Streams as percent of Valley-wide Total</b>	<b>48%</b>		
<b>Notes:</b>			
<sup>a</sup> FFMP - farthest fish migration point in stream			
Source: Mills, 1984			

The economic benefits presented below were calculated by UDWR (1995) and modified and adopted by the U.S. Fish and Wildlife Service (USFWS 1996). It is assumed that the projected increase in trout biomass is dependent upon the Strawberry Exchange and that improvements in adult trout populations are directly proportional to improvements in YOY production.

A computation of increased angler-days of fishing associated with restoration of historic stream flows to the upper Strawberry River and its tributaries is combined with a value endorsed by USFWS to calculate a monetary benefit. The analysis begins with a UDWR estimate that natural reproduction in Strawberry Valley as a whole could free up 38,687 pounds (17,545 Kg) of hatchery reared fish for stocking elsewhere in Utah. Such a reallocation would result in increased angling outside of Strawberry Valley and thus yield a monetary benefit. Thus:

38,687 LBS. (17.5k Kg)	SAVINGS IN HATCHERY PRODUCTION
<u>X 0.48</u>	PROPORTION OF INCREASE FROM AFFECTED STREAMS
18,570 LBS. (8.4k Kg)	SAVINGS IN HATCH. PROD. DERIVED FROM FLOW RETURN

Because this analysis focuses on the angling benefits derived from the re-

allocation of hatchery fish to other waters of the state, the number of fingerling fish available for re-allocation is calculated:

18,570 LBS. (8.4k Kg)	SAVINGS IN HATCH. PROD. FROM FLOW RETURN
<u>X 87 FISH/LB.</u>	NO. OF FINGERLINGS PER POUND
1,615,591 FING.	FISH AVAILABLE FOR STOCKING OTHER WATERS

Factor standard survival rates, angler catch rates, and angler-day values:

1,615,591 FING.	FISH AVAILABLE FOR STOCKING OTHER WATERS
X 0.20	MEAN STATEWIDE SURVIVAL TO CREEL
÷ 0.40 FISH/HR	MEAN STATEWIDE ANGLER CATCH RATE
<u>÷ 4.0 HRS/DAY</u>	MEAN STATEWIDE ANGLER EFFORT
201,946 DAYS	ANGLER-DAYS DERIVED FROM FLOW RETURN

Economic benefits derive by applying an accepted dollar value for an angler-day in Utah:

201,946 ANGLER-DAYS	ANGLER-DAYS DERIVED FROM FLOW RETURN
<u>X 18.40 PER DAY<sup>7</sup></u>	ECONOMIC VALUE OF AN ANGLER-DAY
\$3,715,806 PER YEAR	1996 VALUE OF THE STRAWBERRY EXCHANGE (US\$)

In addition, reoperation of DIC water (2,900 AF per year) to improve streamflows outside the Strawberry River basin yields added benefit. Recognizing a benefit of 660 angler-days per 1,000 acre-feet (1,233,480 m<sup>3</sup>) (IBAT 1988), an additional 1,914 angler-days and \$35,218 (1997 \$US) is estimated for a total annual economic benefit of \$3,771,024 (USFWS, 1997).

## SUMMARY AND CONCLUSIONS

In a changing global society, it is essential that water resources be developed to meet growing population needs. However, progress has costs: we may lose historic information that we, as a society, value. History is made up of only those things that happen to survive, or that people think to save (Peterson 2001). If we do not protect and preserve the past we lose it, sometimes forever; history is a non-renewable resource, and the ultimate losers are our future generations. We

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<sup>7</sup> The economic value of an angler day is variable and different methods of analysis are arguably justified. USFWS (1991) was applied because it is current and presents values specific for trout fishing in Utah (USFWS 1996). Other inflationary indices are available (eg. Gross National Product and Gross Domestic Product price deflators). However the selection of the index may not significantly affect overall results because many of the indices tend to move in unison (USFWS 1997).

can preserve, protect and educate the public about our history by adopting historic preservation as a project goal. The National Historic Preservation Act, and other preservation laws, require U.S. Federal agencies to consider historic preservation in any undertaking. Private enterprise engineering can also benefit by offering preservation concepts to clients in recognition of the additional benefits that may be derived from such planning. Partnering early in the project planning process allows archaeologists to make the best use of their knowledge of the laws and to create ways to preserve the best of the past for the future. It is our position that engineers should work with archeologists to document, preserve and interpret, important historical aspects of their work whenever possible.

The monetary benefits of implementing the Strawberry Exchange are unexpectedly impressive—\$3.7 million per year (\$US). However, in an era when costs for hatchery-reared fish can exceed \$4 per pound (454 grams) (UDWR, 1996), and recreational expenditures are a significant portion of family expenses, the realization that environmental restorations can provide valuable, cost-free goods and services that the public demands (ie., fish and recreational fishing opportunities), should command the attention of planning professionals.

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## APPENDIX A

The Binns HQI Model II was developed as a tool for predicting trout standing crop to assess instream flow needs in the USA intermountain west (Binns, 1982). The method involves the collection of standardized information for various stream habitat attributes and calculation of a Habitat Quality Index that represents the standing crop potential of a stream. The HQI is calculated using weighted values (0 to 4) for nine different habitat attributes. The HQI is an integrated measurement of biological, chemical and physical aquatic habitat attributes.

Field tests of the model on streams similar to the Strawberry River indicated that these parameters explained 96% of the variation in trout standing crop (multiple regression coefficient  $R=0.983$ ). This high rate of statistical reliability suggests a direct relationship between HQI prediction and trout standing crop.

The provision of additional instream flows with retirement of the DIC diversions would be expected to improve several habitat attributes, such as increasing late summer flows ( $X_1$ ), reducing maximum summer water temperatures ( $X_3$ ), and increasing abundance of submerged aquatic vegetation ( $X_9$ ). Improvements in these attributes would predict increases in trout standing crop.

The following habitat quality attributes are measured or qualitatively estimated:

- $X_1$  Late summer stream flow (gage records or on-site measurement)
- $X_2$  Annual steamflow variation (gage records or on-site measurements)
- $X_3$  Maximum summer stream temperature (measured in August)
- $X_4$  Nitrate nitrogen (direct measurements)
- $X_7$  Fish cover ( percent cover in overhanging vegetation, undercut bank, instream structure)
- $X_8$  Eroding streambanks (observed percent eroding banks)
- $X_9$  Submerged aquatic vegetation (direct observations)
- $X_{10}$  Current velocity (surface measurement in feet/second)
- $X_{11}$  Wetted channel width (mean measurement in feet)

The HQI (Y) is calculated using the Model II algorithm:

$$(1) \quad \text{Log}(Y+1) = -0.903 + 0.807\text{Log}(X_1 + 1) + 0.877\text{Log}(X_2 + 1) + 1.233\text{Log}(X_3 + 1) + 0.631\text{Log}(F + 1) + 0.182\text{Log}(S+1)$$

$$\text{where } F = (X_3)(X_4)(X_9)(X_{10}) \quad \text{and } S = (X_7)(X_8)(X_{11})$$

Binns HQI Model II is specific to trout. Application to non-game fish resources requires best professional judgement in assigning ratings.



## IMPLEMENTING THE CALFED BAY-DELTA PROGRAM'S ENVIRONMENTAL WATER ACCOUNT — CALIFORNIA

Leo Winternitz<sup>1</sup>

Jim White<sup>2</sup>

### ABSTRACT

The CALFED Bay-Delta program is a collaborative, state-federal-stakeholder effort that has developed a comprehensive long-term plan to restore ecosystem health and improve water management for the beneficial uses of the Bay-Delta system.

A goal of the CALFED program is to provide water supply reliability to water users while assuring availability of sufficient water to meet fishery protection and restoration/recovery needs. To help achieve this, the CALFED program has established the Environmental Water Account.

The EWA is intended to provide water for the protection and recovery of fish beyond what is available through existing regulatory actions. The EWA will benefit users by acquiring water for fish without impacting state and federal water project deliveries or other users of water. Initial water purchases in northern and southern California and lease of groundwater storage in southern California were secured from willing sellers in year 2000. Acquired assets total about 480,000 acre-feet. A budget of \$50 million has been established for the acquisition, storage, and transfer of this water.

Establishment and implementation of the EWA is a new way of conducting water business in California. Changes have resulted in the normal operations of state and federal water systems and in the way state and federal fishery regulatory agencies conduct their business. This paper describes what the EWA is, how it is being operated, the changes it has brought about, and the actions and status of implementation.

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## INTRODUCTION

Under normal conditions, California is water-rich in the northern half of the state and water-poor in the southern half. California has thousands of miles of rivers and streams that flow from the state's mountains through its valleys and empty in the Pacific Ocean. The largest systems are the Sacramento River and the San Joaquin River systems in the Central Valley. They meet to form the Sacramento/San Joaquin Delta Estuary and then flow through the San Francisco Bay to the sea. (See Figure 1.)

California's Mediterranean climate is characterized by cold wet winters and hot dry summers throughout most of the state. As a result, more than 1,000 dams have been built on California's rivers to control floods, to store water during winter for use in the summer, and to provide water supplies during periodic droughts.

With more than 34 million people, California has the largest population among the 50 states. Precipitation is heaviest in the north and along the Sierra Nevada mountain range, which traverses much of the state. The north also has most of the state's total streamflow. To the south, the land becomes arid and includes large desert areas. Precipitation in California's Central Valley, a fertile agricultural region 400 miles in length, averages 25 inches a year at the northern end and 5 inches in the south. Approximately 75 percent of California's population lives in the southern half of the state while 85 percent of the water originates in the northern half. Most of the state's irrigated agricultural land also lie south of San Francisco. It is this mismatch between the location of the water supply and water needs that has driven water development in the state.

### Water Development

The State Water Project, built in the 1960s and operated by the California Department of Water Resources, and the federal Central Valley Project, built in the 1940s and operated by the United States Bureau of Reclamation, are two of the largest water distribution systems in the United States. The main purpose of these projects is water supply — to divert and store water supply during wet periods and distribute it to areas of need, particularly the drier, more intensively developed south half of the state. (See Figure 2.)



Figure 1. Map of California showing main river systems

# Transbasin Water Transfers

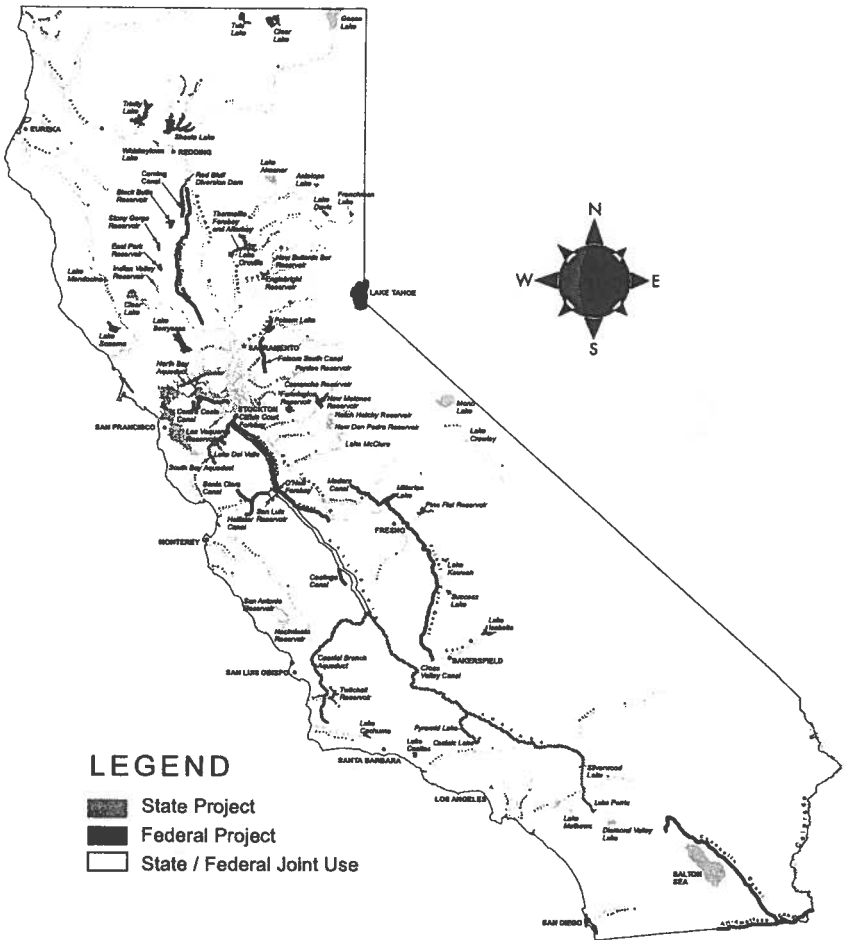


Figure 2. Map of California showing facilities on the SWP and CVP

The State Water Project extends for more than 600 miles – two-thirds the length of California. The project includes 32 storage facilities, 20 pumping plants, 5 hydroelectric power plants and about 660 miles of canals and pipelines. About 30 percent of the water delivered goes to agricultural users and 70 percent to urban users. The federal Central Valley Project includes 20 reservoirs, 11 power plants, 500 miles of canals, and other facilities. Its primary purpose is to provide water for irrigation throughout California's great Central Valley. Both projects have major pumping facilities in the Delta, that area where the Sacramento River and the San Joaquin River converge. Water released from the projects' reservoirs upstream in the watershed flow into the Delta where it is diverted by the state's Banks Pumping Plant and the federal Tracy Pumping Plant, both located in the southern Delta (see Figure 3). When available, uncontrolled flow is also diverted at the Delta by these plants. Together, these water development projects divert about 20 to 70 percent of the natural flow in the system depending on the amount of runoff available in a given year.

### **Resource Conflicts**

There is a rich history of conflict over resource management in the Bay-Delta system. Conflicting demands have resulted in resource threats — including the decline of wildlife habitat; the threat of extinction of several plant, animal and aquatic species; and degradation of water quality — and a levee system faced with a high risk of failure. At the simplest level, problems occur when there is conflict over the use of resources from the Bay-Delta system. A major conflict is one between fisheries and water diversions.

The conflict between fisheries and water diversions results primarily from fish mortality attributable to water diversions from the State Water Project and federal Central Valley Project. The effects of water diversion include direct entrainment of fish at the pumping plants, reduced survival of young fish drawn out of river channels into the Delta, reduced spawning success of adults whose migration is delayed when migratory cues are altered, and reduced extent and productivity of habitat associated with inadequate streamflows and reduced Delta outflows. The need to protect species listed as threatened or endangered has prompted restrictions on pumping and other regulations, which constrain the quantity and timing of diversions. These restrictions have resulted in reduced water supply, particularly to water users in the southern, drier half of the state.

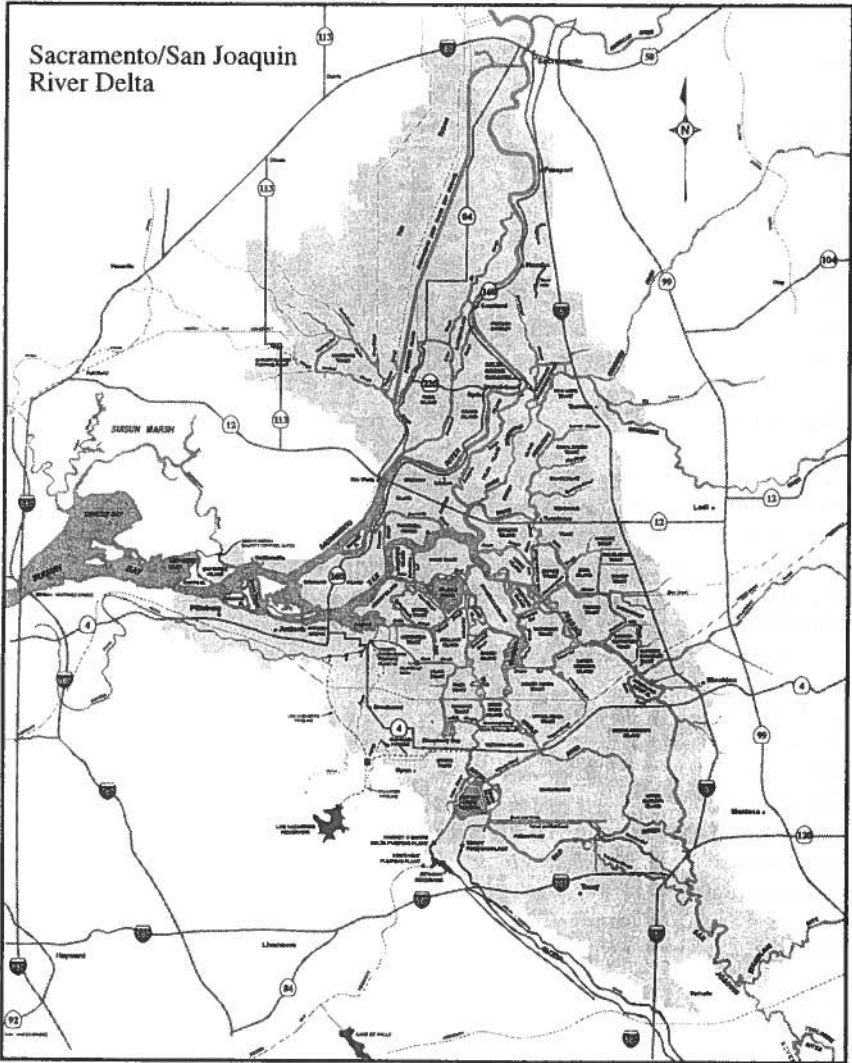


Figure 3. Map of the Delta



The drought of 1987-92 demonstrated just how vulnerable California is to water shortages. Conflicts between water quality, fish protection, and water supply demonstrate how little flexibility there is in the system. The state's population is expected to grow from 34 million today to 59 million in 2040. The need to conserve, to build new facilities, and to operate them more efficiently is greater than ever.

**CALFED Program**

The CALFED Bay-Delta Program is a cooperative state and federal effort established to reduce conflicts in the system by solving problems in ecosystem quality, water quality, water supply reliability, and levee and channel integrity. In addition to the CALFED agencies (see Table 1), representatives of agriculture, urban areas, environment, fishing, business, and rural counties contribute to the process.

One of CALFED's primary goals is to improve the reliability of California's water supply within the context of unpredictable hydrology and competing needs of fish and water users. To address this supply-reliability issue, CALFED has proposed several actions, three of which are germane to this paper. These actions are:

1. Establish a regulatory baseline by defining existing regulatory requirements and clarifying implementation of specific regulatory actions.

Table 1. CALFED Agencies

<u>State Agencies</u>	<u>Federal Agencies</u>
Department of Water Resources	Bureau of Reclamation
Department of Fish and Game	Fish and Wildlife Service
Reclamation Board	Bureau of Land Management
Water Resources Control Board	Geological Survey
Department of Food and Agriculture	Army Corps of Engineers
Delta Protection Commission	Environmental Protection Agency
	National Marine Fisheries Service
	Natural Resources Conservation Service
	Forest Service
	Western Area Power Administration

2. Establish an Environmental Water Account with a quantity of water set aside annually to provide additional water for fish purposes beyond the regulatory

baseline. Water assets are to be acquired and managed by the CALFED agencies.

3. Provide a commitment that future measures to protect fish will not diminish the state and federal projects' water supply provided from the Delta under the baseline regulatory requirements. This commitment initially will be provided for the first four years of what is known as Stage 1 and is conditioned upon the establishment of the Environmental Water Account.

## ENVIRONMENTAL WATER ACCOUNT

### History

The concept of an EWA had its origins in the CALFED program when an agency/stakeholder group called the Diversion Effects on Fish Team was convened in February 1998 to compare the effects on fisheries of three CALFED project proposals. During discussions, the concept of an EWA was considered as an alternative to putting new rigid operating requirements, so-called "prescriptive standards," in place to protect fish. In December 1998, agency and stakeholder representatives took part in the first modeling exercises (gaming) designed to determine whether fishery protections could be provided at reduced water cost. Encouraged by initial outcomes, CALFED agencies continued to evaluate the feasibility and utility of the EWA concept as a fishery protection/restoration tool.

Gaming Evaluations and Conclusions: A gaming approach was used to interactively simulate the effects of fish protection measures on Delta flows and water supply conditions. Historical data on hydrology and density of key fish species (fish per thousand acre-feet of water diverted) were used. A combination of a monthly planning model operated in a year-by-year mode and daily State Water Project and Central Valley Project (SWP and CVP) operations simulation models were used to approximate baseline conditions assuming different sets of facilities and operating rules. The daily models were used to show the daily patterns of reservoir releases and Delta inflows and the effects of various Delta water quality and other regulatory objectives on Delta outflow and allowable pumping. Historical patterns of fish presence were used to make adjustments to daily pumping in a month-by-month gaming exercise and to calculate the fish entrainment protection achieved. A recent period of record (1981-1995) was used for the gaming because it covered both wet and dry conditions and because historical fish salvage records from the SWP and CVP facilities were available. Some conclusions from the gaming are:

- Gallon for gallon, flexibility provided by the EWA could be more effective in reducing fish entrainment at the south Delta pumping plants than rigid prescriptive standards.

- For a given level of protections, the EWA could allow more pumping from the Delta than prescriptive standards.
- Effectiveness of the EWA would be greater with increased quantities and diversity of assets.
- Application of the EWA could provide incidental benefits to water supply and export water quality.

The EWA was viewed as an important supplemental means to provide improved fish protection that may be more effective than additional fixed monthly minimum prescribed regulatory outflow and export limitation standards. Consequently, in August 2000, the CALFED agencies started developing and implementing the EWA.

### **EWA Description**

**Purpose and Principles:** The CALFED EWA is intended to provide additional flexibility in the operation of the state and federal Delta export pumps to protect fish while ensuring that the reliability and quality of water for export water users is not degraded further. The EWA is designed to improve fisheries protection and recovery through environmentally beneficial changes in operations of the SWP and CVP.

The EWA is a cooperative management program between the Management Agencies (U.S. Fish and Wildlife Service, National Marine Fisheries Service and California Department of Fish and Game) and the Project Agencies (U.S. Bureau of Reclamation and California Department of Water Resources). To better protect fish without impacting water supply reliability, the EWA will acquire alternative sources of project water supply called "EWA assets." EWA assets will be used to augment instream flows and Delta outflows, modify exports to benefit fish, and replace the regular project water supply reduced by changes in project operations. The EWA will supplement, not substitute, existing prescriptive standards.

The Management and Project Agencies will implement the EWA. The Management Agencies will manage EWA assets and exercise their biological judgment to determine which changes to project operations are beneficial to fish. The Project Agencies are responsible for acquiring, banking, and conveying EWA assets and implementing the operational changes recommended by the Management Agencies. Four general operational principles guide EWA management activities. They are:

1. Management and Project Agencies shall cooperate to implement the EWA.
2. The EWA shall cause no reduction in project deliveries.
3. The EWA shall impose no net increased incremental costs upon the projects.
4. The EWA shall be responsible for mitigating its water quality, water rights, and environmental impacts as required by law.

EWA Tools: Four tools are available to the EWA. They are:

1. **Water Acquisitions.** Using EWA funds, assets for the EWA are acquired from willing sellers both upstream of the Bay-Delta as well as in the area served by project exports from the Delta. Purchases include leases, options, long-term agreements, storage space, or any type of transactions that make alternative project supplies available. Water is made available through four means:
  - The sharing (on an equal basis) of regulatory water released from upstream sources and pumped by the SWP for its project supplies.
  - A joint point of diversion agreement between the SWP and CVP for wheeling project water. The EWA shares a portion of available capacity for wheeling water from the Delta to points south of the Delta.
  - SWP appropriation of unregulated flow. The SWP may use its Delta diversion rights to pump water from the Delta for EWA purposes when the SWP has diversion capacity but no demand.
  - Project pumping made possible by relaxation of regulatory requirements.
2. **Banking of EWA Assets.** Acquired water may be stored in SWP and CVP project reservoirs upstream of the Bay-Delta and in the export service area.
3. **Borrowing.** Project water may be borrowed to enhance the effectiveness of the EWA. (The converse is also true. When the EWA has supplies but not need, the projects may borrow EWA water for their water supply uses.)
4. **Transfers and Delta Conveyance.** Water assets acquired upstream of the Bay-Delta may be transferred to create EWA assets in the export service areas south of the Delta.

EWA Assets: Immediate development of assets for the first year is critical to the success of the EWA. Generally, EWA assets fall into two categories: fixed assets and variable assets. Fixed assets (shaded portion of Table 2) are those acquired from willing water sellers through purchase and leasing agreements. Their availability is dependent upon current supplies of the sellers and water year type. Generally, more water is available for sale in wetter years than drier years. Except for the one-time purchase of banked groundwater, fixed assets are to be acquired on an annual basis.

Variable assets are made available through the flexibility of the projects. They are made available when conditions are such that the water is available, aquatic species are not at risk, and capacity exists in the system to move the water to storage facilities south of the Delta. Table 2 shows water amounts estimated to be available from variable assets on an average annual basis and amounts of fixed assets to be purchased annually in the case of surface water and in the first year in the case of groundwater.

Table 2. Asset Acquisitions  
Environmental Water Account

Action Description	Water Availability Annually (Avg.)
SWP Pumping of Regulatory Released Water	40,000 acre-feet
EWA Use of Joint Point	75,000 acre-feet
Export/Inflow Ratio (Relaxation of Regulatory Requirements)	30,000 acre-feet
500 cfs SWP Pumping Increase (Relaxation of Regulatory Requirements)	50,000 acre-feet
Purchases – South of Delta	150,000 acre-feet
Purchases – South of Delta Groundwater and Storage (One-time Purchase)	200,000 acre-feet
Lease, South of Delta Surface Water	100,000 acre-feet
Purchases – North of Delta	35,000 acre-feet
Total	680,000 acre-feet

### Status of the Environmental Water Account

The CALFED Record of Decision, signed by the state and federal CALFED agencies in August 2000 requires the development and implementation of an EWA by December 2000. Specifically, the decision requires acquisition of 35 thousand acre-feet of water north of the Delta, 150 taf of surface water south of the Delta, 200 taf of stored groundwater south of the Delta (with the ability to extract 100 taf), and 100 taf of leased water at San Luis Reservoir, south of the Delta. This schedule did not allow much time to find water sources, draft contracts for acquisitions, develop environmental documentation for the actions, develop funding sources for the acquisitions, develop operating protocols for the EWA, and incorporate the EWA into project operations for 2001. However, a dedicated team of federal and state agency staff did just that.

As shown in Table 3, sufficient fixed assets have been acquired (or are in the process of being acquired) to enable an operable EWA. Variable assets were also acquired for the EWA. In October and December of 2000, the Project Agencies took advantage of hydrological conditions and used their operational flexibility to provide an additional 10 taf. That water is currently stored south of the Delta at San Luis Reservoir. As a result of these activities, on January 11, 2001, the Management Agencies concurred with the Project Agencies that the EWA is operable. They subsequently issued commitments that water needed for protection of aquatic species above established baseline conditions will not result in decreased water deliveries to SWP and CVP water users.

## Transbasin Water Transfers

Table 3. EWA Assets Acquired (Or In Process of Acquisition)

	Quantity (taf*)	
	Dry	Wet
North of the Delta Goal: 35 taf		
Yuba County Water Agency 2001 purchase	50	50
Oroville Wyandotte 1D 2000	10	0
Subtotal North of Delta	60	50
South of the Delta Goal: 150 taf		
Initial Water in San Luis Reservoir	72	72
Westside Mutual 2000 Purchase	15	15
Westside Mutual 2001 Purchase	0	55
Rosedale Rio Bravo 2000 Purchase	19	19
Arvin Edison 2000 Purchase/Exchange	10	10
Arvin Edison 2001 Purchase/Exchange	10	10
BVWD/RRB/WKWD (spot market)	0	35
Nickel/ID4	10	15
Semitropic WSD/ Tulare Irrigation District	15	15
Subtotal South of Delta	151	246
Groundwater Storage/Extraction Goal: 200/100 taf		
MWD - Semitropic 2001 GW Purchase	32	32
MWD - Semitropic 2001 GW Recovery	0	0
Santa Clara Semitropic 2001 Purchase	30	30
Santa Clara Semitropic 2001 Recovery	30	0
Westside Mutual 2001 GW Purchase	50	50
Westside Mutual 2001 GW Recovery	20	0
Cawelo 2001 GW Purchase	10	10
Cawelo 2001 GW Recovery	5	0
BV/WK/RRB 2001 GW Purchase	25	0
BV/WK/RRB 2001 GW Recovery	25	0
Rosedale Rio Bravo 2001 Recovery	45	45
Rosedale Rio Bravo GW Storage Service	45	45
Subtotal Groundwater Storage	192	167
Subtotal Groundwater Extraction	125	45
Source Shifting Goal: 100 taf		
Metropolitan Water District	100	100
Subtotal Source Shifting Agreements	100	100

\*taf: thousand acre-feet

**Recent EWA Activities:** The Management Agencies will use the EWA to improve the survival of both migratory fish and resident fish in the Delta. The fish species most vulnerable to the effects of water diversion in the Delta varies by season (see Figure 4). In the fall and winter, juvenile salmon and steelhead migrating from freshwater through the Delta to the ocean are the main concern. Delta smelt become an additional concern when adult smelt move upstream from the estuary to the Delta in the winter, and after spawning takes place in the spring, young delta smelt become vulnerable to effects of diversions until they move downstream out of the influence of the pumps. The general seasonal pattern of fish occurrence in the Delta and the extent of vulnerability of fish to diversion effects is modified to a degree by annual variation in hydrology. Other fish species will benefit from operations changes targeted primarily to improve survival of salmon, steelhead, and delta smelt.

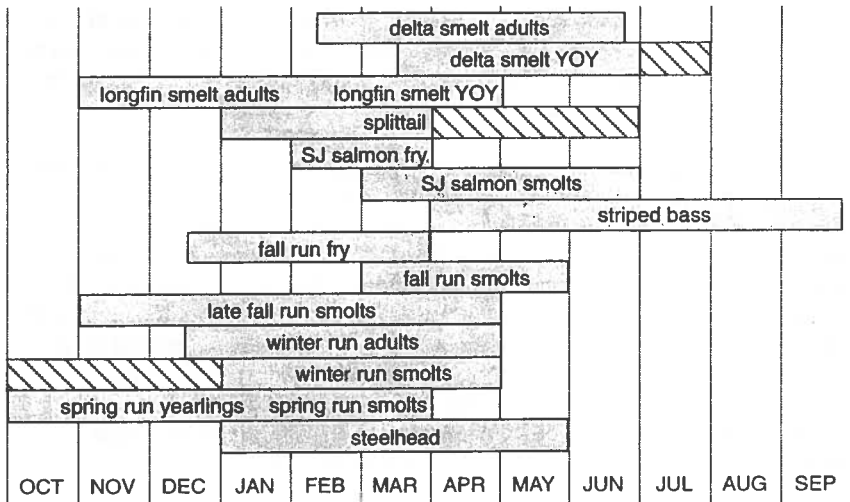


Figure 4. Fishery Protection Proposal

To make decisions on when to use the EWA, the Management Agencies rely on fishery monitoring upstream and in the Delta to characterize fish distribution and migration patterns. Data from the fish salvage facilities at the South Delta diversions also provide valuable information. The Management Agencies have developed documents that explain how monitoring results and other information will be evaluated in making EWA decisions.

The Management Agencies called for operations changes on three occasions in January 2001. In the first case, an export reduction to 3,000 cfs for three days was requested to simultaneously improve salmon protection and allow a study of the effects of Delta flows on the migration of juvenile salmon by tracking the

movement of salmon with radio transmitters attached. Because of increased salinity in the Delta and the need to avoid violating a requirement in the state's Bay-Delta Water Quality Control Plan, the projects had to reduce diversions independent of the fishery agencies' request. Because the export pumping had to be reduced by the Project Agencies pursuant to a baseline regulatory requirement, no EWA assets were used. In the second case, a five-day reduction in exports to 6,000 cfs was requested when Delta salmon monitoring indicated an increase in the number of juvenile salmon moving into the Delta. Nested within the five days was a 3-day reduction to 3,000 cfs to repeat the radio-tagged salmon tracking study. This five-day fish action did reduce Delta exports compared to the no-action case. The EWA, as well as a CVPIA water account with a similar purpose, will be charged for the difference, expected to be about 40 taf to 50 taf. The third action was a request to reduce exports from a base rate of about 11,000 cfs to 6,000 cfs in response to observed high losses of juvenile salmon at the water diversions on several days in succession. This curtailment, undertaken as this is being written, was put in place for three days, with a decision to continue or not to be based on new information as it is collected. As is always the case, the cost to the EWA, if any, will be computed after the action is completed.

Science Advisory Board: Acquisition of EWA assets on an annual basis requires significant expenditure of funds (\$50 million per year) and commitment of significant resources for operation of the account. To ensure biological justification for the use of EWA assets, a Science Advisory Board has been established. In the short-term, this board will review recommendations from the Management Agencies for use of EWA assets. For the longer term, the board will recommend appropriate studies to evaluate the biological effects resulting from use of the EWA and will recommend research to identify the mechanisms responsible for the biological effects. This relationship between action, evaluation of the action and reaction in terms of new management strategies represents the adaptive management component of the EWA.

Next Steps: The EWA will be operated on a trial basis for the next four years. Each year the effectiveness of EWA actions for increasing both fish protection and water supply reliability will be evaluated. Based on this assessment, strategies for the acquisition and management of EWA assets will be made annually in an effort to improve the results. In the first year we have encountered some circumstances, not anticipated during development of the EWA concept, that may lead to changes. At the end of four years the CALFED agencies will decide whether to continue the EWA and, if so, what modifications may be needed to make the EWA perform better.

Establishing the EWA is a historic accomplishment. For the first time ever, state and federal resource agencies have been provided an acquired water supply to manage for the benefit of aquatic assets. Regardless of whether the EWA is



continued, it has caused a change in the way business is conducted by the state and federal fish and water agencies in California.

As a result of the EWA and its inherent water management implications, fish agency biologists and managers now must think more like water managers in making decisions about the use of EWA to protect aquatic resources. Conversely, while working to accommodate the water management needs of the fish agencies, water agency staff and managers are developing an understanding of the biological basis and significance of decisions made by fish agencies. Increased communication and understanding has resulted in greater cooperation among the agencies and more informed, more timely and, hopefully, more effective decision-making. The goals of water supply reliability and resource protection are more shared among the agencies than they have ever been. The EWA has helped foster a more collaborative working relationship between biologists and project operators; ostensibly one that will continue even if the EWA does not. While it is early in our experience with the EWA concept, it is already difficult to envision a scenario that would have the projects operating in the future without some form of an EWA.



## HISTORY OF THE CENTRAL UTAH PROJECT A FEDERAL PERSPECTIVE

Reed R. Murray<sup>1</sup>

Ronald Johnston<sup>1</sup>

### ABSTRACT

The Central Utah Project (CUP), located in the central part of Utah is the largest water resources development program ever undertaken in the State. The project provides Utah with the opportunity to beneficially use a portion of its allotment from the Colorado River water through a transbasin diversion. Water resources development has long been a part of the area's history. Settlement of the Salt Lake Valley in 1847 by Brigham Young and the Mormon pioneers launched the first large scale irrigation in the United States. The CUP concept was first conceived in 1902, when farmers investigated the feasibility of diverting water from the Colorado River to the Bonneville Basin in central Utah. Since that time the CUP has evolved from studies of various independent projects. The U.S. Bureau of Reclamation began investigations of the CUP in 1945 and published a feasibility report of their findings in February 1951. Portions of the CUP were authorized for construction in 1956 by the Colorado River Storage Project Act, and other portions were authorized in 1968 by the Colorado River Basin Project Act. In October 1992 final construction of the CUP was re-authorized through public law 102-575 of which titles II through VI comprise the Central Utah Project Completion Act. This Act was unprecedented in that it transferred the responsibility for completion of the CUP from the U.S. Bureau of Reclamation to three joint lead entities comprised of a state organization, a presidential commission, and a federal office.

### BACKGROUND

The name Utah comes from the Native American Ute Tribe and translates "people of the mountains." Utah, located in the western United States is home to the Uinta and Wasatch Mountain Ranges (See Figure 1). The Uinta Range, the only major east-west trending range in the U.S., claims the highest mountain in Utah, Kings Peak, over 13,500 feet. Wasatch peaks are lower, with the highest, Mount Nebo, just under 12,000 feet. Utah also consists of a variety of landscapes including high mountain lakes, salt flats, deserts, and plateaus.

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<sup>1</sup> Ronald Johnston is the Program Director and Reed Murray is a Program Coordinator for the Central Utah Project Completion Act Office, Office of the Secretary, U.S. Department of the Interior.

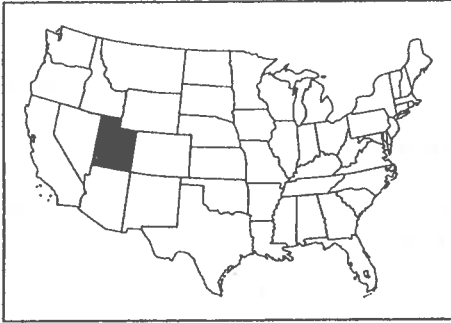


Figure 1 - Utah and the United States

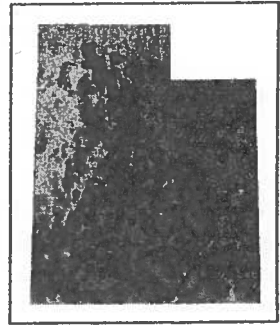


Figure 2 - State of Utah

Most of eastern and southern Utah rivers drain into the Colorado River system. Other major rivers in the State terminate at the Great Salt Lake Desert or, like the south-to-north flowing Jordan River, drain into the Great Salt Lake, the remains of a large inland lake having no outlet. Utah is justifiably ranked the second driest state in the United States. In most of the State annual precipitation averages between 8 and 16 inches, but in the Great Salt Lake Desert annual rainfall is less than 5 inches. By contrast, high mountain precipitation averages more than 40 inches annually, mostly in the form of snow that can reach depths up to 30 feet.

Most of the population resides along the Wasatch Front, a narrow corridor of land extending 120 miles along the western base of the Wasatch Mountains from Ogden on the north to Nephi on the south. The Wasatch Front is the most fertile and productive part of Utah. Chief field crops include hay, wheat, and barley.

### EARLY WATER DEVELOPMENT IN UTAH

#### Private Development

The first known development in Central Utah by non-Native Americans occurred in 1822, when a group of fur traders established a trading post at Utah Lake, known as Fort Ashley. Even then, it was well known that the Salt Lake Valley suffered from an inadequate water supply. Mountain man Jim Bridger offered to pay \$10,000 for the first bushel of corn produced in the valley.

Settlement of Utah's Salt Lake Valley began in 1847 by western colonizer Brigham Young and the Mormon pioneers.<sup>2</sup> Under Young's leadership, these

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<sup>2</sup> Members of the Church of Jesus Christ of Latter-day Saints are referred to as Mormons because of their belief in the *Book of Mormon*.

pioneers launched the first large-scale irrigation system in the United States. Young is credited with instituting a system of irrigation that subsequently laid the basis for irrigation law in the West. He reportedly said, "No man has the right to waste one drop of water that another man can turn into bread." The principle was laid down that the water belonged to the people, "all the people," said Young, and no man could gain a right to more than he could beneficially use.

The pioneers soon learned that streams entering the Salt Lake Valley from the Wasatch Mountains did not maintain sufficient flow to support large-scale irrigation. Eventually farmers shifted their irrigation development to the Uinta Mountains where the larger Weber, Bear, and Provo Rivers originated. Young's principle of cooperative use of resources led to the doctrine of beneficial use and appropriation of water as the underlying legal basis for distributing water to local consumers. This doctrine held that all individuals desiring the use of water were entitled to an equal share of available water, regardless of when they settled the area or what their proximity to the water.

### **Federal Projects**

As irrigation projects increased in scale, local water users turned to the Federal Government for expertise and funding. Under the new Reclamation Act of 1902 several early Federal projects were authorized by Congress and constructed by the U.S. Bureau of Reclamation (Reclamation). Early Federal projects constructed in Utah included the Strawberry Valley Project, Uintah Indian Irrigation Project, Provo River Project, and Moon Lake Project.

**Strawberry Valley Project:** In August 1902, a group of farmers and civic leaders traveled east to Strawberry Valley to investigate the feasibility of diverting water for their farms in South Utah County. The diversion would bring water from the Uinta Basin, a part of the Colorado River Basin, to the Bonneville Basin, a part of the Great Basin. The services of Reclamation were solicited, and preliminary surveys for supplemental water storage and investigations of irrigable lands were conducted in 1903. Thus the Strawberry Valley Project became one of the earliest projects investigated under the new Reclamation Act.

**Uintah Indian Irrigation Project:** During the years 1904-05, the United States granted irrigation and grazing allotments to individual Native American Ute Indians. In 1906 Congress authorized construction of the Uintah Indian Irrigation Project (UIIP), owned and operated by the U.S. Bureau of Indian Affairs for irrigation and grazing allotments in the Duchesne River Basin. At least 22 canals were completed for the UIIP by 1922. No tribal lands were included in the project, although the Tribe has since acquired a number of project allotments. About 60,000 acres currently receives water, with approximately 28,500 acres served by the project now being held in fee by non-Native Americans.

Provo River Project: The Provo River Project was initiated under provisions of the National Industrial Recovery Act of 1933. Municipalities in Utah and Salt Lake Valleys who needed additional municipal supplies joined with irrigation interests to sponsor the project. Construction of the Provo River Project started in 1938, but when World War II began in 1941 the project was severely hampered by scarcities of manpower, materials, and funds and was not completed until 1952.

Moon Lake Project: Even before the arrival of homesteaders in 1905, Native American inhabitants had established water rights for irrigation of their lands throughout the Uinta and Duchesne River Basins. As the settlers began to irrigate, it became apparent that the streamflow was insufficient to satisfy existing Native American rights and also irrigate some 70,000 acres owned by the settlers. Local interests began investigations and planning for the Moon Lake Project in 1922. Construction began in 1935 and was completed in 1941.

These early Federal projects served the people for a time, but as water users sought to expand or enlarge their projects, the idea of a Central Utah Project developed, which became part of the massive Colorado River Storage Project.

## MODERN WATER DEVELOPMENTS IN UTAH

### Colorado River Storage Project

The Colorado River is one of the most important and thoroughly used rivers in America. Draining one-twelfth the area of the continental United States, the 1,400-mile-long river provides water to seven Colorado River Basin states. The river flows through a dry and barren land made productive only by irrigation. This needed irrigation is made possible by the Colorado River Storage Project (CRSP) through a series of dams, reservoirs, and canals.

The CRSP serves millions of people by providing water for farms, municipalities, industry, wildlife, and recreation along with hydroelectric power which is distributed for use throughout the West. Revenues from the sale of this water and power, as required by law, are paying for the CRSP storage units and for the CRSP participating projects, of which the Central Utah Project is one.

The CRSP was envisioned at the time of the Colorado River Compact of 1922. The compact set aside 7.5 (seven and one-half) million acre-feet of Colorado River water for consumption in the Upper Basin each year. However, this allocation was contingent upon the upper basin's delivering to the lower basin not less than 75 million acre-feet of water in any period of 10 consecutive years and delivering additional water for use in Mexico under certain circumstances. The compact guaranteed the Lower Basin its share, even when flows were far below average.

Since the flow of the Colorado River is extremely erratic, varying from 4 to 22 million acre-feet annually at Lees Ferry, it was necessary to construct large Storage Unit dams and reservoirs in the Upper Basin that could be filled when flows were high to provide the additional water needed for compact fulfillment. Construction of four storage units of the Colorado River Storage Project and 11 participating projects were authorized by the act of April 11, 1956 (Public Law 485, 84th Cong., 70 Stat. 105) known as CRSPA. The four storage units, called the main stem projects, are shown in Table 1. The Central Utah Project was authorized as one of the 11 participating projects.

<u>Project Name</u>	<u>Key Feature</u>	<u>Location</u>
Glen Canyon Unit	Glen Canyon Dam	Arizona/Utah
Flaming Gorge Unit	Flaming Gorge Dam	Utah/Wyoming
Navajo Unit	Navajo Dam	New Mexico/Colorado
Curecanti Unit	Blue Mesa Dam	Colorado

Table 1 - CRSP Main Stem Projects

## ORIGIN OF THE CUP

### Introduction

The Central Utah Project (CUP), located in north-central Utah, is the largest water resource development ever undertaken in the State. The project benefits the State and provides much of Utah's rapidly expanding population, now surpassing 2 million, the opportunity to use a portion of its allotment from the Colorado River, by means of a transbasin water diversion.

The concept of a project for central Utah was envisioned when a reconnaissance investigation of the newly conceived Colorado River-Great Basin Project was conducted by Reclamation from 1939 to 1943. The project plan called for an annual transbasin diversion of 1 million acre-feet of water from the Green River of the Colorado River Basin to the Great Basin.

Close on the heels of the Colorado River-Great Basin Project was another forerunner of the Central Utah Project, the Strawberry Valley Project. The possibility of expanding the existing 1913 Strawberry Valley Project was considered as early as 1919 by local municipal and agricultural water users and other leaders, who recognized future water requirements in Central Utah.

Reconnaissance investigations for obtaining additional water for the Strawberry Valley Project were started in the spring of 1945. The name Central Utah Project was given to an extended version of the plan, which covered essentially the same area as that considered in the Colorado River-Great Basin Project. Results of the

investigations were contained in a planning interim report of September 1945. The report included a reconnaissance plan which provided for the exportation of 575,000 acre-feet of water from the Colorado River Basin to the Bonneville Basin.

A Central Utah Project Office was established in 1946, and feasibility investigations were carried out over the next several years. Results of these investigations were compiled in a feasibility report released in 1951. This widely circulated report served as the basis for authorizing the initial phase of the Central Utah Project in 1956. The plan for development was similar to that reported in the 1945 reconnaissance report, with refinements and modifications that greatly reduced the transbasin diversion from 575,000 to 141,400 acre-feet.

In 1956 Congress authorized construction to begin on the Central Utah Project, Initial Phase, and the Bonneville Unit Definite Plan Report (DPR) was published in August 1964. The DPR contained the results of many years of comprehensive planning. The report was approved by the Commissioner of Reclamation on November 5, 1965, and the project lands were certified December 28, 1965, by the Secretary of the Interior. The project plan was basically the same as that contained in the 1951 feasibility report, with some modifications that reduced the transbasin diversion to 136,600 acre-feet.

As planning for the CUP was being refined by Reclamation, local support for the project was clearly evident. In 1965 George D. Clyde, then Governor of Utah said: "The Central Utah Project is the key to development of Utah's resources for the next 100 years. Without it, Utah can never get the benefits of its share of the Colorado River, our last major water resource." The truth of his statement, is reflected not only in the revenues the project has brought to the State, but also in water resources development for municipal, industrial, and agricultural uses; recreational opportunities; fish and wildlife enhancement; and flood protection.

The CUP was introduced in two phases: the Initial Phase included four of the six units: Bonneville Unit, Jensen Unit, Vernal Unit, and the Upalco Unit, and the Ultimate Phase involved the remaining two units, the Uintah Unit and the Ute Indian Unit.

### **Water Rights**

On September 4, 1946, Reclamation filed an application (No. 18043) with the State Engineer covering the appropriation of water for both the initial and ultimate phases of the Central Utah Project. This application sought the appropriation of 800,000 acre-feet of water from lakes, streams, and proposed reservoirs in the Uinta Basin along the 37-mile-long Strawberry Aqueduct. The aqueduct was to extend from Brush Creek on the east to Strawberry Reservoir on the west.



On November 19, 1964, a second application (No. 36639) was filed for 500,000 acre-feet for the main Bonneville Unit supply including the Strawberry Aqueduct and Collection System and related facilities. This latter application was approved June 14, 1965, paving the way for construction to begin. The Bonneville Unit plan called for enlarging Strawberry Reservoir from its initial capacity of 270,000 acre-feet to an active capacity of close to 1.4 million acre-feet (1,370,000). The application covered all reservoirs and points of diversion along the collection system as well as lands in the Bonneville Basin only. This latter application was approved June 14, 1965.

### **Organization of the Central Utah Water Conservancy District.**

Early in the planning process, Reclamation and local sponsors recognized the need to organize a conservancy district to represent the people within the project area, and to collect payments from water users to repay the United States Treasury for project costs. Petitions to create the conservancy district were initially signed by Duchesne, Juab, Salt Lake, Summit, Uintah, Utah, and Wasatch Counties, with the Central Utah Water Conservancy District (CUWCD) later approving the inclusion of Garfield, Millard, Piute, Sanpete, and Sevier Counties. Since then Millard, Sanpete, and Sevier Counties have withdrawn from the CUWCD and/or the CUP Project.

On March 2, 1964, the CUWCD was established and organized under the laws of the State of Utah. A repayment contract between the United States and the CUWCD was executed December 28, 1965.

### **Ute Deferral Agreement**

On September 20, 1965, Contract No. 14-06-W-194 was executed among the United States (Reclamation and the Bureau of Indian Affairs), the Ute Indian Tribe, and the CUWCD. In this deferral agreement, the Indian Tribal authorities agreed to defer development of 15,242 acres of land, which allowed construction of the Bonneville Unit to proceed. It was agreed that the year 2005 would be the maximum date of deferral or that equitable adjustments would have to be made to permit the immediate Native American use of water previously deferred. It was further agreed that facilities would be provided to mitigate for losses to fish, wildlife, and recreation upon the lands owned by the Ute Indian Tribe.

### **Congressional Actions**

As the CUP was developed, the Utah Congressional delegation fought to establish funding in Congress. Money was earmarked in Congress to start construction of the Bonneville Unit, only to have the Senate cut the construction funds from the 1966 appropriations. Eventually the appropriation was approved at \$3.5 million

to initiate construction, and the groundbreaking was held May 31, 1967. As construction on the CUP continued, the Utah delegation fought to maintain the needed level of funding, but since the beginning support for the CUP has fluctuated in Congress.

### ENVIRONMENTAL CONSIDERATIONS

Beginning in the mid 1960s, environmental concerns about the CUP began to appear from local outdoor groups. These issues eventually caught the attention of national organizations such as the Sierra Club. The main points centered around the proposed diversions from streams in the Uinta Basin. The Sierra Club voiced misgivings about moving water from the Uinta Basin to the Wasatch Front, stating: "The net result of the CUP will be to force all future growth in Utah to occur along the populous Wasatch Front." The Federal government saw the need to protect the environment and soon enacted major laws, among them the Environmental Policy Act of 1969.

#### National Environmental Policy Act of 1969

Environmental concerns were also growing around the nation, which resulted in enactment of the National Environmental Policy Act of 1969 (NEPA), signed into law January 1, 1970. NEPA was described as the most important and far-reaching environmental and conservation measure ever enacted by the Congress. NEPA applies to all Federal agencies and to every major action taken by these agencies that would significantly affect the quality of the human environment.

With the new law in place, Reclamation began to work on an environmental Impact statement. In August 1973 Reclamation issued the Bonneville Unit Final Environmental Impact Statement. The document was a programmatic environmental impact statement for the entire Bonneville Unit, but also provided specific NEPA compliance for construction of the Strawberry and Starvation Collection Systems. In 1974 the United States District Court for the State of Utah ruled that the Bonneville Unit Final EIS was in compliance with NEPA, and this decision was upheld by the United States Tenth Circuit Court of Appeals. Reclamation committed to prepare a site-specific EIS for each of the remaining Bonneville Unit Systems before initiating construction. Reclamation accordingly published the Bonneville Unit Municipal and Industrial System Final Environmental Statement October 25, 1979.

#### Endangered Species Act of 1973

The Endangered Species Act (ESA) was enacted to allow protection and conservation of endangered and threatened species and their natural environment. The ESA, administered by the U.S. Fish and Wildlife Service (FWS), is a program to identify and conserve endangered and threatened species. The

ultimate goal and purpose of the ESA is for full recovery of these species. The FWS has the responsibility to determine which species is threatened with extinction and whether the species decline is the result of human activities. Species may be listed as endangered, threatened, or candidate.

The enactment of ESA also prompted State and private entities to study species of concern. The State of Utah has created a State Sensitive Species list to identify species in the State that are most vulnerable to population or habitat loss. The list is intended to stimulate management action for the sensitive species before they reach the point where they may require listing under the ESA. Several special status species have been considered during development of the CUP as shown in Table 2.

<b>Endangered species</b>	
<b>Common Name</b>	<b>Scientific Name</b>
Peregrine falcon	<i>Falco peregrinus</i>
Humpback chub	<i>Gila cypha</i>
Bonytail chub	<i>Gila elegans</i>
Razorback sucker	<i>Xyrauchen texanus</i>
June sucker	<i>Chasmistes liorus</i>
Colorado squawfish	<i>Ptychocheilus lucius</i>
<b>Threatened species</b>	
Bald eagle	<i>Haliaeetus leucocephalus</i>
<b>Candidate species</b>	
Spotted frog	<i>Rana pretiosa</i>
Least chub	<i>Iotichthys phlegethontis</i>
<b>Conservation species</b>	
Bonneville cutthroat trout	<i>Oncorhynchus clarki utah</i>

Table 2. Special-Status Species Potentially Occurring Within the CUP

### **Instream Flow Agreement**

As NEPA documents were being prepared for the Diamond Fork Power System of the Bonneville Unit, Federal and State fishery biologists realized that the mitigation flows of 6,500 acre-feet as suggested in the Bonneville Unit EIS were insufficient. This opinion was echoed by several organizations. At the request of the governor of Utah, an Interagency Biological Assessment Team (IBAT) was organized to evaluate alternatives to mitigate for the Strawberry Collection System and the Bonneville Unit Instream Fisheries Flow Agreement (Instream Flow Agreement) was produced by the IBAT.

The Instream Flow Agreement was executed February 27, 1980, after which a supplemental memorandum of agreement was signed September 25, 1981, and amended September 13, 1990. The Instream Flow Agreement was created to provide minimum streamflows on some of the streams affected by the Strawberry Aqueduct and Collection System. The agreement required providing an additional 37,900 acre-feet to Rock Creek, Currant Creek, and the Strawberry River. When combined with the original 6,500, the total streamflow is 44,400 acre-feet. This agreement mitigates for half the required flows for the Strawberry Aqueduct and Collection System.

To offset the remaining loss of fishery habitat in other streams which were taken for project purposes, the Refined Aquatic Mitigation Plan for the Strawberry Aqueduct and Collection System was drafted in December 1984. One of the three major components of the refined plan was the Upper Strawberry Exchange. The concept for this exchange was to terminate completely the existing transbasin diversions from four streams in the upper Strawberry River drainage into Daniels Creek in the Provo River drainage. Under this action, natural streamflows would be restored to the upper Strawberry River tributaries. In February 1990 the Diamond Fork Supplemental EIS was filed, which contained commitments regarding the Aquatic Mitigation Plan.

### **Changes to the CUP Plan**

Reclamation routinely refines definite plan reports to accommodate changed conditions which necessitate adaptations and modifications of the original plan. In 1988 Reclamation prepared the Supplement to the Definite Plan report to address refinements made to the Bonneville Unit since 1964 when the Bonneville Unit was conceptually divided into six systems as shown in Table 4.

Construction progress on the Bonneville Unit proceeded slowly because of the enormity and complexity of the unit and because of unforeseen events. Chief among these were the new federal environmental laws and inadequate Federal funding. The slow progress prompted State and local officials to request Congress to make unprecedented changes to the way federal water projects are planned and constructed.

## NEW MANDATE

**Central Utah Project Completion Act**

Priorities within the wide geographical areas served by Reclamation and delays in the CUP led officials to appropriate funds earmarked for the CUP to other Reclamation projects. This created a difference of opinion between local representatives of Utah and Reclamation.

Congress responded to these local concerns about delays in construction, high overhead, and Reclamation's practice of combining cost ceiling figures of the Central Utah Project by passing Public Law 102-575, of which Titles II through VI comprise the Central Utah Project Completion Act (CUPCA). The law was enacted October 30, 1992, amending CRSPA. Under CUPCA, the Congress provided direction for completing the CUP with certain modifications to Reclamation's plan of development. With CUPCA, Congress approved and made final the 1988 Supplement to the Central Utah Project, Bonneville Unit, Definite Plan Report, which identified modifications to Reclamation's plan. It also called for a new supplemental DPR to be written. These modifications resulted in the current CUP as shown in Figure 3.

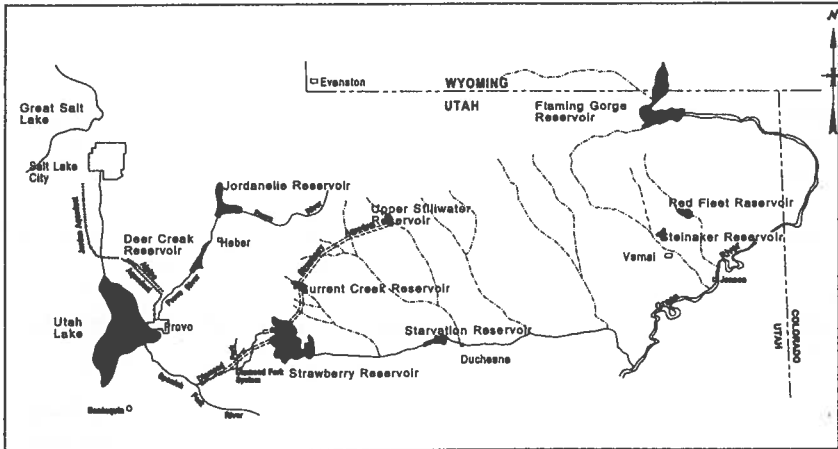


Figure 3. Central Utah Project.

The primary purpose of CUPCA is to provide for the orderly completion of the CUP by increasing the appropriations ceiling, by authorizing certain water conservation and wildlife mitigation projects, and by providing funding for

construction of certain project features for delivery of water for irrigation, municipal and industrial use, and instream flows for fisheries to specified areas within the CUP service area. To implement CUPCA, Congress established a partnership arrangement among the Department of the Interior, CUWCD, the Utah Reclamation Mitigation and Conservation Commission, and the Ute Indian Tribe.

Department of the Interior: The Department of the Interior (Interior) appointed a Program Director to oversee accomplishment of the CUPCA in Utah. The Program Director and his limited staff work with agencies within Interior through cooperative agreements, to fulfill Interior's role in CUPCA. All Federal funds for CUPCA are appropriated through the Program Director.

Central Utah Water Conservancy District: Under provisions of CUPCA, the CUWCD was authorized to plan and construct specified features identified in the Act. CUWCD was also tasked with developing a quantitative water conservation goal which must be met within 10 years of CUPCA's enactment. Failure to meet the goal would result in significant financial penalties.

Utah Reclamation Mitigation and Conservation Commission: CUPCA also provides for the establishment and funding of the Utah Reclamation Mitigation and Conservation Commission, composed of five directors appointed by the president of the United States. The purpose of the Commission is to complete recreation, fish and wildlife, and conservation projects in Utah associated with the CUP.

Ute Indian Tribe: The Ute Indian Tribe of the Uintah and Ouray Reservation is authorized by the Act to quantify its reserved water rights by compact directly with the State of Utah and to settle long-outstanding Tribal claims against the United States arising out of the Central Utah Project.

Additionally, the Act stipulates cost-sharing of project capital costs; allows local entities to construct certain project features; requires compliance with environmental laws; and establishes a program of water conservation.

CUPCA Titles: CUPCA is comprised of titles II through VI of public law 102-575, which stipulate the following:

Title II provides for cost-sharing of project capital costs, allows local entities to construct certain project features, requires compliance with environmental laws, and establishes a program of water conservation.

Titles III and IV establish administrative and funding mechanisms to mitigate damages to fish and wildlife resources already caused by construction of the CUP and other CRSP projects in Utah. These titles also provide for ongoing administration and funding of activities to conserve, mitigate, and enhance fish,

wildlife, and recreation resources affected by the development and operation of Federal reclamation projects in the State of Utah.

Title V authorizes the Ute Indian Tribe of the Uintah and Ouray Reservation in Utah to quantify by compact its reserved water rights held by the State of Utah and to settle long-outstanding claims against the United States arising out of construction of the Central Utah Project.

Title VI provides that nothing in the other titles of the Act would be interpreted as modifying or amending the provisions of the Endangered Species Act or the National Environmental Policy Act.

**Refinements and Modifications to Bonneville Unit Components**

Of the six original units of the CUP, only the Vernal and Jensen Units have been completed. The Upalco Unit has been indefinitely postponed, the Uintah Unit has been classified as inactive, the Ute Indian Unit has never been authorized for construction, and the Bonneville Unit is currently under construction. Enactment of CUPCA necessitated refinement to Bonneville Unit components. Table 3 presents a list of these components and indicates new components added to the Bonneville Unit.

<u>Previous Component</u>	<u>New Component</u>
Diamond Fork Power System*	Additional Studies
Irrigation and Drainage System*	Conjunctive Use of Groundwater Program
Municipal and Industrial System	Diamond Fork System*
Starvation Collection System	Fish, Wildlife, Recreation Mitigation and Conservation
Strawberry Collection System	Uinta Basin Replacement Project
Ute Indian Tribal Development	Utah Lake Drainage Basin Water Delivery System*
	Ute Indian Water Rights
	Wasatch County Water Efficiency
	Water Management Improvement

\*The Diamond Fork Power System was changed to the Diamond Fork System and the Irrigation and Drainage System was changed to the Utah Lake Drainage Basin Water Delivery System.

Table 3. Bonneville Unit Components

### FUTURE OF THE CUP

The CUPCA re-authorized planning and construction of the original Bonneville Unit Irrigation and Drainage System. This final component of the Bonneville Unit has now been named the Utah Lake Drainage Basin Water Delivery System (Utah Lake System). Construction of this system will complete the project and allow the transbasin diversion of the remaining portion of the approved 101,900 acre-feet of water from the Colorado River Basin to the Great Basin.

The Utah Lake System will connect with the Diamond Fork System to convey project water for irrigation, municipal and industrial, and fish and wildlife uses. The system would have the capability of delivering water to locations throughout the Wasatch Front as well as by exchange from Utah Lake. The available water supply will derive from several sources, including Strawberry Reservoir, Utah Lake, Jordanelle Reservoir, and the Provo River. The remaining water supply could vary from 30,000 to 70,000 acre-feet, depending on the place of use, subsequent return flows, and the use of such return flows. During the planning process for the Utah Lake System, other additional uses of Bonneville Unit water on the Wasatch Front and all remaining environmental issues and commitments associated with the Bonneville Unit will be addressed.

### REMAINING ISSUES

Since its inception, the CUP has faced financial and environmental challenges. Project construction delays have been costly not only in the time value of money but in the changing social climate of Utah and the United States. When the CUP was initiated the project purpose was primarily for agricultural development. Today the Wasatch Front is one of the most urbanized areas of the American West. People no longer have an agrarian connection to the land and are increasingly turning their attention to the environment. These changes are highly apparent in the enactment of CUPCA which added water conservation, water efficiency, and wildlife enhancement to the purposes of both the CUP and CRSP.

As the final component of the Bonneville Unit is planned several issues must be addressed in all Utah Lake System alternatives. These issues include: aggressive water conservation policies; endangered species recovery; resolution of project water rights in Utah Lake; maintaining water quality in Utah Lake; identifying, measuring, and protecting project return flows; and the urbanization of agricultural lands and conversion of project water.

CUPCA provides sufficient authority to address these remaining issues. Section 207 provides funding for implementation of water conservation measures as a means to reach the mandated water conservation goal. Section 202 provides for a groundwater/surface water conjunctive use grant program. Several sections of



CUPCA provide for acquisition and maintenance of minimum flows in streams to support endangered and sport fish. The Aquatic Mitigation Plan has also been updated for continued mitigation.

### **CONCLUSION**

In a 1960 preliminary plan formulation document, Reclamation identified several challenges facing the CUP. These included (1) clarifying water rights for the CUP, (2) maintaining water quality in Utah Lake, (3) identifying and measuring return flows, and (4) converting irrigated lands to residential, commercial, and industrial use. Although 40 years have passed since these issues were recognized, the challenges remain today. Other new challenges have also developed during the CUP's long history. The completion of the CUP continues to require creative solutions.

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# THE TENO - CHIMBARONGO CANAL: AN EXAMPLE OF COORDINATION AND COOPERATION

Rodrigo Gómez<sup>1</sup>

## ABSTRACT

The Teno River, which belongs to the Mataquito River basin, and the Estero Chimbarongo, which belongs to the Rapel River basin, are located in the Central Zone of Chile, where the Mediterranean climate predominates and irrigated agriculture is the basis of the economic activity in the area. The Teno-Chimbarongo transbasin water transfer canal is a fundamental factor in this development. Additionally, this canal supports hydroelectric generation, a highly profitable factor for this sector since the investment has been fully recovered. The initial purpose was to build a canal with capacity of 25 m<sup>3</sup>/s (882.25 ft<sup>3</sup>/s) for hydroelectric generation, but an additional 40 m<sup>3</sup>/s (1,411.6 ft<sup>3</sup>/s) was considered adequate in order to satisfy the irrigation demands in areas located before the hydropower dam. In this way, the canal became an hydraulic work with two pre-established purposes: to provide hydraulic resources for hydroelectric generation and to increase the security of irrigation. In the history of this canal, after 25 years of operation, the different stakeholders related to this project are fully satisfied with the results and both objectives have been reached. This paper presents the historic development, the difficulties, the achievements and the experience obtained from the point of view of the parties involved, emphasizing the example of coordination and cooperation and effective results, as well as the future perspectives associated with this canal.

## INTRODUCTION

The Teno – Chimbarongo Canal is a transbasin water transfer canal built at the beginning of the decade of 1970, and has resulted in an important mixed development, of irrigation and hydroelectricity, in the central zone of Chile. This case is a practical example which shows that the satisfaction of the different interests of the parties is possible, a key factor in the present and future water resources management. This canal is the second work that joined, by an

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artificial canal, two natural river courses belonging to two different river basins<sup>2</sup>. It is economically important because with a small investment and without constructing another electric hydropower plant it was possible to produce a significant amount of energy. To regulate the operation of the canal and coordinate the different parties involved an agreement was signed.

## GENERAL BACKGROUND

### Geographic location

The Teno-Chimbarongo canal connects the basins of the River Teno, which is a sub-basin of the Mataquito River, and the basin of Estero Chimbarongo, which is a sub-basin of the Rapel River. The water resources are taken from the River Teno and transported to the Estero Chimbarongo. In the last basin, the water is a source for the hydroelectric generation power plant of Rapel. This hydropower plant is located in the basin of the same name and receives, in addition to the water carried by the canal, the resources from Estero Chimbarongo, the Tinguiririca River, the Cachapoal River and Estero Alhue. In the future, the water transferred by the canal would be used as a feeder for the Convento Viejo Dam and would be used for the irrigation of the area located downstream of this reservoir. A location map is shown in Figure 1, and includes the canal and dam.

### Objectives and history

The canal is a project designed by the Department of Civil Engineering of the National Electricity Company (ENDESA) in order to conduct the water, through the natural streams, to the Rapel hydropower dam to increase the electricity generation until the Irrigation Directorate could finish the construction and put in operation the Convento Viejo Dam. The Teno – Chimbarongo canal takes the water from the excess waters of the Teno River. It is a feeder canal to the Convento Viejo Irrigation Dam, which is located in the Rapel river basin. In this way the water transported by the canal has two uses, for irrigation and as water for hydroelectric production.

In 1960 ENDESA performed preliminary studies to divert water from the Teno River to the Estero Chimbarongo in order to use those resources in electric

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<sup>2</sup> The first canal was the Canal San Carlos, with construction started during the 18th century (1742) and finished at the beginning of the 19th century (1825). The canal was built because of the necessity to satisfy the demand for water from the city of Santiago and the increase of the irrigation area which made insufficient the water from the Mapocho River. The canal takes water from the Maipo River Basin and transfers it to the Mapocho River Basin.

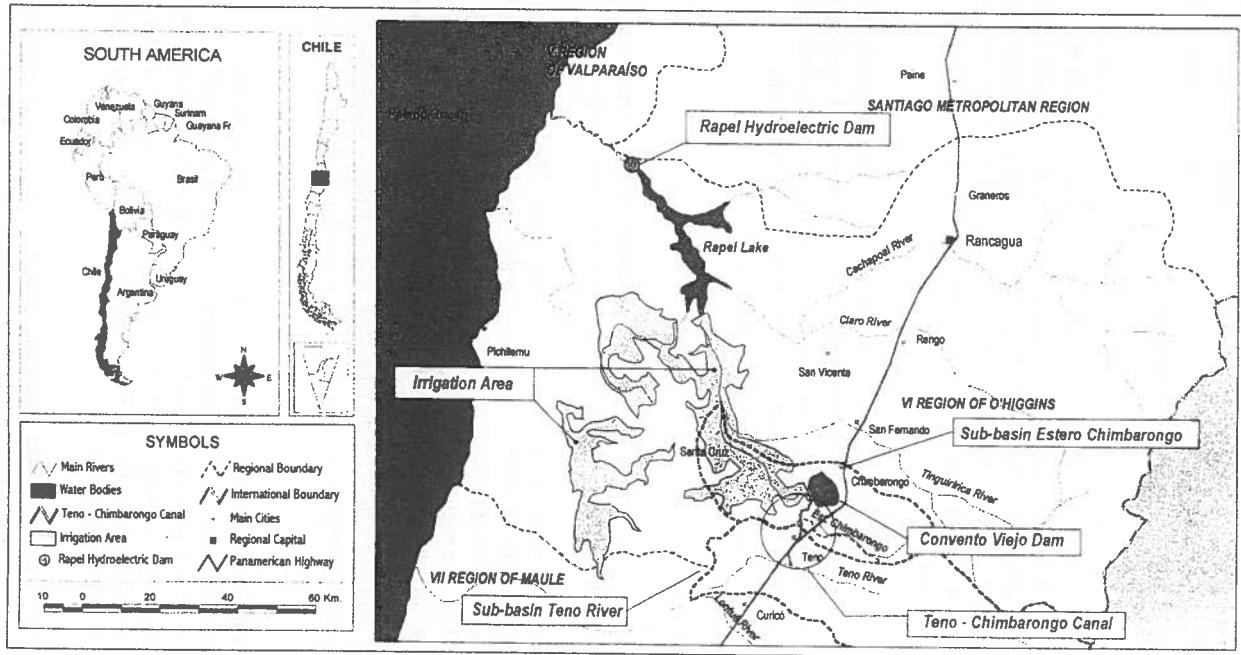


Figure 1: General Layout

generation at the Rapel hydropower plant. In 1968 the Irrigation Directorate from the Ministry of Public Works developed a project called Convento Viejo Irrigation Project in which a water transfer of surplus waters from the river Teno was considered by means of a canal of 40 m<sup>3</sup>/s (1,411.6 ft<sup>3</sup>/s).

The objectives of the Convento Viejo project were to increase the amount of irrigated land and to improve the irrigation security of the area served by the resources of the Estero Chimbarongo and Tinguiririca River, in the Rapel River Basin. Later studies performed by ENDESA in 1972 determined the capability to increase the maximum capacity of the canal to 65 m<sup>3</sup>/s (2,293.85 ft<sup>3</sup>/s), so that 40 m<sup>3</sup>/s (1,411.6 ft<sup>3</sup>/s) would be used for irrigation and 25 m<sup>3</sup>/s (882.25 ft<sup>3</sup>/s) in hydroelectric generation.

The construction of the Convento Viejo Dam started in 1970 and stopped in 1975. Later, the works continued during the years 1978 – 1979, but stopped again, up to 1993, the year in which the First Step was finished, which is at present operating with 27 million cubic meters of capacity (952.83 million ft<sup>3</sup>). The Teno-Chimbarongo canal was built and started its operation in 1975.

### **The works of the system**

The principal works of the system are: the Teno-Chimbarongo transbasin canal, the Convento Viejo First Step Dam and the Rapel Hydroelectric Plant.

The canal consists of an intake, a canal and a delivery work. The intake is located at 470 m (1,541.6 ft) upstream of the Teno bridge at the Pan-American highway. It consists of a barrier, 272 m (892.16 ft) long, which closes the river; a mobile barrier, composed by five sector gates of 4,20 m (13.78 ft) wide and 4,05 m (13.28 ft) high, two of which are used to clean sediments and the other three are operating as evacuators during floods; and an intake work with four flat gates of 3,60 m (11.81 ft) with and 1,70 m (5.78 ft) height, which allow a maximum discharge of 65 m<sup>3</sup>/s (2,2983.85 ft<sup>3</sup>). In Figure 2 a general plan of the intake is shown.

The canal has a trapezoidal section, 13,66 km (7.38 miles) long, without revetments. Some short stretches have compacted earthfill. The typical dimensions are two: the first, between km 0,00 to 2,00 ( mile 0 to 1.08) is of 8,25 m (27,06 ft) wide at the base, 4,50 m (14.76 ft) depth and slopes of 2:1=H:V; and the second, between km 2,00 and 13,66 (mile 1.08 to 7.38) the base wide is 10,25 m (33.62 ft) and the slopes are H:V=1,5:1.

The canal discharges the water to the Quebrada Quinta, a natural river bed that arrives at the Estero Chimbarongo after travelling approximately 3 km (1.62 miles). The canal has five small spillways with the purpose to lose elevation, the

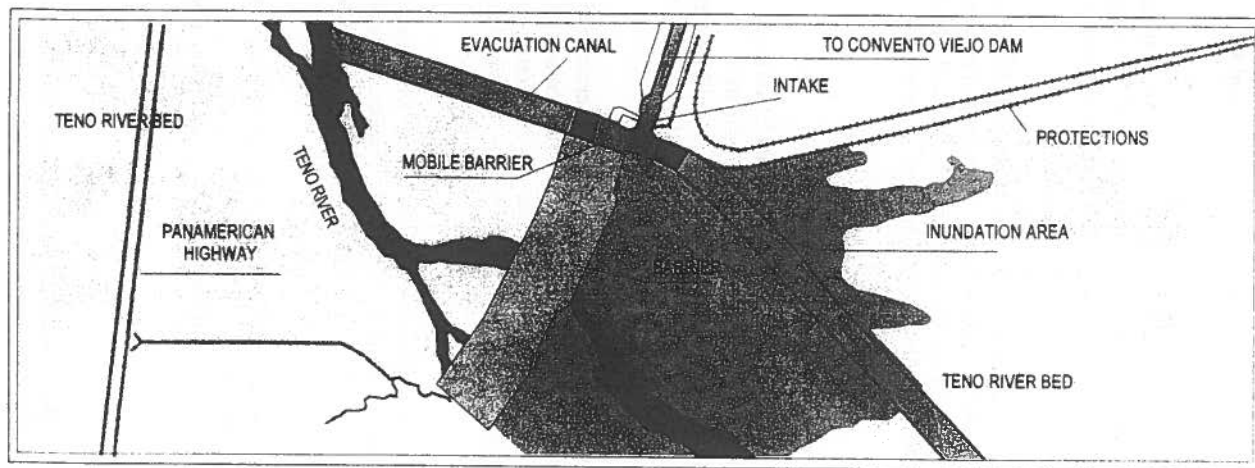


Figure 2: General Plan of the Intake

Source: ENDESA, 1975.

necessary works to cross irrigation canals and other watercourses, and some bridges and local roads.

The Convento Viejo First Step consists in a earth wall of 16,5 m (54.12 ft) height and 450.000 m<sup>3</sup> (15,880,500 ft<sup>3</sup>) of embankment, with 500 m (1,625 ft) length. It has a spillway of maximum capacity of 1.160 m<sup>3</sup>/s (40,936.4 ft<sup>3</sup>/s), controlled by five tank gates with manual control

The Rapel Hydroelectric plant is located in the Rapel River Basin and was built in 1968. The generation capacity is 350 MW and has an average annual production of 1.038 GWh. The work consists of a concrete arch gravity dam, and a reservoir of 696 million cubic meters (24,561.84 million ft<sup>3</sup>). This hydropower plant operates during peak hours.

### **Parties Involved**

This work involves the following principal parties: the National Electricity Company (Empresa Nacional de Electricidad -ENDESA), the Irrigation Directorate of the Ministry of Public Works (Dirección de Riego del Ministerio de Obras Públicas) and the irrigation users from the Teno River and from the Estero Chimbarongo.

At the time when the project was constructed, ENDESA was a governmental company and its objective was the execution of the electrification projects of the country. On the other hand, the Irrigation Directorate was also a governmental organization in charge of the design, studies and construction of the irrigation works.

The private sector, represented by the irrigation water users, were well organized in the Teno River through a Vigilance Committee (Junta de Vigilancia), but the situation was not the same in the Estero Chimbarongo where the organization was more precarious.

At present, ENDESA is a private company, and the Irrigation Directorate was transformed into the Hydraulic Works Directorate and continues as a governmental organization. On the other hand, the farmer's organization at the Estero Chimbarongo has improved.

### **Legal Framework**

The Chilean Water Code in force at the moment of the design and construction of the project, and also in the present Water Code in force since 1981, does not include any special consideration for the regulation of the transbasin water



transfers. There is only one condition that should be fulfilled, which is applicable in general for all the uses, and requires that any use should not affect the use of the water rights of third parties (Article nº14).

To regulate the use of the resources of the canal, in 1971 a convention was signed between ENDESA and the Irrigation Directorate in which it was established that from the moment in which the Convento Viejo Dam was finished and started to operate, the Irrigation Directorate would have a preferential right for the use of the flows diverted by the canal, up to 40 m<sup>3</sup>/s (1,411.6 ft<sup>3</sup>/s). Then, ENDESA would have the right to use the rest of the flow, up to the maximum capacity of the canal. On other hand, ENDESA would have right to use all the excess water produced by the system, and to demand the operation of the canal even if the Irrigation Directorate does not need the water for the Convento Viejo Dam.

With regard to this, at this moment a clarification of the water rights associated with the canal is in process. The Irrigation Directorate requested a water right of consumptive type and of permanent and discontinue use, for a maximum of 40 m<sup>3</sup>/s (1,411.6 ft<sup>3</sup>/s) from the River Teno and up to a maximum volume of 599,7 million cubic meters (21,163.4 millions ft<sup>3</sup>) per year, considering a reserved water for the Convento Viejo Dam that was granted in 1983. Additionally, ENDESA requested in 1970 a water right of eventual type of 11,6 m<sup>3</sup>/s (409.36 ft<sup>3</sup>/s) as an average annual discharge from surface water resources from Teno Rive, which was granted in October of 1995 as an average monthly flow to be used in hydroelectric generation at Rapel hydropower plant.

Additionally, in 1975 another convention was established between the Irrigation Directorate and ENDESA, in which it was agreed that the canal would operate when a surplus exists in the Teno River. The flows beyond which a surplus exists were defined and agreed upon in 1975, considering the rate of rational and beneficial use according to the Water Code in force at that moment. The canal operates when the flow in the river is more than the needs of the irrigation canals downstream of the intake; that is, more than aproximately 15 m<sup>3</sup>/s (529.35 ft<sup>3</sup>/s). It is important to mention that in the Southern Hemisphere the seasons are opposite to the seasons in the Northern Hermisphere, and for that reason the irrigation period starts in September and ends in April. In Table 1 the flows over which ENDESA can take water from the Teno River are shown.

Table 1. Minimum Flows in Teno River over which ENDESA can divert water in the Teno – Chimbarongo canal since 1975

Month	Flow m <sup>3</sup> /s
September	10
October	12
November	14
December	16
January	18
February	20
March	22
April	24

In Figure 3 the relationship between the available flows in the Teno River, the diverted flows through the canal and the minimum flows over which the canal can divert water from the River Teno are shown.

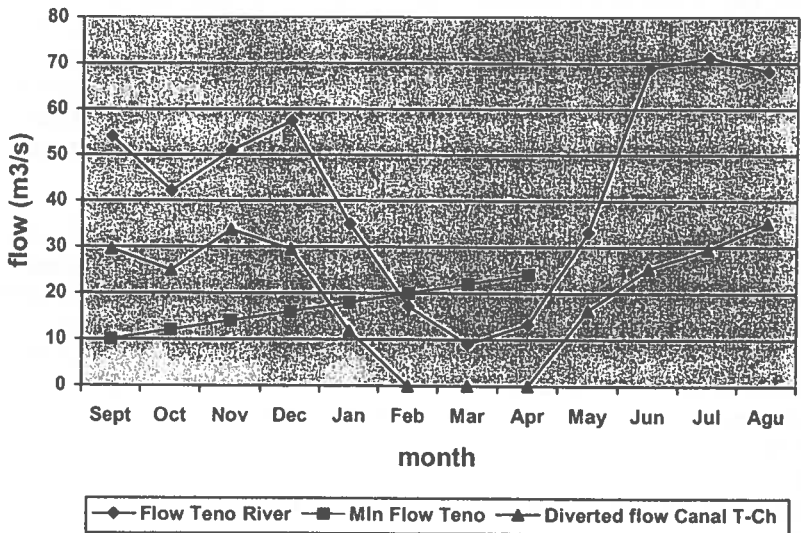


Figure 3. Relationship between the flows in River Teno and flows diverted by the Teno-Chimbarongo Canal.

## THE IMPACT OF THE CANAL TENO – CHIMBARONGO

### On Irrigation

In the situation without a project; meaning, without the Teno – Chimbarongo Canal and without the Convento Viejo First Step Dam, the available water resources in the Tinguiririca River and Estero Chimbarongo could irrigate, inefficiently, an area of approximately 120.000 hectares (300,000 acres). Of this surface, 77.000 (192,500 acres) hectares could be supplied with 85% security, using for that purpose the water resources available at the Estero Chimbarongo, Estero Las Toscas and Tinguiririca River; in the meantime the remainder 43.000 hectares (107,500 acres) had only eventual irrigation.

The Convento Viejo First Step Dam has been a key factor in reducing the impact of droughts in the irrigation area served by this dam. This has been particularly remarkable during the dry periods of the years 1996-97 and 1998-99. For this reason the farmers of the Estero Chimbarongo are very interested in the possibility of a bigger dam.

The idea of building a bigger dam has always been considered as a possible alternative. The dam would consist of an increase in the height of the present embankment, thus increasing the capacity of the reservoir. In November 2000 a new study was performed in order to update the studies of the Big Convento Viejo Dam. That analysis recommended a dam with a reservoir of 472 million cubic meters (16,656.88 million ft<sup>3</sup>) of capacity, which would improve the irrigation of 14.308 hectares (35,770 acres) of existing land and 34.516 hectares (86,290 acres) of a new irrigation area. Considering this, the total impact of the dam would reach an area of 76.254 hectares (190,635 acres).

During the initial 15 years of operation of the canal, there was only one problem detected. The problem was regarding timely information about the operation of the gates for the sediment cleaning operation at the intake to the irrigators in Teno River. This should be done in order to give sufficient time to take measures to protect the intakes of irrigation canals which are close to the diversion structure of the Teno – Chimbarongo Canal and that could be affected by its operation. The cleaning operation is gradual, can take about 10 hours and it is done every 15 days, approximately. This situation is completely solved at present. ENDESA communicates on time the program of sediment cleaning to the irrigators and also the company facilitates the adequate machines to solve problems that can be attributed to the operation of the gates. At present, the irrigators are completely satisfied with the coordination procedure.

### On Hydroelectric Generation

The Rapel Hydroelectric Plant has received all the benefits from the transferred resources from the beginning of the operation of the canal in 1975. This is because the Convento Viejo Dam has not been built. When the studies of the canal were done, ENDESA estimated that the investment would be recovered in approximately 7-1/2 years. Considering this, it is reasonable to suppose that this projection has been accomplished and that the additional years of operation have signified additional benefits. It is important to remark that from the point of view of the impact of the canal for ENDESA, the objectives and expectations of this project have produced total satisfaction.

### On the Community

On some occasions there have been doubts about possible damages that could be attributed to the canal. Actually, during winter time and rainy years, in spite of the fact that the canal has the intake closed, the registered flows at the discharge to Quebrada Quinta have reached up to 65 m<sup>3</sup>/s (2,293.85 ft<sup>3</sup>/s) and more. Under the described circumstances the Estero Chimbarongo has been affected by floods. This has been the reason for claims from the municipalities of Santa Cruz and Chépica. It was demonstrated that the water comes from the collection of waters coming from streams and land through which the canal crosses. To reduce this impact, hydraulic defenses have been built in the Estero Chimbarongo.

On the other hand, in the Estero Chimbarongo the intakes for irrigation are rustic and, in the years with abundant snow melt, the water transported through the canal causes damage to them. Under these circumstances, a decrease in the diverted water has been requested to ENDESA to repair of the intakes. Considering this, the irrigators of the Estero Chimbarongo have the perception that it would have been better to develop a project to improve the irrigation intakes together with the project of the Teno-Chimbarongo Canal. It is important to note that the canal was developed as an isolated project, without considering other elements or factors from the point of view of the river basins involved.

## **THE EXPERIENCE AND THE FUTURE PROJECTIONS**

The Teno – Chimbarongo water transfer Canal is the fundamental work without which there is no possibility to build the Convento Viejo Dam with its consequences of increased irrigation security and irrigation area. At present the irrigators of the Estero Chimbarongo have improved their irrigation security thanks to the present dam of 27 million of cubic meters (952.83 million ft<sup>3</sup>) and exists the possibility to increase the capacity of this dam, up to 472 million of cubic meters (16,656.88 ft<sup>3</sup>), increasing the total impact of the dam up to 76.254 hectares (190,635 acres). Additionally the improvement of the management

capacities of the irrigators of Estero Chimbarongo should be noted, which has been accomplished together with the construction of the dam. At present they are organized as a Vigilance Committee and have an office, secretary and a permanent engineer to perform their tasks. They help to solve the problems of the operation of the system and about 2,800 farmers receive the benefits of this organization. A good indicator of the produced benefits is that at present the irrigators contribute money to pay the operational costs of the dam and give to the Hydraulic Work Directorate the schedule of releases that is of their convenience.

It is also remarkable that the compromises and agreements achieved between the different parties involved have been fully accomplished and respected, in spite of the changes of the characteristics of the parties, from governmental to private, in the case of ENDESA, and more attributions from irrigation to hydraulic works, in the case of the Hydraulic Works Directorate.

To get a vision about the management that has resulted from the construction of this hydraulic transbasin work, the following factors are considered, in the frame of the collected antecedents and the perception resulting from the conversations with the different parties: the legal framework, the transparency in the decision making, the responsibility of the participants and the environment in which the management is developed.

Regarding the legal framework, it is remarkable that the existence of two agreements allow, on one hand, to comply with the Water Code, and on the other hand, to regulate the singular aspects associated to the transbasin work, such as the way in which the studies and investments would be developed; the way the operation and maintenance works would be developed, both in aspects technical and economical; the way in which the resources should be used, before and after the Convento Viejo Dam was built; the way to solve the unforeseen aspects, and other aspects related with the construction and use of the canal. These agreements are in force and are respected by the parties involved.

Also, it is remarkable that all the decisions related to the operation of the canal are communicated to the users, the flows diverted by the canal are registered and it is possible to know them, which gives clarity and transparency to the different parties. In particular, the cleaning operations are known with anticipation and the dates and procedures are respected. This makes a good basis for the existence of confidence between the users, the Hydraulic Works Directorate and ENDESA.

The different parties involved have shown disposition to answer to the problems that occur and that could be attributed to the canal. ENDESA organizes meetings with the irrigators of the Teno River and coordinates with them for the cleaning operations of the intake, and also attends to the requirements of the irrigators of Estero Chimbarongo when it is necessary to modify the diverted flow. Also, the

Hydraulic Works Directorate operates the present dam according to the requirements of the irrigators, which are fully satisfied. The users of Estero Chimbarongo contribute money for the operation, a clear demonstration of interest and confidence in the management of the system.

Finally, the author can verify that the environment among the different involved parties is favorable for the development of conversations to solve problems, configuring a very good situation for the development of management procedures.

In summary, the construction of the transbasin water transfer Canal Teno – Chimbarongo has produced no relevant problems, and the unique problems have been solved through conversation and agreement between the parties. The experience shows that the canal has benefited ENDESA and the irrigators of the Rapel River Basin, and does not represent any damage to the irrigators of the Teno River. On the basis of the satisfaction of the interested parties is a convention that regulates the conditions for the use of the canal.

#### ACKNOWLEDGMENTS

The author wishes to thank to the authorities of the Hydraulic Works Directorate (DOH) and from the National Electricity Company (ENDESA) for the support and cooperation given to this investigation.

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## RIO SÃO FRANCISCO TRANSBASIN DIVERSION NORTHEAST REGION, BRAZIL

Larry D. Simpson<sup>1</sup>

### ABSTRACT

The Rio Sao Francisco rises in the Cerrado of the State of Minas Gerais and Goiás in the Central Region of Brazil fed by the runoff from orographic rainfall of the Central Plateau and Chapadas that divide this drainage from the Tocantines and Amazon Drainages to the Northwest. The river arises in the State of Minas Gerais in the Serra da Canastra at an elevation of approximately 1600 m. From there it winds 2,700 km north and east through the semi-arid lands of the Northeast Region of Brazil crossing much of the area defined as the Drought Polygon of the country.

The flows of this drainage provide the hydropower to fuel the industry of the region, the water to supply the growing fruit and vegetable production industry, the transportation for goods and services. This river system holds the key for the future of the region, but also represents one of the major potential sources of conflicts as the many developing demands for scarce water supplies within the Northeast of Brazil compete for the lifeblood of the river. These demands are not just limited to the riparian states of the river basin. The non-riparian semi-arid states of the Northeast have long coveted the waters of this river system and proposals for major transbasin diversions to the north and east of the drainage have been put forth for over 75 years. The emotional, environmental, political and economic struggles that such diversions proposals will spawn have just begun to emerge. This river system will be the subject of intense study, development and controversy during the coming century and the solution of these controversies will require the best technical and political minds the country has to offer.

The complexities of this system will require the use of the latest in computer and hydro-meteorological information technology to provide the decision-makers and diplomats with the information and tools necessary to forge compromises and to develop and prioritize the competing and, frequently, conflicting uses of the resources of the basin. The challenge of meeting the multi-purpose demands for the water of the river system in a sustainable and environmentally acceptable manner will tax the future thinkers and decision-makers to the limit. The equally important challenge of providing for these demands in a manner that does not threaten or destroy the unique ecology of the river and pollute its scarce and

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valuable water supply will require compromise, sound planning, political and scientific cooperation and a tremendous amount of effort, time and financial resources. The present proposal to divert flows from the Rio Sao Francisco amounts to proposed diversions of less than 1 % of the annual river flows. However, the diversion of these flows, originally proposed in 1900, has been vigorously opposed since that time by the riparian states, principally Minas Gerais, Bahia, Pernambuco, Sergipe and Alagoas. Of these, Minas Gerais and Bahia are extremely powerful from both an economic standpoint and a political standpoint.

In the last two years, the balance of political power and tradeoffs has changed to the benefit of the proposed recipient states through political coalitions. Consequently, this project is now moving on a fast track. From an economic standpoint, it has debatable benefits and strong impacts on the existing hydro-power system in the river system. This will be further exacerbated by recent energy cost increases in fossil fuels. The project, however, will probably never be judged by the economic standard as it is primarily a political project, reminiscent of the Central Arizona Project. From an environmental standpoint, the project is relatively benign with the exception of the impacts of additional growth created in the recipient states by the new water. The river downstream of the proposed diversion is highly impacted by large hydro-power dams and related hydro-electric power releases. Any flow impacts will be totally absorbed by the downstream storage systems.

This highly emotionally charged project, at a cost of over a billion dollars, promises to generate extreme political controversy over the next 10 years and beyond.

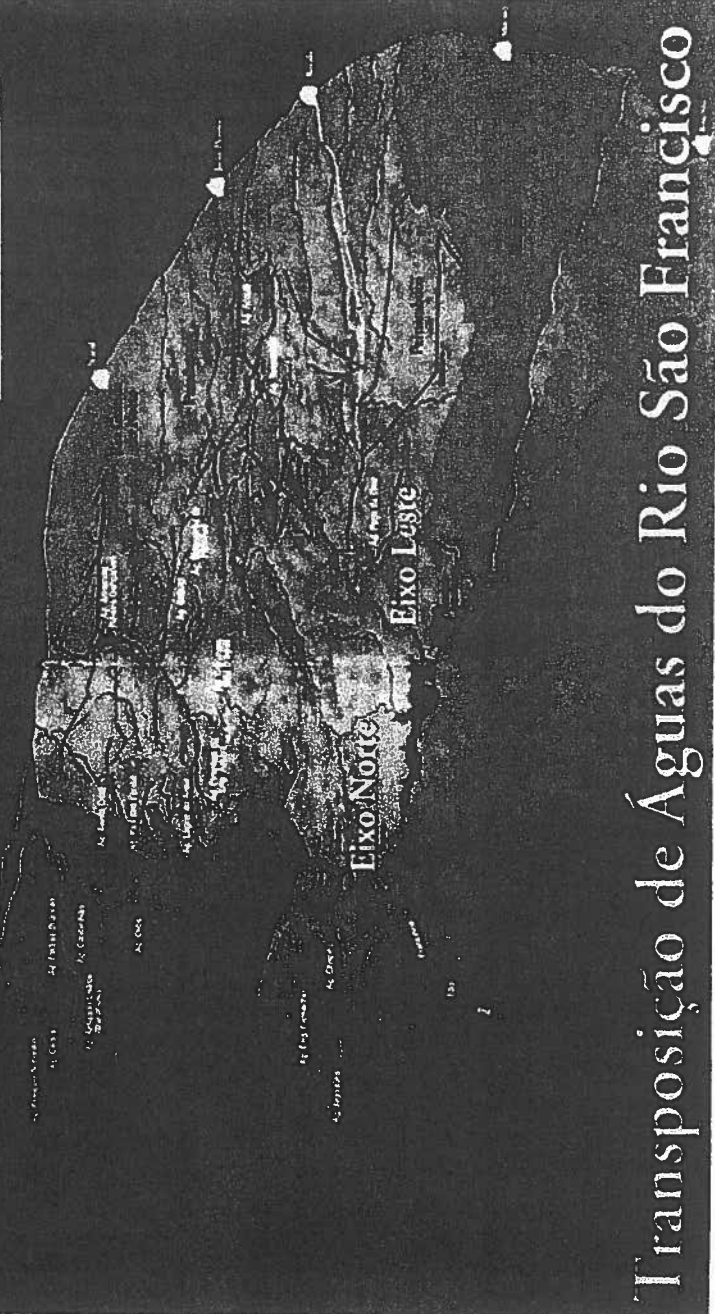
## BACKGROUND

The Rio Sao Francisco rises in the Cerrado or steppes of the States of Minas Gerais and Goias in the Central Region of Brazil fed by the runoff from orographic rainfall of the Central Plateau and Chapadas or highlands that divide this drainage from the Toncantines and Amazon Drainages to the Northwest. The river arises in the State of Minas Gerais in the Serra da Canastra at an elevation of approximately 1600 m. From there it winds 2,700 km north and east through the semi-arid lands of the Northeast Region of Brazil crossing much of the area defined as the Drought Polygon of the country. The flows of this drainage provide the hydropower to fuel the industry of the region, the water to supply the growing fruit and vegetable production industry, and the transportation for goods and services. This river system holds the key for the future of the region, but also represents one of the major potential sources of conflicts as the many developing demands for scarce water supplies within the Northeast of Brazil compete for the lifeblood of the river. These demands are not just limited to the riparian states of the river basin. The non-riparian semi-arid states of the Northeast called the



# Transposição de Águas do Rio São Francisco

- Projeto de Integração Saneamento (PIS)
- Estrada
- Aldeia
- Barragem
- Barragem de Bacia Hidrográfica
- Barragem de Regularização
- Barragem de Transposição
- Barragem de Transposição (em estudo)
- Barragem de Transposição (em projeto)
- Barragem de Transposição (em construção)
- Barragem de Transposição (em operação)



Setentrional Northeast have long coveted the waters of this river system and proposals for major transbasin diversions to the north and east of the drainage have been put forth since 1847.

This arid area has suffered periodically with long and severe droughts that have decimated the economy of the Northeast and caused innumerable deaths and a persistent emigration of the rural people from this region to the urban areas of the South of Brazil with attendant social impacts, poverty and disruption of the culture. For example, in a major prolonged drought during the period of 1845 to 1848, more than 500,000 people of the Northeast died of starvation and health impacts from this severe drought.

The dream of supplementing the unreliable supplies of the region with a transbasin diversion project from the Rio Sao Francisco has recently moved closer to becoming reality at both the political and technical level. The National Ministry of Integration (MIN) has in the past two years, contracted a series of engineering studies designed to evaluate both the engineering and economic viability of diverting water to the Northeast states of Ceara, Rio Grande do Norte, Paraiba and Pernambuco (Setentrional Northeast). Although the riparian states of the Sao Francisco basin tend to be generally against any transbasin project, the number of Brazilian state that appear to be in favor of the project has been on the increase, as well as apparent approval at the Federal level within the administration, centered generally in the National Ministry of Integration.

The project has been faced with a number of key technical, social, political and economic issues over the last few years. This paper will attempt to address some of these issues along with the rationale being advanced by the project proponents relating to these issues.

### TECHNICAL ISSUES

At the technical level one of the main concerns has been the hydrologic record of both the basin of origin and the recipient region, as well as the reliable assessment of present demands and rational estimates of future demands. This is key to assuring the riparian states that the project will have little adverse impact on their future water supplies. In addition, minimization of losses from the system, impacts on river morphology and optimization of the project to minimize pumping costs and maximize the use of "off-peak" energy have been analyzed.

The Rio São Francisco has a relatively steady hydrograph, with sufficient flow in most years to meet the presently proposed transbasin diversion as well as the present and projected uses within the basin and to support the extremely important hydroelectric generation within the basin. Supplemental water supplies to the Setentrional Northeast states from the São Francisco would help to optimize the efficiency of existing water retention structures in the region, allowing greater

drawdown with the assurance of the replenishment during wet years from this additional source.

The water supply studies of both basins have been based upon lengthy records of moderate reliability. While the impacts of climate change theories could change the available amounts, this is not considered to be quantifiable in any real sense and has been treated subjectively. Accordingly, the hydrological analyses done to date appear to be reliable and indicate that the future supplies of the basin of origin would not be adversely impacted by the presently proposed transbasin diversion.

With regard to demand questions, this area of analysis has been subject to a great deal more speculation. The growth estimates for the urban areas of the Setrentional states are based on past growth trends during a recent period of economic growth that far exceeds the past. The estimates for demand assume that this growth will continue as it has in the recent past, or in some cases, accelerate. The use of some of the transbasin water for municipal/industrial use in the metropolitan areas of Fortaleza, Ceara and Recife, Pernambuco has received less opposition but the demand projections have been questioned. In addition, assumptions have been made that all irrigable areas within the recipient basins that are amenable to the production of high value crops will be developed. This is important to the demand evaluation, as this type of agriculture is the only type that could afford the cost of the transbasin water in a sustainable manner. This proposed use of some of the water for high value agricultural irrigation has been strongly questioned. Project opponents have argued that the use of the same water for irrigation of similar crops in the Rio Sao Francisco Basin makes more economic sense. This argument has been countered by proponents, who claim that the water of the Rio Sao Francisco is from a Federal river and, under Brazilian law and is available to all Brazilian states and all Brazilian citizens. Further, the development of the arable land within the recipient states would create employment within the rural population that would stabilize these populations and diminish emigration to the South with its attendant problems. The demand figures developed from the MIN studies include both the projected M&I growth as well as irrigation. Sensitivity studies conducted by the MIN, have evaluated changes in the demand estimates with regard to the viability of the project. These studies indicate that variations in the development of demand would primarily affect the timing of the demand growth as opposed to the eventual development of the demands. This factor affects both the basin of origin as well as the recipient basins. This is presently under study by the MIN to evaluate staging opportunities for project construction that might provide more flexibility in matching supplies to demands within the project as demand develops. However, many components of the project are not amenable to staging and would have to be constructed at full capacity at the outset.

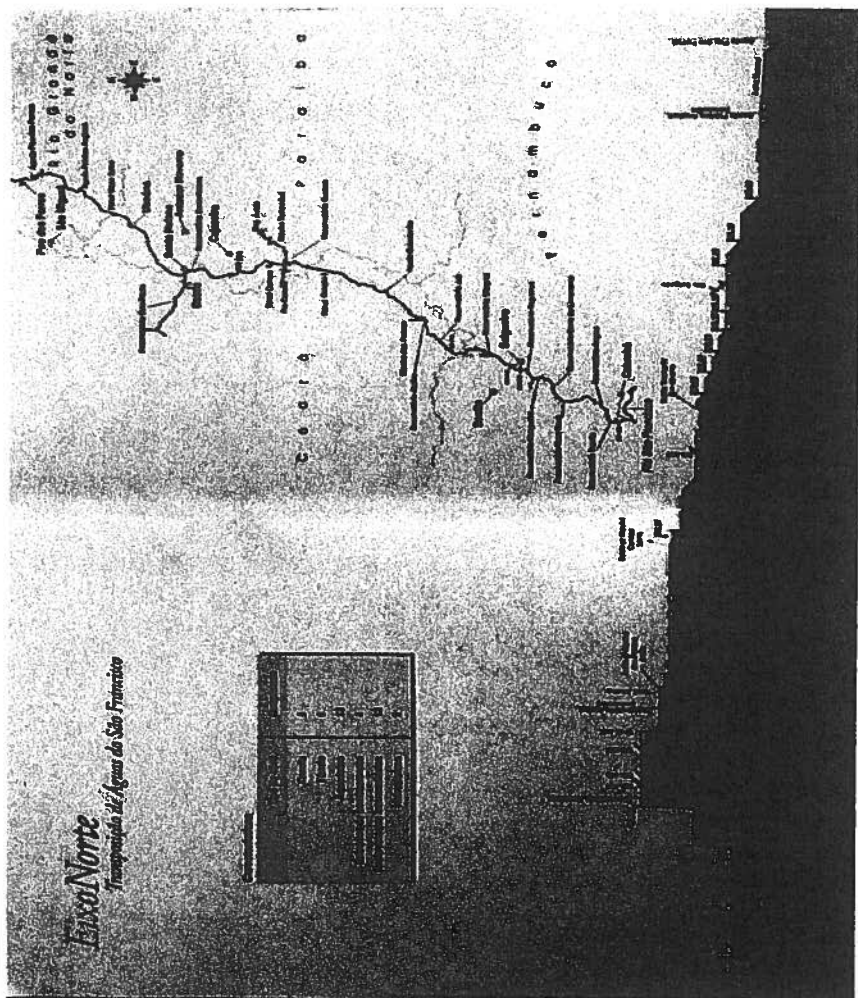
An extensive alternatives analysis was conducted to examine alternative supplies within the recipient basins as well as the use of conservation techniques to reduce or delay demands. Given the extreme shortage of water within this region during the cyclical droughts that occur, it is not surprising that the alternatives to this additional water supply result in inhibited growth, continued adverse impacts on the rural poor and an inability to optimize the operation of present and proposed water supply systems within the region. At best, the alternatives to this project just delay the inevitable need for additional supplies to the region.

As evaporation is extremely high in this region of Brazil, design of the proposed system to optimize the project efficiency has been a main concern. This is particularly of concern with regard to re-regulation storage reservoirs and terminal storage. The MIN has evaluated this and has optimized the use of such reservoirs. In the process, reservoir facilities that do not contribute a substantial gain in project yield were eliminated. The use of impermeable membranes under all concrete canal linings has been specified to minimize seepage losses as well as the use of pipelines and tunnels through critical areas. The original plan considered the use of natural drainage reaches to transport some of the diverted water. However, closer evaluation of many of these reaches indicated that losses would not be in the range of feasibility and that morphologic impacts on these natural drainages from the increased flows would be intolerable. As a consequence, the use of canals, pipelines and tunnels was chosen in most cases. Natural drainages will still be selectively used after careful analysis of the river morphology of the related reaches.

The project will not only consume energy for pumping, but will also divert water that is presently being used for the generation of hydroelectric energy at three large installations downstream. This impact has been the source of a great deal of controversy as the consumption of energy for pumping raises the variable operation costs of the project. In addition, the losses of energy that was formally generating energy downstream has been criticized. While the bulk of this energy is used in the Northeast, it is also transported to the industrial regions to the south. Potential use of the water after it passes through the generation system is minimal as it flows into the Atlantic Ocean downstream. This tradeoff has been carefully evaluated by the MIN as a part of the economic analysis and will continue to be a factor in the political debates that will be had as the project reaches approval stages. The cost of the energy lost was calculated into the over-all cost benefit analysis of the project.

### ECONOMIC ISSUES

Key economic issues evaluated as a part of the project included the cost/benefit analysis but also the analysis of the energy forgone as a result of the project. Economic analysis regarding the opportunity cost of the project as it relates to other alternative investments that might be made by the Government of Brazil



such as highways, railroads, education or other uses of public funds has not been made. It is assumed that such choices will be made in the political arena as are most such decisions in most countries. The lack of such an opportunity cost analysis has been criticized by the economic community as are most uses of public funds. The internal rate of return for this project at a discount rate of 10% was preliminarily calculated to be 24.9%. The over-all capital cost for the project is estimated at 2.74 billion reais in 1968 values. Present rate of exchange is approximately 2 reais to 1 US Dollar. The impact of changes in the exchange rate on over-all project cost is under evaluation by the MIN on a continuing basis.

As was mentioned above, the opportunity cost of the loss of energy compared to alternative sources to generate this energy was not evaluated. This has been of concern to economists. The cost of the water to the user to fully recover the costs of operation and maintenance for the project, including energy, would be about \$R70 per 1000 cu meters. At the present exchange rate, this would be about \$US 35 per 1000 cu meters. This would be equivalent to a cost of about \$US 43 per acre foot delivered. For M&I use as well as for the irrigation of high value fruit crops for export, these costs are within reasonable ranges. The repayment of the capital cost of the project is not being considered as this project is considered an investment on the part of the Government of Brazil and the relevant states in order to provide an incentive for economic development and to alleviate the costly impacts of periodic drought within the region.

### THE POLITICAL ASPECTS

As is the case with most transbasin diversions throughout the world, this project has been a major political subject. Since first proposed in 1847, the project has been debated within the political arena and has been inserted into the platform of political candidates, both on the pro and con side, for generations. Many candidates for office have used this project as a base for stirring up the emotions of the electorate. This has placed many political figures in almost irrevocable positions with regard to any compromise. It remains to be seen if these long held and emotional positions can be reconciled with any sort of political compromise to allow the project to go ahead. Unfortunately, if the project proceeds without such compromise and agreement, it faces a rocky road in the area of future appropriations for completion in the later years if political powers change, as they surely will. At present, it would appear that the project is moving ahead for a proposed construction contract by the Fall of 2001, provided that it does not get entangled in political stalemates once again.

## THE PROJECT

The Rio São Francisco Transposição (Transbasin Diversion Project), as presently proposed, will have two major eixos or diversions. The first diversion will divert from the river just below the existing Sobradinho Dam at a point known as Cabrobo and will divert an average flow of 99 cumecs from the river through the use of a series of 3 major pumping stations, 15 regulatory reservoirs, 229 km of canals, 23 km of tunnels, and 3 km of aqueducts. The system is designed to deliver the water to the states of Ceará, including the capital city of Fortaleza, Pernambuco, Paraíba and Rio Grande do Norte. . The second major diversion will be from the existing Itaparica Dam and Reservoir located further downstream on the river, will divert 28 cumecs into a system of canals pipelines and reservoirs that will provide water to the States of Paraíba and Pernambuco and eventually to Recife, the capital city of Pernambuco. This system will include 6 pumping stations, 297 km of canals, 84 km of pipelines, 9.2 km of tunnels and 2.5 km of aqueducts.

The project will also include the construction of at least two intra-system hydroelectric plants with a total capacity of 52 MW. It is anticipated that additional studies will be made regarding other opportunities for generation to offset pumping costs within the project.

The total average diversion of the two eixos will be approximately 127 cumecs. The average flow of the Rio São Francisco into the Atlantic Ocean downstream is approximately 90 billion cubic meters per year. It is anticipated that the proposed project would divert approximately 1.5 billion cubic meters per year, or approximately 1.6% of the average flow of the river. The contemplated operational plan for the project would operate the system during wet years and during wet seasons of the year, thereby minimizing the impact of the diversion on the river downstream. It is also contemplated that the project would operate in a manner that optimizes the use of off-peak energy in order to obtain the lowest energy rates possible. The development of an operational model to be used for this complex project will be a major task.

The recipient states have the responsibility of the construction of terminal storage and the intra-state distribution and management systems. Some states, such as Ceará are well advanced in this process. However, other states will need considerable development in the water resources management area from both a physical and institutional standpoint in order to optimize the use of these new supplies when the project is finally in place.

It has been estimated that the project will take at least 5 years to construct. However, given the complexity of the project and the normal difficulties encountered in obtaining a reliable flow of funds from Federal sources, a more realistic estimate would probably be 10 years. This also assumes that future

political leadership will have the same level of support for the project that is apparently, existing within the present administration.

### OPERATION AND MAINTENANCE

Also key to the project will be the institutional and physical framework developed for the continued operation and maintenance of the system when completed. The MIN is presently considering the use of a concession contract or direct operation and maintenance contract with the private sector to operate and maintain the project. The detailed plans for this have not yet been made available. The overall success of the project will greatly depend on the level of expertise and experience obtained for the long term O&M of the system. The determination and negotiation of tariffs for this water to be paid by the recipient states or their bulk water agencies has yet to be accomplished. It is anticipated that this effort should begin in earnest when construction begins on the project.

While the development of the long-term operation and maintenance framework for both the recipient states and the project itself are key, one other facet of maintenance is also extremely important. With projects of this complexity and length of construction time, it is doubtful that it will let as a single contract or that it will not face work stoppages for funding or other reasons. Consequently, it will be imperative that an institutional framework be established and adequately funded so that the various pieces of the project be adequately maintained and secured from vandalism and destruction by the elements as each phase of the facility is completed. This can be the responsibility of the general contractor until over-all project completion or can be contracted to an operation and maintenance contractor separately. In either case, a small but highly experienced team of maintenance specialists should be formed within the project implementation team that assure that this area receives proper emphasis and is not dropped through the cracks. The MIN is presently evaluating this aspect of the interim maintenance of the system as it is constructed.

### ENVIRONMENTAL ISSUES

Brazil has strong environmental laws that are supervised by the Federal Environmental Agency, IBAMA. As a consequence, the project has been the subject of a rigorous environmental analysis and the preparation of an environmental impact statement or RIMA. This has been submitted for the project and is presently under review by IBAMA.

The impact of the diversion on the riparian system of the Rio Sao Francisco will be minimal as the major hydroelectric dams located downstream totally re-regulate the flow of the river. They, likewise, disrupt migratory fisheries and entrap natural sediment transported by the river. As a consequence of the minimal percentage of diversion of the total flow, it is not anticipated that the



impact of the project on the riparian system of the Rio Sao Francisco will be measurable. However, the impact of the project along the axis of the system will be more significant. With the length of canals and number of regulatory reservoirs, considerable environmental work was needed to evaluate the impact. It is highly probable that IBAMA will require the acquisition of native desert lands for preservation as compensation for the loss of such habitat and ecosystems to the project. It does not appear that any areas of cultural significance will be impacted, nor will any endangered fauna be impacted within the project area.

### SUMMARY

The transbasin diversion of water from the Rio Sao Francisco or Transposicao do Rio Sao Francisco as it is called in Portuguese has been high on the agenda of the Northeast Region of Brazil for over one and a half centuries. The need for this project has greatly increased due to the economic development of the region and its trend toward the exportation of high value fruit crops. The political system, at present, appears to support the project and strong efforts are being made to inaugurate the construction of the project in the coming year. While the project still faces tough opposition, it appears ready for construction from a technical and needs standpoint. It remains to be seen whether the project, once started, can engender sufficient long-term support within the Brazilian political system in order to be completed in an efficient and timely manner. As has been the case in almost all transbasin diversions constructed in the United States, the intervention of other political priorities, changes in administrations and other unforeseen events seem to always delay and frustrate the most efficient completion of projects of such magnitude. The major projects such as the Central Arizona Project and the Colorado-Big Thompson Project are strong cases in this regard. Provided that it is even started, the Rio Sao Francisco Transbasin Diversion Project will take perseverance, patience and a lot of time to complete. By the time that it is finally on line, any overestimates in the demand curves for the project should have been well compensated for. This endeavor will require a great deal of diplomacy, political skill and technical skill to be completed and placed in efficient and sustainable operation for the benefit of the citizens of the Northeast of Brazil.



## NECESSITY OF TRANSBASIN WATER TRANSFER – INDIAN SCENARIO

NIRMAL JOT SINGH<sup>1</sup>

A.K. KHURANA<sup>2</sup>

### ABSTRACT

Transbasin water transfer is an important activity in the field of water resources development. Although a river basin is the basic hydrologic unit for water resources, the same may not work out to be a proposition for optimum utilisation in the case of surplus water. The assessment may bring out that some basins have surplus water whereas the others may have deficit supplies. The National Water Policy was adopted by the Government of India in the year 1987. The policy emphasises the transbasin transfer of water. The policy states "Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another based on a national perspective, after taking into account the requirements of the areas/basins". For meeting the shortages, transbasin transfers of water may be necessary. The necessity of transbasin transfers will depend upon the future projections for the enhanced demand for irrigation, domestic, industrial requirements etc.

Considering medium variant, the population of India in the year 2050 AD is expected to be 1640 million as per "Sustaining Water – An Update (1994)" by the United Nations. The food requirement has to be worked out on the same basis. At present, the annual food grain production in India is about 200 million tonnes. This annual requirement of food grain would increase to about 500 million tonnes by the year 2050 A.D. Accordingly, it is imperative to have transbasin transfer of water so as to facilitate increased irrigation to meet the food grain production needs and other usages etc. It is considered that the population of the country may stabilise by that time. Transfer of water from surplus basins to the deficit basins will to some extent solve the problem of uneven spatial distribution of water resources in the country. For attaining this, it is envisaged to construct large reservoirs to store monsoon flows for diversion. The main issues are economics, time frame and environmental. The more important issue is the concurrence of States of a basin on its surplus and the extent of such surplus. Finally, the integrated planning at the basin level takes into account all demands, which will indicate the quantum of surplus or deficit.

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## GENERAL

In view of scarce water resources, planning and development of water resources is an important activity. Pressure on water resources has increased considerably during the last five decades and will continue to increase. It is a fact that if the water resources are not managed and conserved properly, the whole exercise will be futile. The present scenario calls for a sustainable development to take into account the growth of population vis-à-vis increase in food and fibre requirements. Although our water and land resources are large, their per capita availability is much below the international standards. The main reason is that the distribution of water resources is temporal and spatial leading to various problems of shortages and excesses of water.

The rapid growth in population has put much pressure on water resources to meet food and fibre needs for the country. As population is expected to increase and stabilise by middle of this century, the demand for water will also increase. The sustainability of water resources has gained increased importance as scarcity is being felt in some parts of the country. The water resources in this millennium will pose more challenges in view of growth in demand and deterioration in the quality of utilizable resources.

The river basin may be a basic unit for planning of water resources but this may not in any way make headway for utilisation of surplus water resources in various parts of the country. Many basins in the country may be surplus in water resources even in the ultimate stage of development, while other basins may face shortages in respect of water. To overcome this situation, transbasin transfer of water may be necessary for development of water resources so as to meet requirements of deficit areas leading to equitable distribution and optimum utilisation of water resources. India has started a systematic study of transbasin transfer proposals to maintain self-sufficiency in food which is bound to bring overall prosperity to the region in the future.

The paper describes in brief the scenario of food production and demands in the near future and the extent to which transbasin transfers can help in bridging the gap between demand and supply. Some of the issues with respect to implementation of transbasins transfer proposals are highlighted and discussed.

## WATER RESOURCES

India is a vast country comprising extremes of climate. The location map of India is as per Figure 1. There is a variation in rainfall, and rainfall is concentrated in about four months of the year. In most parts of the country, rainfall occurs for a few days with very high concentration. The average annual precipitation including snowfall is about 141,240 Thousand Million Cubic feet (TMC) [4000

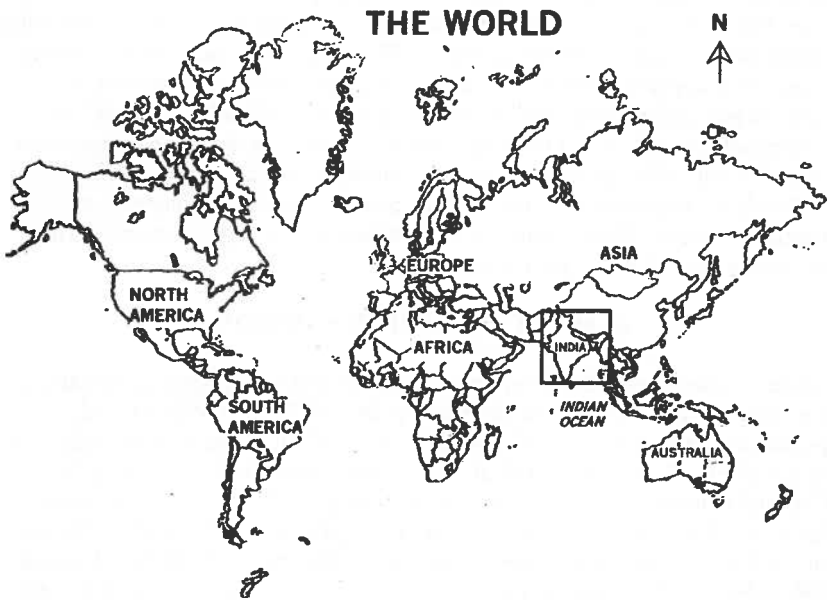


Figure 1. Location Map of India

BCM] and the monsoon rainfall during June to September itself is about 105,930 TMC (3,000 BCM). The annual average runoff in the rivers is estimated as about 67,089 TMC (1,900 BCM). About 80% of the annual runoff in the rivers occurs during four months of monsoon. Unless flood waters are stored in surface reservoirs, the water wastes into the sea because of limitations in availability of sites to store water. There are 12 major river basins and a total of 20 river basins. Rivers like Brahmaputra, Ganga, Mahanadi and Godavari have surplus water after meeting their present and future demands. Rivers like Krishna, Pennar, Cauvery, Vaigai and Vaippar are water short. The annual water resources potential in respect to per capita availability varies from about 635,580 cft (18,000 m<sup>3</sup>) in Brahmaputra to as low as 13,418 cft (380 m<sup>3</sup>) in some of the east flowing rivers of Tamil Nadu. The international agencies consider availability below 35,310 cft (1,000 m<sup>3</sup>) per capita per year as a scarcity condition leading to planning of remedial measures. Thus, scarcity conditions already exist in the country. The river basins of India are as per Figure 2.

### DEMAND AND SUPPLY POSITION

Because of uneven distribution of water resources and topographical difficulties, the average annual utilisable surface water is 24,364 TMC (690 BCM) and replenishable ground water is 15,254 TMC (432 BCM). At present, the irrigation requires about 22,245 TMC (630 BCM) of water, domestic 1,165 TMC (33 BCM) and industrial 1,059 TMC (30 BCM), energy 953 TMC (27 BCM) and other uses 1,059 TMC (30 BCM) totalling to 26,483 TMC (750 BCM). By the year 2025, the demand in irrigation would be 27,189 TMC (770 BCM), domestic 1,836 TMC (52 BCM) and industry 4,237 TMC (120 BCM), energy 2,507 TMC (71 BCM) and other uses 1,306 TMC (37 BCM) totalling to 37,075 TMC (1,050 BCM). The requirement will thus match with the availability. The rough projections indicate that by the year 2050, the utilization may increase annually to about 45,903 TMC (1,300 BCM). This may be possible by various means and transbasin water transfer may be one of the leading options.

Present annual food grain production is over 200 million Tonnes (MT) and is based on the average food grain consumption of about 1.22 lbs. (550 gms) per capita per day. This requirement is met by considering the present irrigated area of 148 million acres (60 Mha) and rainfed area of 173 million acres (70 Mha) with yield as 1 Ton per acre (2.5 T/ha) for the irrigated area and 0.28 Ton per acre (0.7 T/ha) for the rainfed area.

This requirement increases to about 380 MT by the year 2025 AD and is based on the projected consumption of 1.66 lbs (750 gms) per capita per day. This requirement shall be met by increasing the gross irrigated area under food grains to about 235 million acres (95 Mha) and reducing the rainfed area to 124 million acres (50 Mha). Also, the improved yield values for the irrigated and rainfed

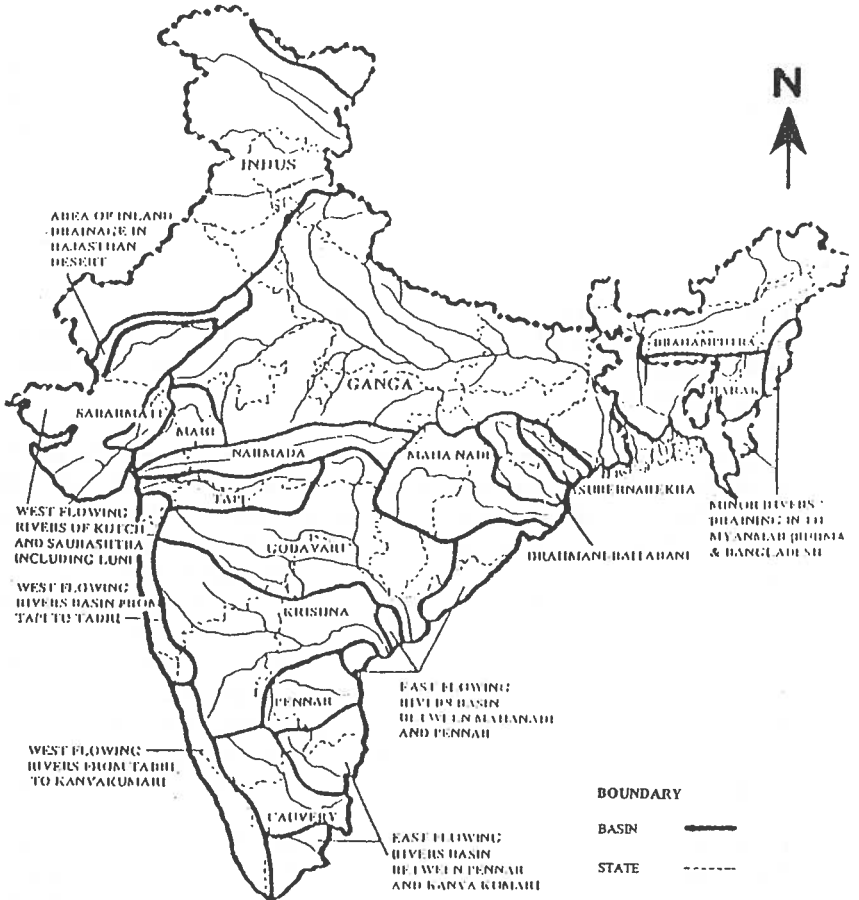


Figure 2. India- States & River Basins

areas shall be 1.39 Ton per acre (3.5 T/ha) and 0.4 Ton per acre (1.0 T/ha) respectively. For the year 2050 AD, taking the projected consumption of about 1.66 lbs. (750 gms.) per capita per day, the requirement shall be met by increasing the gross irrigated area under food grains to 296.5 million acres (120 Mha) and reducing the rain fed area to 99 million acres (40 Mha) for feeding a population of 1640 million.

To meet irrigation requirements up to the year 2025 AD, it is proposed to utilise the existing water resources i.e. 24,717 TMC (700 BCM) through surface water and 12,358 TMC (350 BCM) through ground water [total 37,075 TMC (1,050 BCM)] by construction of conventional structures. However, to meet irrigation requirements by the year 2050 AD, it is imperative to have transbasin transfer of water so as to facilitate additional utilisation of about 8,828 TMC (250 BCM) when it is expected that the population of the country stabilizes.

### TRANSBASIN WATER TRANSFER PROPOSALS

Transbasin water transfers are already being practised in India. The Periyar-Vaigai, the Kurnool-Cuddapah Canal, the Rajasthan Canal, the Telugu Ganga, the Sardar Sarovar etc. are some of the examples pertaining to transbasin transfers in India. The details are shown in Figure 3.

Large scale transbasin transfers were proposed by Dr. K.L. Rao in the year 1972 for the Ganga-Cauvery link and also by Captain Dastur in the year 1977 in the form of Garland Canal. It was found that the proposal of Dr. K.L. Rao i.e. Ganga-Cauvery link alone would amount to about US\$ 15,560 millions (Rs.  $7 \times 10^5$  millions) (capital cost) at 1995 prices and it would require larger blocks of power (5 to 7 million kw) for lifting of water. It will also have no flood control benefits. The cost of Captain Dastur's proposal would be about US\$ 2,667,000 millions (Rs.  $12 \times 10^7$  millions) at 1979 prices. The experts who examined the proposal considered that Dastur's concept on holding back surplus water from running down to the sea or causing floods and utilising it for irrigation and power generation is unassailable and also methodology and engineering are not acceptable for various reasons. Both the proposals were, therefore, not pursued.

Further studies in this connection were done for the 'National Water Perspective'. The National Water Development Agency (NWDA) was set up in the year 1982 to carry out the water balance and other studies on a scientific and realistic basis, based on various inputs from the field data for optimum utilisation of water resources and for preparation of feasibility reports so as to give concrete shape to 'National Perspective Plan'. Also, the National Water Policy was adopted by the Government of India in the year 1987. The policy states, "Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another based on National Perspective after taking into account the requirements of the areas/basins".



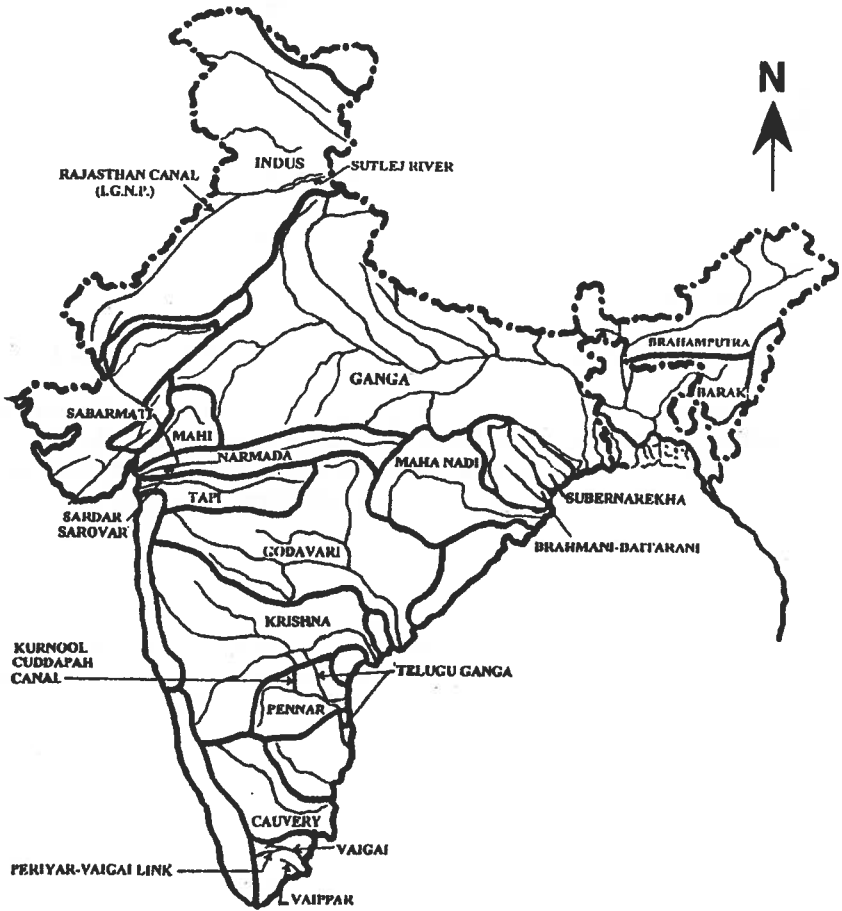


Figure 3. Examples of transbasin water transfer projects

As per present assessment, the total irrigation potential of the country is about 346 million acres (140 Mha) of which only 144.5 million acres (58.5 Mha) would be from major and medium schemes and the balance from minor irrigation surface schemes and ground water. The assessment is based on the possibilities of utilisation of water resources by the States. The scope of irrigation can be significantly increased by utilizing the surplus water available in some rivers and transferring the same to water scarce regions. It is thus seen that by inter-linking of rivers, the ultimate irrigation potential can be increased by about 86 million acres (35 Mha) and also 34,000 MW of hydropower can be generated.

The plan would also provide additional water for augmentation of flows at Farakka required interalia to flush the Calcutta port and the inland navigation system across the country.

#### **CONSTRAINTS IN TRANSBASIN TRANSFER LINK PROJECTS**

The assessment of water resources vis-à-vis surpluses in an inter-state river and its diversion to be utilised in various basins is a complex issue. Some of the important aspects pertaining to technical, environmental, inter-state co-operation, apprehensions of State Governments are discussed below:

##### **i) Technical**

Transbasin transfers involve long distance link canals which have no major technical problems. Pumping huge quantities of silt-laden water over high heads during monsoons, tunnelling, high embankments, long river crossings, minimising seepage losses etc. are really difficult problems but with solutions. Modern technology would help overcome them.

##### **ii) Environmental**

All activities pertaining to development of water involve changes in the environment. It is a vital concern for one and all. The direct concern is submergence of land under reservoirs which includes forest and cultivated lands and displacement of population. The most sensitive problem is relocating the displaced population to suitable new locations with better civic facilities. The relocating package has to be suitable to match the present quality of life in the existing settlement. Relocating is looked at as socio-economic transformation and measures are devised so that economic conditions of Project Affected Persons (PAPs) improve after their relocation. PAPs would need to be made aware of the packages they are offered and the commitment towards their proper settlement in new locations. They also need to be educated about the benefits which they are likely to get from the new environment.

For environment and ecology, after meeting downstream requirements, a minimum flow of 10% of the inflow at diversion structures should be maintained and with storages, this could be of the order of 10% of average lean season natural flow downstream of the storage.

The canals will be generally aligned through non-forest areas. Only in limited reaches the link canals may pass through reserved/degraded forests. To the extent possible, even the agricultural area needs to be avoided. It is expected that the link canals may not pose serious environmental implications. The service areas of the link canals are also not likely to cause any water logging and salinity problems in view of their topography, soil drainability, conjunctive use of surface and ground water as well as the effective cropping pattern adopted in the proposals.

### iii) Inter-state co-operation

Since some of the rivers in India are inter-State in character thereby involving the catchments in different States, no water resources development may be possible until and unless the States cooperate with each other. Any unilateral and isolated action by a State is considered undesirable and invites criticism leading to confrontation with the other basin state. In some cases, though tribunals have been set up to decide about the water allocation among the States, yet the awards could not be implemented as the participating States do not cooperate. In some cases, there has been significant achievement in respect of water resources development after the agreements have been signed. However, in many cases, some of the issues are still unresolved. As such, the developments in the basin could not be achieved.

So far as transbasin transfer links are concerned, once agreements are signed amongst the basin states, the major objection to the implementation of the link proposals may be from the environmentalists. To negate these effects, it may be possible to reduce the dam heights which may lead to increase in the pumping head. However, these aspects may require to be studied in greater detail at a later stage at the time of preparation of the Detailed Project Reports. It may be required to work out packages for Rehabilitation and Resettlement to take positive decision for implementation of the link projects.

### iv) Apprehensions of the State Governments

Some states have expressed concern about the reliability and adequacy of the water transfer from distant sources because in-basin irrigation might suffer for want of water. The links are to be operated in an integrated manner to transfer only surplus waters. Before any water is diverted from any basin, it would be ensured that the entire reasonable in-basin needs in the ultimate stage of development are met with first.

In India most of the major rivers flow through one or more states and the lean season flows of the rivers get reduced after the monsoons. In case the State on the upper reaches envisage a dam, the state(s) on the lower reaches immediately raise an objection that the water availability gets reduced considerably. The dispute arises and is so intricate that the technocrats and politicians are unable to resolve their differences and finally the dispute is referred to tribunal which decides the final allocation of water among the basin states. Some states have expressed concern about Tribunal awards fearing that these may get disturbed. They feel that no water can be taken out of the basin due to the Tribunal Awards. It is envisaged that Tribunal awards are sacrosanct in nature and are not disturbed for transbasin transfer of water and Tribunal being the mechanism for inter state allocations for water.

Studies for transbasin transfer are for the optimum utilization of the water. Surpluses are worked out after considering all the in-basin needs. After the studies are over, the states can consider them and enter into a fresh agreement for the sharing of the water. The feasibility studies will form a useful basis for discussions and agreements among the concerned states.

### **DEVELOPMENT AND MANAGEMENT OF LINK PROJECTS THROUGH RIVER BASIN ORGANISATIONS**

For water resources planning, a river basin is generally considered as the basic unit. Even the National Water Policy recognises the drainage basin or sub basin as a unit for planning, management and development adopting a holistic approach by planning and formulation of projects. The development of surface and ground water should be planned together for water and land use.

For water resources to be utilised in an optimum capacity, the projects may be formulated within basin/sub-basin for planning stage. The planning would require coordination among different users of water viz. domestic, irrigation, hydropower, navigation and industrial users etc. Planning will be not only based on present demands but also on future projections.

The River Basin Organisations (RBOs) formulated with multi disciplinary units only can achieve the desired results. RBOs for interstate rivers are encouraging tools as agreements regarding water surplus or deficit in a basin could be mutually discussed by the RBOs of the respective basins to arrive at a consensus at the earliest as the function of RBO shall be to collect data, disseminate them in local languages, formulate integrative master plans and consider the proposals from concerned states on various issues, including project proposals in the basin and implementation of projects. The RBO would also be the forum for mutual discussions among the states concerned and also to resort to conciliation to resolve differences.

The river basin can be a basic unit for planning, it may not lead to optimal utilisation of surplus water resources in various regions of the country. Many basins in the country may be surplus in water whereas the others may be facing a shortage of water. To meet the shortages, long distance transbasin transfer of water may be required for equitable distribution and optimum utilisation. The RBOs with requisite statutory powers for development and management of interstate river basins and for implementation of transbasin transfers, are required to be set up.

### CONCLUSIONS

India has planned for self sufficiency in food even in the face of uncertain population growth and likely increase in food demands and dietary changes. Keeping in view the water resources scenario for 2050 AD, it may be imperative to go for transbasin transfers.

The implementation of the proposals may not pose any technical problems in view of the experience and expertise available. Resettlement of project affected people would be required to be done with humane approach. The inter-state issues will be required to be resolved with a give and take policy. This will pave the way for river basin development with transbasin transfers for optimum development of water potential of the rivers leading to overall development of the region.

The paper presents various aspects with a view to exchange the experience and to gain from experience of other countries.

### ACKNOWLEDGEMENTS

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# EVOLUTION OF TRANSMOUNTAIN WATER DIVERSIONS IN COLORADO

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## ABSTRACT

Trans-basin water diversions exist all along Colorado's Front Range, constructed to provide increased reliability of water supplies. Subsequent experience with water yields has pointed out the advantages of trans-basin diversions both in firm yields and in the ability to repeatedly utilize imported water to exhaustion.

Four river systems (Rio Grande, Arkansas, Platte, and Colorado) originate within Colorado. The first three of these rivers receive trans-basin diversion water from the Colorado River basin, with some diversions between adjacent pairs of those basins. Front Range urbanization has been facilitated by the availability of large, reliable water supplies from trans-basin diversions. The relative ease of change-of-use, coupled with the ability to use supplies to exhaustion, have made trans-basin diversion projects prime targets for land developers in search of water supplies. Virtually all of the existing trans-basin projects have seen shifts of first-use yields from commodity-based industries to municipal water supplies. These shifts have been accompanied by changes in seasonal usage patterns, and increases in unit value of the water resource, thus favoring further investment in trans-basin diversion infrastructure to improve both reliability and ease of operation.

Future trends would indicate increased conversion of trans-basin diversions to municipal supply as first use. Further water wars can also be expected as new projects are sought to respond to Front Range municipal thirst. Any improvements to existing projects would likely further physically stabilize the source environment and improve operational characteristics. New proposals for trans-basin diversions will face substantial challenges from compact restrictions and environmental concerns in basins of origin. The net result will be growing economic pressures for change of use and physical improvements to existing trans-basin diversions.

## INTRODUCTION

Trans-basin water diversions exist throughout Colorado, but also particularly all along the state's Front Range, from the southern to the northern state lines. Of

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particular interest to this paper are those trans-basin diversions between the largest river basins in the state—where water is rerouted to a different watercourse leaving the state at a different location—referred to as transmountain diversions by the State Engineer. This diverted water is then denoted as imported water in the receiving basin.

The primary objectives for the earliest projects were to provide increased reliability of water supplies. Water developers who arrived somewhat later in the settlement process typically found it necessary to look further into the mountain watersheds to secure adequate and reliable water supplies. Subsequent experience with water yields—especially during drought periods—has pointed out two notable advantages to transmountain diversions: (1) firm yields are not as susceptible to local drought effects as native water diversions; and (2) imported water may be utilized repetitively to exhaust the entire diverted volume.

Four river systems (Rio Grande, Arkansas, Platte, and Colorado) originate within Colorado. For management purposes within Colorado, the Colorado River is further divided into the Yampa, Colorado, Gunnison, and San Juan River basins. The Platte River is further divided into the North Platte and South Platte Rivers. The first three of these rivers receive trans-basin diversion water from the Colorado River basin, with some diversions also occurring between adjacent pairs of those basins. The earliest diversions were typically by open channels traversing high-altitude catchments over mountain passes to serve agricultural or mining projects. More recent diversions have been large-scale multi-purpose projects, typically featuring large-scale carry-over and compensatory storage reservoirs, in both the source areas and basins of importation. Diversion conveyances are typically large-capacity tunnels and penstocks with power generation facilities at discharge ends.

### ORIGINAL DECREES

The following analysis was completed for transmountain diversions which are currently in use. Any diversions not reported on the annual Division Engineers' reports (Colorado State Engineer's Office, 1999) have been assumed to be abandoned and no longer in use. Each of the importing basins are addressed individually below. A schematic overview of the nature of the analyzed transmountain diversions between adjacent basins is shown in Figure 1.



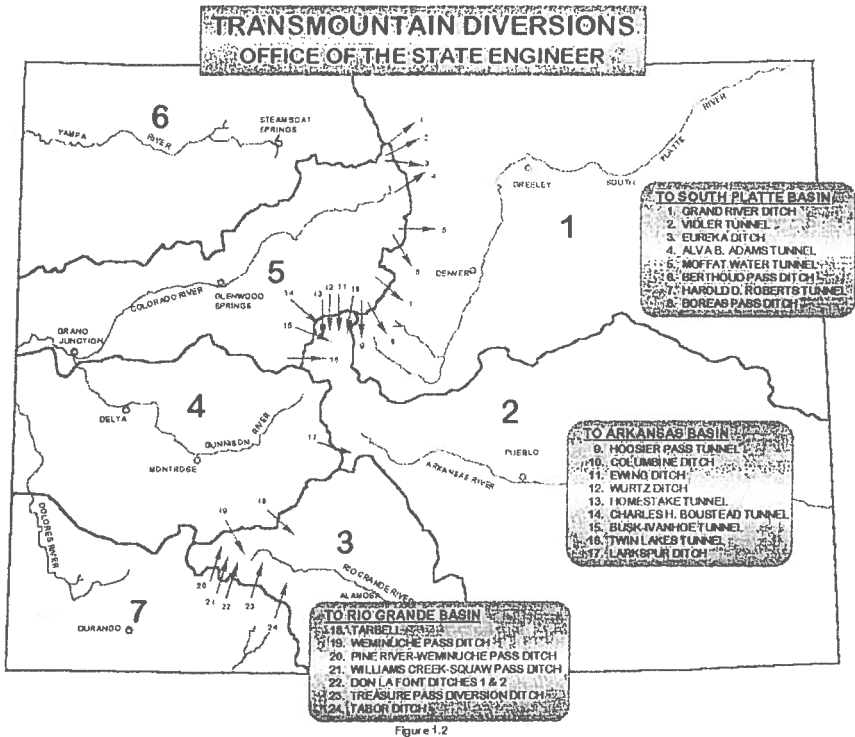


Figure 1.2

**Figure 1** Transmountain Diversions in Colorado (Colorado State Engineer’s Office, 2001)

For trend-spotting purposes, the myriad beneficial water uses were simplified into four categories for this analysis: Irrigation, Industrial (including mining), Municipal (including domestic, commercial, and fire), and Habitat (including recreation). A more detailed review of all of the pertinent decrees would likely result in different numerical values, but the trends would be consistent with those shown in this paper.

The South Platte River basin (Division 1) is the recipient of the greatest quantity of imported flow from the widest number of sources. Diversions to the South Platte basin are shown in Table 1. While a majority of the original decreed diversions into this basin were destined for irrigated agriculture, there were also several significant diversions—such as the Moffat and Roberts Tunnels—intended solely for municipal use. The South Platte basin is also the only basin within the state that does not export water to another basin.

## Transbasin Water Transfers

Table 1: South Platte Import Diversions

Diversion	Exporting Division	Original Decree	
		Use	Quantity (cfs)
Adams Tunnel (CBT)	Colorado	municipal	0
Adams Tunnel (CBT)	Colorado	irrigation	550
Berthoud Pass Ditch	Colorado	irrigation	53
Boreas Pass Ditch	Colorado	irrigation	88
Grand River Ditch	Colorado	irrigation	525
Homestake Tunnel	Colorado	municipal	350
Hoosier Pass Ditch	Colorado	municipal	400
Moffat Tunnel	Colorado	municipal	100
Roberts Tunnel	Colorado	municipal	1000
Straight Creek Tunnel	Colorado	irrigation	10
Vidler Tunnel	Colorado	irrigation	52
Bob Creek Ditch	North Platte	irrigation	60
Cameron Pass Ditch	North Platte	irrigation	28
Columbine Ditch	North Platte	irrigation	20
Deadman Ditch	North Platte	irrigation	275
Laramie-Poudre Tunnel	North Platte	irrigation	442
Michigan Ditch	North Platte	irrigation	146

The Arkansas River basin (Division 2) is also a recipient of significant quantities of imported flow. Diversions to the Arkansas basin are shown in Table 2. Many of the early transmountain diversions were for mining purposes, although the more recent works have been for the benefit of municipal water supplies. A significant project is the Homestake Tunnel which provides carriage for municipal water for the City of Colorado Springs in the Arkansas basin, but also carries flows which are further diverted into the South Platte basin for the City of Aurora.

Table 2: Arkansas Import Diversions

Diversion	Exporting Division	Original Decree	
		Use	Quantity (cfs)
Hudson Ditch	Rio Grande	irrigation	1
Medano Ditch	Rio Grande	irrigation	21
Larkspur Ditch	Gunnison	irrigation	10
Boustead Tunnel (Fry-Ark)	Colorado	municipal	1800
Columbine Ditch	Colorado	irrigation	30
Ewing Ditch	Colorado	irrigation	18
Homestake Tunnel	Colorado	municipal	350
Ivanhoe Tunnel	Colorado	irrigation	35
Twin Lakes Tunnel	Colorado	irrigation	100

The Rio Grande River basin (Division 3) primarily received imported flow initially for use in limited agricultural operations. Diversions to the Rio Grande basin are shown in Table 3.

Table 3: Rio Grande Import Diversions

Diversion	Exporting Division	Original Decree	
		Use	Quantity (cfs)
Tabor	Gunnison	irrigation	21
Tarbell	Gunnison	irrigation	25
Don LaFont #1 Ditch	San Juan	irrigation	4
Don LaFont #2 Ditch	San Juan	irrigation	6
Pine River-Weminuche Pass Ditch	San Juan	irrigation	40
Treasure Pass Ditch	San Juan	irrigation	7
Weminuche Pass Ditch	San Juan	irrigation	18
Williams Creek Squaw Pass	San Juan	irrigation	10

The Gunnison River basin (Division 4) received primarily irrigation flows for lands along the Uncompaghre River. Diversions to the Gunnison basin are shown in Table 4.

Table 4: Gunnison Import Diversions

Diversion	Exporting Division	Original Decree	
		Use	Quantity (cfs)
Leon Lake Tunnel/Canal	Colorado	irrigation	54
Carbon Lake Ditch	San Juan	irrigation	30
Mineral Point Ditch	San Juan	irrigation	11
Red Mountain Ditch	San Juan	irrigation	6

The central Colorado River basin (Division 5) originally imported flows from adjacent basins for a variety of purposes, including irrigation, power, and municipal uses. Diversions to the central Colorado basin are shown in Table 5.

Table 5: Colorado Import Diversions

Diversion	Exporting Division	Original Decree	
		Use	Quantity (cfs)
Arkansas Well (Stevens-Leiter)	Arkansas	municipal	2
Divide Creek Highline Feeder	Gunnison	irrigation	50
Fruita Pipeline/Water Works	Gunnison	municipal	0
Redlands Power Canal	Gunnison	industrial	850

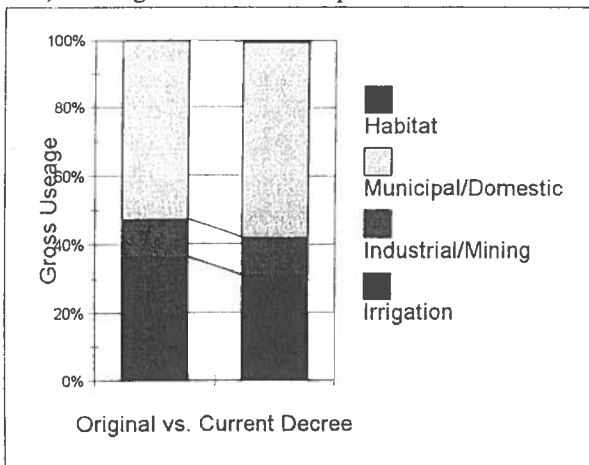
Diversion	Exporting Division	Original Decree Use	Decree Quantity (cfs)
Dome Creek Ditch	North Platte	irrigation	5
Sarvis Creek Ditch	North Platte	irrigation	43
Stillwater Ditch	North Platte	irrigation	31

Within Colorado, the North Platte River (a subset of Division 1), Yampa River (Division 6), and San Juan River (Division 7) basins are exporting basins only. Thus there is no analysis of imported flows for these basins in this paper.

### CURRENT DECREES

Front Range urbanization has been facilitated by the availability of large, reliable water supplies from trans-basin diversions. The relative ease of change-of-use, coupled with the ability to use supplies to exhaustion, have made trans-basin diversion projects prime targets for land developers in search of water supplies. Virtually all of the existing trans-basin projects have seen significant shifts of first-use yields from commodity-based industries to municipal water supplies. These shifts have been accompanied by changes in seasonal usage patterns, and increases in unit value of the water resource, thus favoring further investment in trans-basin diversion infrastructure to improve both reliability and ease of operation.

Gross changes of decreed use for imported flows among all the basins are shown in Figure 2 and numerically in Table 6. Diversion-specific information is then discussed below; unchanged decrees are not presented in this discussion.



**Figure 2** Composition of Use of Transmountain Diversions in Colorado

Table 6: Changes of Use

Use Change	Percentage
Irrigation	-17.1%
Industrial	0.0%
Municipal	8.2%
Habitat	100.0%

The South Platte River basin has experienced the largest population increase of the state's basins, and thus has demonstrated the greatest amount of incentive to change decreed uses toward municipal use. Gross changes in decreed diversions to the South Platte basin are shown in Table 7.

Table 7: South Platte Import Changes

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Straight Creek Tunnel	irrigation	municipal	10
Michigan Ditch	irrigation	municipal	146

The Arkansas River basin has also experienced significant population growth, and is likewise seeing conversion of imported flows to municipal use, as well as conversions to protect environmental and habitat conditions. Changes in decreed diversions to the Arkansas basin are shown in Table 8.

Table 8: Arkansas Import Changes

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Medano Ditch	irrigation	habitat	21
Twin Lakes Tunnel	irrigation	municipal	100

The Rio Grande River basin has not experienced comparable population growth as the Front Range basins (South Platte and Arkansas), but has still seen changes in use of imported flows. The most prominent changes have been from irrigation useage to habitat maintenance for wildlife refuges in the western portion of the Rio Grande River valley, as well as changes to municipal/domestic use within the valley. Changes in decreed diversions to the Rio Grande basin are shown in Table 9.

Table 9: Rio Grande Import Changes

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Tabor	irrigation	municipal	21

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Pine River-Weminuche Pass Ditch	irrigation	municipal	40
Weminuche Pass Ditch	irrigation	habitat	18
Williams Creek Squaw Pass	irrigation	municipal	10

With the Animas-La Plata project not yet constructed, the Gunnison River basin imports have remained largely unchanged. Changes in decreed diversions to the Gunnison basin are shown in Table 10.

Table 10: Gunnison Import Changes

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Mineral Point Ditch	irrigation	habitat	11

The central Colorado River basin has also not experienced significant change in use of imported flows. Changes in decreed diversions to the central Colorado basin are shown in Table 11.

Table 11: Colorado Import Changes

Diversion	Original Use	Current Use	Gross Quantity (cfs)
Dome Creek Ditch	irrigation	municipal	5
Stillwater Ditch	irrigation	municipal	31

### FUTURE TRENDS AND INDICATIONS

A case study in the useage conversion of a transmountain diversion, presented separately at this conference, is the Michigan Ditch which brings flows into the Cache la Poudre River within the South Platte basin. Originally permitted for irrigation uses, this facility is now wholly owned and operated by the City of Fort Collins for municipal uses. As with many of the other early transmountain diversions, the Michigan Ditch experienced a period of decreased useage before being revitalized with a new owner and decreed use.

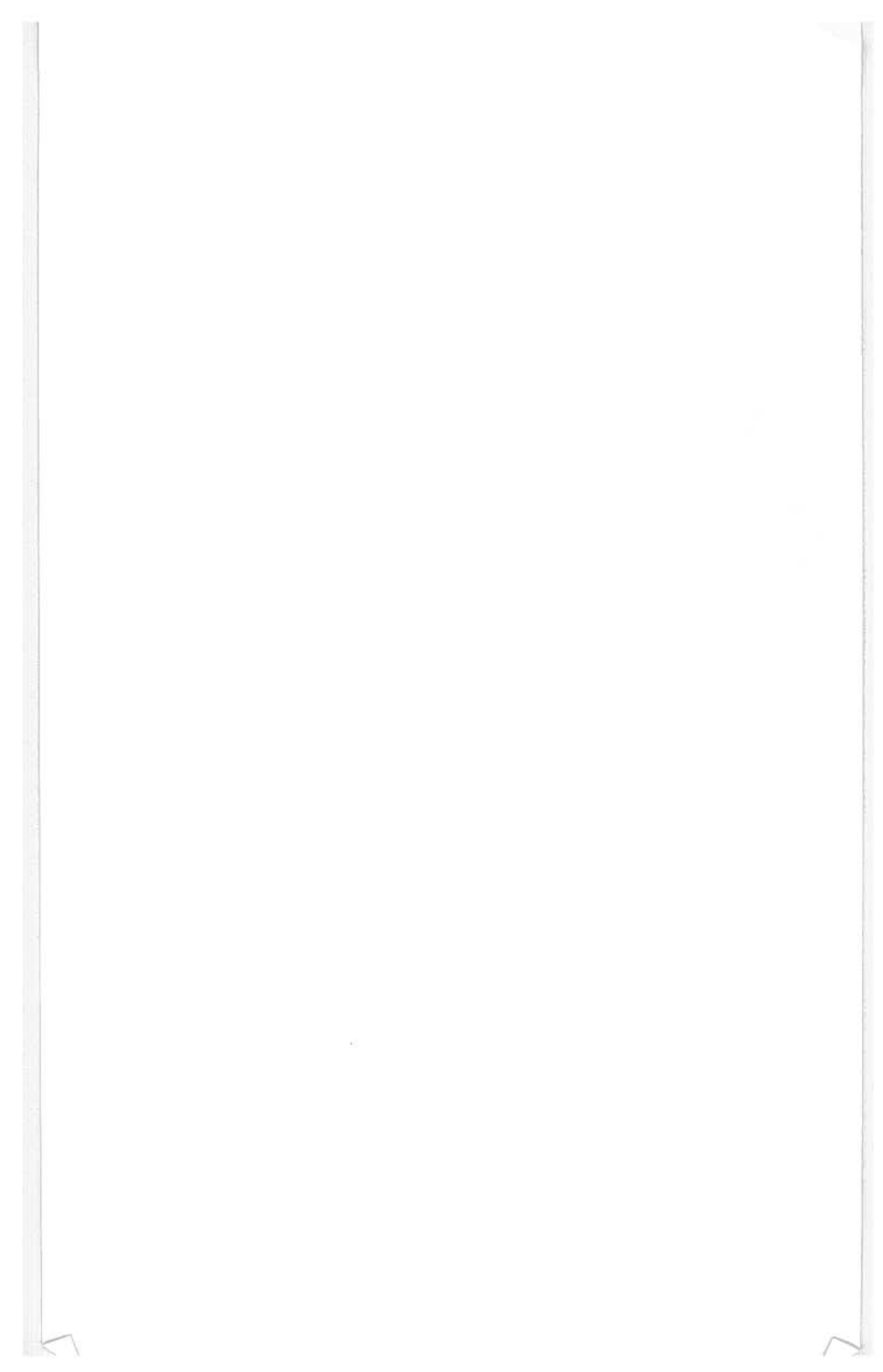
Review of the annual reports show transmountain diversions in every importing basin with indications low or non-existent use. Owners of these diversions may be well-advised to maintain levels of flow through their facilities to establish value for any future change-in-use proceeding. As a corollary, municipal water

suppliers may desire to review these same facilities as potential investments for enhancing or diversifying urban water supplies in that same change-of-use venue.

Future trends would indicate increased conversion of transmountain diversions to municipal supply as first use. Further water wars can also be expected as new projects are sought to respond to Front Range municipal thirst. At the same time, conversion of transmountain diversions to habitat maintenance and wildlife refuge uses may also receive strong public support. Any improvements to existing transmountain diversion projects would likely further physically stabilize the source environment and improve operational characteristics. New proposals for transmountain diversions will face substantial challenges from compact restrictions and environmental concerns in basins of origin (Barry, 2001). The net result will be growing economic pressures for change of use and physical improvements to existing transmountain diversions, as well as growing public debate over the function and use of these diversions.

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**A CASE STUDY OF TRANS-BASIN WATER TRANSFER  
POSSIBILITIES BETWEEN THE GODAVARI AND  
THE KRISHNA BASIN IN INDIA**

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C.S.P.Ojha<sup>3</sup>

**ABSTRACT**

The basic philosophy of trans-basin water transfers presumes the need to correct the natural imbalance of inequitable distribution of water resources over the region from surplus water in the Godavari basin to water deficit areas of the Krishna basin.

In India Supreme Court judgements strengthened the view that the right of access to clean water has been linked with the fundamental right of life. Thus, the trans-basin water transfer to non co-basin states to provide access to clean water seems to have a strong justification. Inter-basin links and interstate projects would physically make the states interdependent. This will foster day to day co-operation and lead to a feeling of oneness. Thus trans-basin water transfer projects would improve national solidarity.

In India amongst peninsular rivers, the Mahanadi and the Godavari basins have sizeable surpluses after meeting the existing and realistically projected needs of the states within these basins. It is therefore proposed to provide terminal storages on the Mahanadi and the Godavari rivers to divert surplus flows from the Mahanadi to the Godavari system and to further transfer surplus from the Godavari system to water deficit rivers further south namely the Krishna, Pennar, Cauvery and Vaigai. This paper describes the possibilities of trans-basin water transfer between the Godavari and the Krishna rivers in India.

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## INTRODUCTION

India is a country of monsoons. Most of the rainfall occurs only during 3-4 months from June to September. Even this rainfall is not spread uniformly over the country. While some regions are blessed with the precipitation over and above their requirement, other regions suffer from water shortages to meet even their basic needs. This temporal and spatial variability of water availability has many times caused ironic situations like floods at some places with drought at some other places at the same time.

The government of India, after considering this situation and negotiating with all the state governments came up with a National Perspective Plan (NPP) for water resources development in the country in 1980. The national perspective plan (NPP) has two components viz. (IWRS, 96).

- (i) Himalayan rivers development and
- (ii) Peninsular rivers development.

The National Water Development Agency, a Government of India society under the Ministry of Water Resources, was set up in 1982 to firm up the National Perspective proposals after detailed studies.

In the national perspectives for water resources development formulated by Government of India, the first part of the peninsular rivers development envisages the diversion of the surplus flows of the Mahanadi to the Godavari system and then a further transfer of surplus waters from the Godavari system to the water short Krishna, Pennar and Cauvery basins. This would benefit the drought prone areas of Andhra Pradesh, Karnataka, Maharashtra, Orissa and Tamil nadu states.(IWRS, 96).

## NEED FOR TRANS-BASIN WATER TRANSFERS IN INDIA

The needs for trans-basin water transfers in India can be appreciated by better visualising future projections of the demand of irrigation, domestic water supply, hydropower etc.

- (i) **Irrigation:** The population of the country is expected to stabilise at 1500 to 1800 million by 2050 AD which would require about 450 million tonnes of food grain annually at the present level of consumption. To meet the country's food demands reasonably well, a production of not less than 500 million tonnes of food grains has to be planned by 2050 AD. The ultimate irrigation potential with existing conventional sources is estimated at 140 million hectares. The situation calls for improvements in water management and faster developments in

biotechnology to increase the productivity. It will require trans-basin water transfers in India to develop more irrigated land.

(ii) **Metropolitan Water Supply:** Most of our cities are already water short, inspite of priority being given to urban and industrial water supply . The alternatives for coping with the progressive increased requirements up to 2050 AD have to be planned. Such a planning can have trans-basin water transfer as one of its options.

(iii) **Hydropower:** The ministry of power, Government of India has projected that the demand of power by the year 2050 AD would be 8.3 million MW at a growth rate of over 9% annually. All the resources such as thermal power, hydropower, etc. are to be tapped and harnessed to meet the demand. Ironically, about 79% of the country's hydropower potential of 84,000 MW has not yet been tapped. Hence, there is every need for exploitation of power potential of Himalayan rivers with which the Himalayan links projects would become feasible (IWRS, 96).

#### **THE MAHANADI-GODAVARI-KRISHAN-PENNAR-CAUVERY-VAIGAI LINK SYSTEM**

Among the peninsular rivers, the Mahanadi and Godavari basins are found to have surplus over and above their realistically projected requirements in the ultimate scenario in 2050 AD. The other peninsular rivers Krishna, Pennar, Cauvery and Vaigai will be deficit in water resources to meet their projected needs. Therefore, it is proposed to divert the surpluses of the Mahanadi and Godavari rivers to Krishna, Pennar, Cauvery and Vaigai basins through a net work of trans basin water transfer links. The link system is more familiarly known as southern water grid, which is shown in Fig. 1. As per the water balance studies of the NWDA, the Mahanadi and Godavari rivers are surplus to the tune of 11,176 Mm<sup>3</sup> and 15,017 Mm<sup>3</sup> respectively. The Krishna, Pennar and Cauvery are water deficient in the order of 3200, 3800 and 16,000 Mm<sup>3</sup> respectively.

The flow chart of the inter-linking system from the Mahanadi to the Vaigai in Fig. 2 shows how the surpluses of Mahanadi and Godavari are proposed for to be used in the deficit areas of Krishna, Pennar, Cauvery and Vaigai.

The present paper describes the trans-basin water transfer links from the Godavari to Krishna of the Mahanadi-Vaigai link system in detail. The surplus water of the Mahanadi (11,176 Mm<sup>3</sup>) are proposed for diversion through the Mahanadi- Godavari link, which would deliver 6500 Mm<sup>3</sup> of water at Dowlaiswaram (Colton Barrage) on the Godavari river.

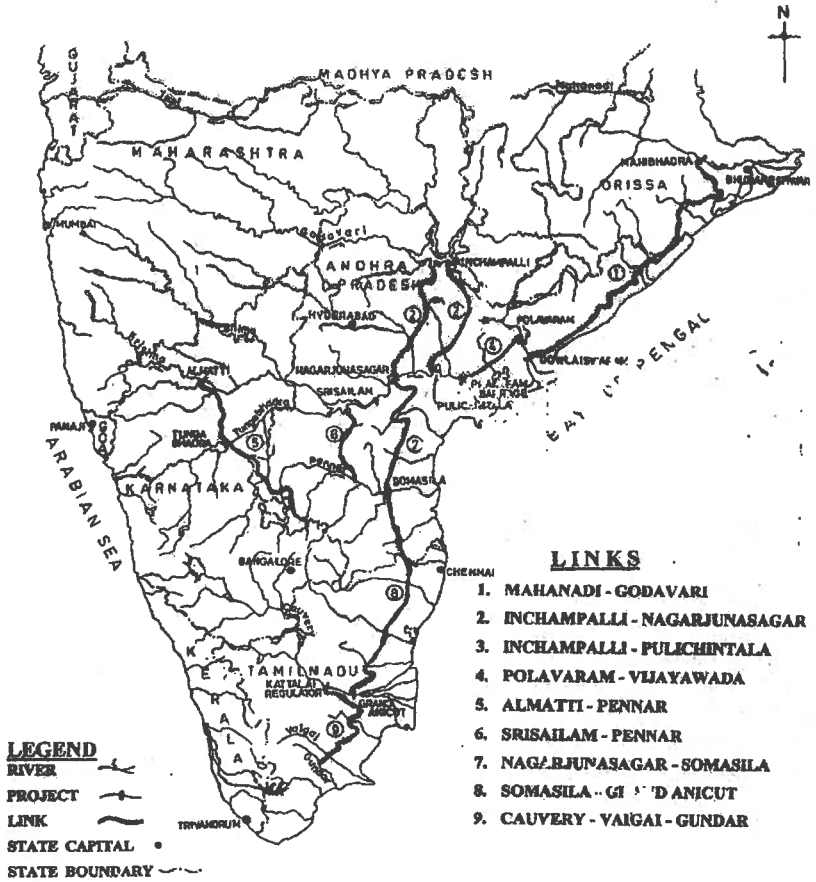
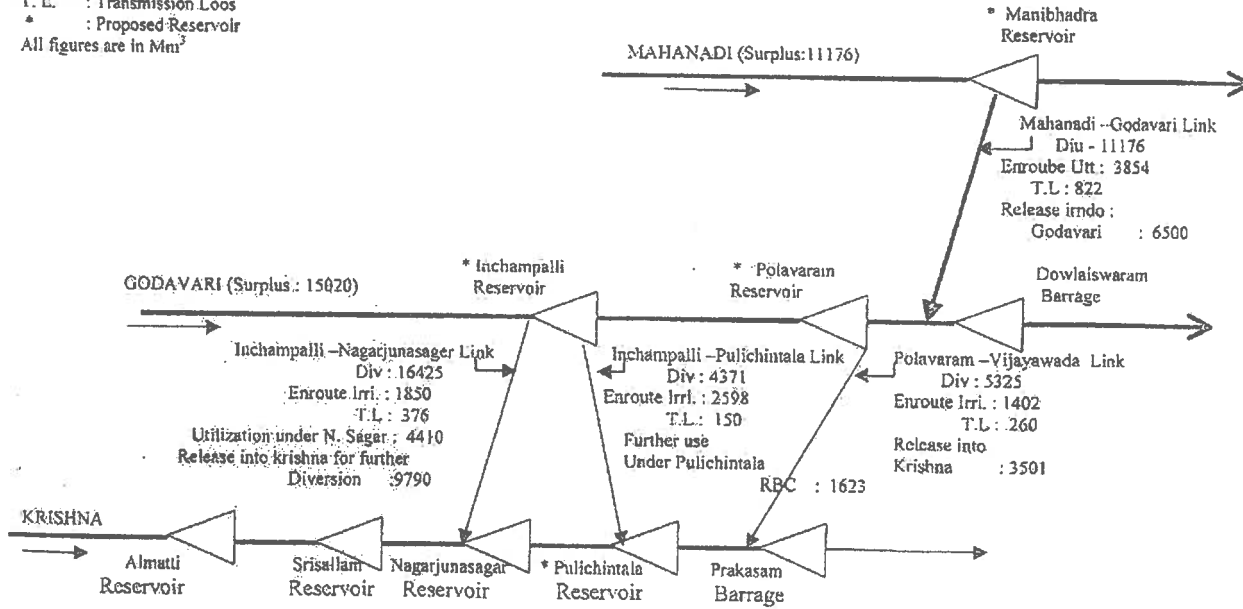


FIG. 1. PROPOSED LINK CANALS OF SOUTHERN WATER GRID

**ABBREVIATIONS**

- Div. : Diversion
  - Irr. : Irrigation Use
  - T. L. : Transmission Loss
  - \* : Proposed Reservoir
- All figures are in Mm<sup>3</sup>



**Fig. 2. TRANS-BASIN WATER TRANSFER LINK CANALS CONNECTING MAHANADI - GODAVARI - KRISHNA - RIVERS**

The combined surplus of 21,517 Mm<sup>3</sup>, i.e. 15017Mm<sup>3</sup> of Godavari and 6500 Mm<sup>3</sup> of the Mahanadi basins, is proposed to be diverted from Godavari to Krishna through 3 links namely

Inchampalli - Nagarjunsagar link

Inchampalli - Pulichintala link

Polavaram - Vijaywada link

### GODAVARI BASIN

The river Godavari is the second largest river in India and the largest in southern India Rao (1975). It rises in the Sahyadri hills at an altitude of 1067m near Trimbakeswar in the Nasik district of Maharashtra State and flows across the Deccan Plateau from the Western Ghats to Eastern Ghats. It flows for a total length of about 1465 Km in a general southeastern direction through the states of Maharashtra and Andhra Pradesh before joining the Bay of Bengal near Rajahmundry in Andhra Pradesh.

The total basin area is 312,813 Km<sup>2</sup>, spread in the states of Maharashtra, Madhya Pradesh, Karnataka, Orissa and Andhra Pradesh. The major tributaries joining the Godavari are the Pravara, the Purna, the Manjra, the Maner, the Pranhita, the Penganga, the Wardha, the Wainganga, the Indravati and the Sabari.

### WATER BALANCE STUDIES IN GODAVARI

The catchment area of the Godavari basin consists of independent catchments of the Pravara, Purna, Manjra, Maner, Penganga, Wardha, Pranhita, Indravati and Sabari sub-basins and the catchment of the main Godavari. For the purpose of assessing water balance at Inchampalli, the catchment area of Godavari basin between Sriramsagar project and Inchampalli only has been considered for the reasons given below.

The water availability and culturable area are not spread proportionately in the vast catchment area of the Godavari basin and consequently the water balance situation is also not uniform in the basin area. In the upper reaches of the Godavari basin, more culturable area is available than that can be brought under irrigation by the available water resources. The water balance in respect of different sub-basins of the Godavari basin have been studied from which it is found that the water available in the Godavari basin upstream of the existing Sriramsagar project is not sufficient to bring the available culturable area in that part of the basin under irrigation. The yield available below Sriramsagar project is such that it gives rise to sizable surplus water, after meeting all the surface water requirements. Transfer of this surplus water available in the lower reaches of the Godavari to the water short areas in its upper reaches may be economically feasible.

The water short areas in the Godavari catchment above the Sriramsagar project are mostly located in the reach between the Jayakwadi project (Paithan Dam) and Sriramsagar project. As such, for the benefit of these areas, the water is required at Paithan. The surplus waters of Indravati are available for diversion below BhopalPatanam, ie. near Inchampalli project only. As for the surplus waters of the Wainganga, these surpluses are available only below Gosikhurd project i.e. near Garchiroli, the elevation of which is around 215m, whereas the full reservoir level (FRL) at Paithan dam is 463.90m. The distance between the above two points is also more than 500Km. Thus, a huge lift may be required if Wainaganga waters are to be transferred to Paithan.

Hence, the water balance studies considering the entire Godavari basin from its source to Inchampalli as a single catchment may not be realistic. To eliminate the cumulative effect of the water deficiency in the upper reaches of the basin on the water balance study at Inchampalli, it may be more realistic to consider the Sriramsagar project itself as the starting point of the Godavari basin. Hence for the purpose of the water balance studies at Inchampalli, only the Godavari basin below Sriramsagar project is considered. Accordingly, the surface water availability as well as water requirements are assessed for the catchment of the Godavari basin below Sriramsagar project upto Inchampalli. To assess the water balance studies for the Godavari basin catchment, the sub-basin yields of middle Godavari below Sriramsagar project, Maner, Penganga, Wardha, Pranhita, Indravati and Lower Godavari upto Inchampalli is considered. The water requirements for irrigation, domestic, industrial and hydropower have been worked out for various sub-basins and part sub-basin as above between Sriramsagar project and Inchampalli project. The water balance has been workedout by deducting the total water requirement from the overall water availability. Inview of the fact that the surplus waters are mainly contributed by the lower tributaries of Godavari such as Pranhita, Indravati and Subari and also that the transfers of these surplus waters for utilisation in the upper needy areas within Godavari basin is neither technically feasible nor economically viable, the utilisation of Godavari waters is planed in the water short areas of basins such as Krishna, Pennar, Cauvary through the aforesaid three link projects (NWDA, 1999).

### KRISHNA BASIN

The Krishna basin is the second largest river in the peninsular India. The river rises in the Mahadev ranges of Western Ghats near Mahabaleshwar at an altitude of 1337m and traverses a distance of about 1400Km through the states of Maharashtra, Karnataka and Andhra Pradesh before flowing into the Bay of Bengal. The river drains an area of 258948Km<sup>2</sup> which is nearly 8% of the total geographical area of the country. The percentages of the area of the basin in the states of Andhra Pradesh, Karnataka and Maharashtra are 29.4, 43.8 and 26.8

respectively. The principal tributaries of the Krishna are the Ghatprabha, Malaprabha, Bhima, Tungabhadra, Musi, Palleru and Muneru.

### **GODAVARI (INCHAMPALLI)-KRISHNA (NAGARJUN SAGAR) LINK CANAL**

The length of the link canal will be 298.70Km up to the Nagarjunsagar reservoir and will cross the main ridge between the Godavari and the Krishna through a tunnel of 9.00Km length. The proposal envisages the construction of one storage dam at Inchampalli on river Godavari. The Inchampalli reservoir is proposed as a joint project between the states of Andhra Pradesh, Maharashtra and Madhya Pradesh as per the inter-state agreement and it is agreed by the three states to construct the dam with F.R.L. of 112.77m and gross storage capacity of 10,374Mm<sup>3</sup>. The FRL and gross storage capacity of the existing Nagarjunsagar reservoir on river Krishna are 179.832M and 11,569Mm<sup>3</sup> respectively.

#### **LINK PROPOSAL**

The Godavari (Inchampalli)-Krishna (Nagarjunsagar) link will comprise the following components.

- A storage reservoir on river Godavari at Inchampalli with FRL of 112.77m, gross storage capacity of 10,374Mm<sup>3</sup>, live storage capacity of 4,285Mm<sup>3</sup> and minimum draw down level of 106.98m.
- A link canal of 298.70Km length including a tunnel of 9.00Km length for crossing the ridge between Godavari and Krishna basins.

The link canal is proposed to divert 16,426Mm<sup>3</sup> of water in a period of 195 days from river Godavari. Out of this, 1850Mm<sup>3</sup> is to be used for irrigation enroute in the Warangal plateau and 376Mm<sup>3</sup> will be lost in transmission and the balance 14200Mm<sup>3</sup> will reach river Krishna at the existing Nagarjunsagar reservoir. The link canal is to be lined throughout its length. It is proposed that the all the water diverted to Nagarjunsagar dam site will be used in meeting the entire deficit in Krishna basin and for meeting the requirement of Nagarjunsagar project. By replacing the water received to the existing Nagarjunsagar command, that water, can be further diverted beyond Krishna from Nagarjunsagar. Srisailem and Almatti Dams on the Krishna river for irrigating the drought prone areas.

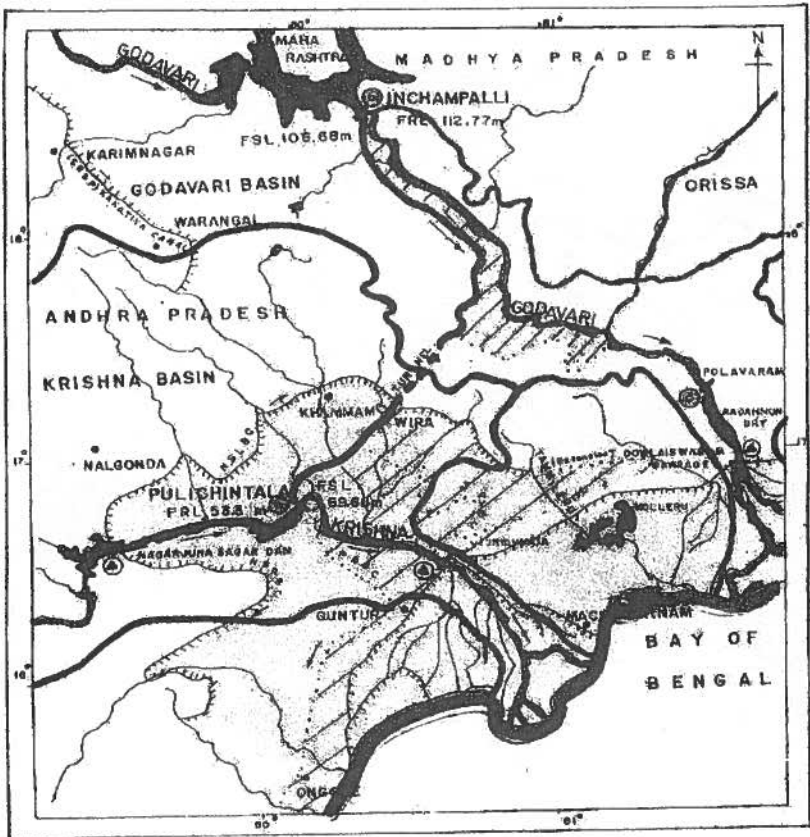
The water received at the tail end of the link canal will be stored in the existing Nagarjunsagar reservoir on the Krishna river. The gross and live storage capacities of the reservoir at F.R.L. of 179.83m are 11,569Mm<sup>3</sup> and 6,797Mm<sup>3</sup> respectively. This link proposal involves lifting of water in the initial reaches for a total lift of 116m in 4 stages. The proposed link is shown at Fig. 3.





LEGEND	FEATURES
BASIN BOUNDARY	QUANTUM OF DIVERSION : 16426 Mm <sup>3</sup>
RIVER	LENGTH OF LINK : 296.70 km
LINK CANAL	ANNUAL IRRIGATION : 319706 ha
LINK COMMAND	ANNUAL UTILISATION : 1850 Mm <sup>3</sup>

FIG. 3. INCHAMPALLI - NAGARJUNSAGAR LINK



LEGEND	FEATURES
BASIN BOUNDARY	QUANTUM OF DIVERSION : 4371 Mm3
RIVER	LENGTH OF LINK : 270.36 Km
LINK CANAL	ANNUAL IRRIGATION : 694882 hc
LINK COMMAND	ANNUAL UTILISATION : 4221 Mm3

FIG. 4. INCHAMPALLI - PULICHINTALA LINK

### **GODAVARI (POLAVARAM)-KRISHNA (VIJAYWADA) LINK**

The Godavari (Polavaram)-Krishna (Vijaywada) link canal as conceived by NWDA will replace the right main canal of the Polavaram project. The link canal is designed to carry 5325 Mm<sup>3</sup> of water, comprising 3501 Mm<sup>3</sup> for transfer to the Krishna delta (2265 Mm<sup>3</sup> as per Godavari water disputes tribunal award and additional transfer of 1236 Mm<sup>3</sup>); 1402 Mm<sup>3</sup> for providing irrigation to 139,740 ha culturable command area (CCA) enroute, 162 Mm<sup>3</sup> for meeting domestic and industrial needs of the command area with 260 Mm<sup>3</sup> of transmission losses. The transferred water delivered for use in the Krishna delta facilities exchange of an equal quantity of Krishna water for use in the drought prone upper reaches of Krishna basin and for further transfer to the water short Pennar and Cauvery basins.

Thus, the Godavari (Polavaram)-Krishna (Vijaywada) link canal project envisages the construction of a link canal with a capacity for carrying 5,325 Mm<sup>3</sup> from the Polavaram reservoir replacing the supply of the Right Main Canal of the Polavaram project.

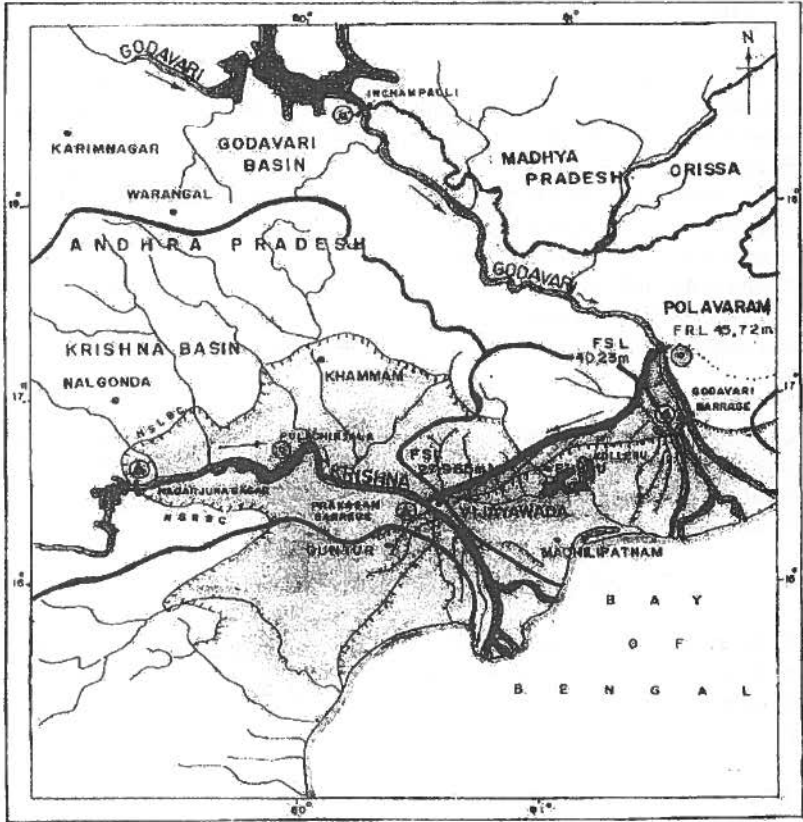
### **POLAVARAM MULTI-PURPOSE PROJECT**

The Polavaram project envisages the construction of an earth and rockfill dam 1600m long across the Godavari river at Polavaram, about 42 Km upstream of Godavari barrage at Dowlaiswaram. The reservoir of 2130 Mm<sup>3</sup> live storage capacity will be created by the dam.

The project envisages two canals, one on the left side and the other on the right side. The left main canal will be 208 Km long and Right main canal will be 174Km long. The left main canal will provide irrigation to a CCA of 0.175 millions ha in the upland area of East-Godavari and Vishakhapatanam districts of Andhra Pradesh.

The canal will also provide urban water supply to Vishakapatanam. In addition, the left main canal will also have a provision for navigation.

The right main canal will be 174Km long and is envisaged to provide irrigation to a CCA of 0.14 million ha-besides transfer of 2,265 Mm<sup>3</sup> of Godavari waters to Krishna (as per Godavari Water Dispute Tribunal Award ). A power house with an installed capacity of 720 MW is envisaged on the left flank of the dam near the non-overflow section generating 60 MW of firm power.



LEGEND		FEATURES	
BASIN BOUNDARY		QUANTUM OF DIVERSION	: 4803 Mm <sup>3</sup>
RIVER		LENGTH OF LINK	: 174 km
LINK CANAL		ANNUAL IRRIGATION	: 222627 ha
LINK COMMAND		ANNUAL UTILISATION	: 1448 Mm <sup>3</sup>

FIG. 5. POLAVARAM - VIJAYAWADA LINK

### POALVARAM-VIJAYAWADA LINK CANAL

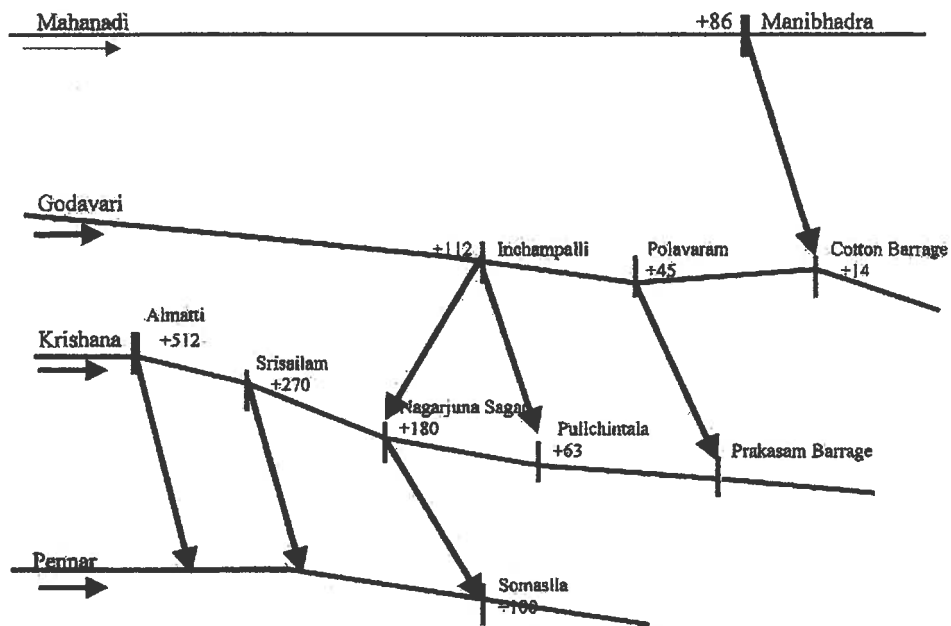
The head sluice proposed in the right flank by the side of the spillway of Polavaram dam, releases water from the main reservoir into two subsidiary reservoirs. From these subsidiary reservoirs water will be let out into the tunnel and then into a stilling basin. The Polavaram-Vajaywada link canal starts from the head regulator proposed in the stilling basin and runs for 174 Km terminating in the Budameru river (which flows into Kolleru lake) at a point upstream of an existing regulator at Velaguleru village.

From Velaguleru regulator, water proposed for transfer to Krishna will flow through the Budameru Diversion Channel (BDC) to fall into the Krishna, 8Km upstream of Prakasham barrage at Vijaywada.

The gross enroute command area of Polavaram –Vijaywada link canal (i.e. 162,690 ha of which 29,178 ha lies in the Godavari basin and the remaining 133,513 ha lies in the Kolleru lake catchment. The corresponding CCA is 139,740 ha (25,060 ha in the Godavari basin and 114,680 ha in the Kolleru catchment).

### CONCLUSIONS

The Mahanadi-Vaigai link system popularly known as Southern water grid in India can provide immense benefits of irrigation, hydropower, domestic and industrial supply in the Peninsular region. The three link projects from Godavari to Krishna in addition to provide irrigation needs of the area enroute will supply water to Krishna basin to wipe out its deficit. Further, part of the supplied water can be transferred beyond for meeting the needs of the Pennar, Cauvery, Vaigai and other intermediate small basins. The link system has been planned to function on the principle of substitution and exchange to avoid unnecessary lifts. That is, the surplus water available in Godavari are proposed to be utilized in the Nagarjunsagar project command and Krishna delta thereby substituting for the release requirement from upstream projects. In exchange, diversions are proposed from upstream projects, like Srisaillam and Almati to irrigate needy upland areas without any additional lift. Otherwise additional lift would have been required to cover these upland areas directly from Inchampalli on Godavari. In finalizing the link, every care has been taken to insure that the proposals are designed to run by gravity and only in the exceptional circumstances will there be lift in limited reaches which not exceed 120 m. With this minimum lift, the upland areas in Krishna basin more than 400m above the source point, i.e. Inchampalli on Godavari, are expected to be provided with the irrigation benefits through the principle of substitution and exchange. The philosophy of substitution and exchange is well illustrated in Fig.6. These proposals interalia will also moderate flooding, improve groundwater supply and provide socio-economic uplift in the region. These proposals are worth implementation in the interest of overall well being of the nation.



All Figures in m(above mean sea level )

**FIG. 6. INTERLINKING OF RIVERS – PHILOSOPHY OF SUBSTITUTION & EXCHANGE**

### ACKNOWLEDGEMENT

In preparation of this paper, the various technical reports of National Water Development Agency, New Delhi have been referred and are duly acknowledged here.

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## TRANSBOUNDARY CONSIDERATIONS IN EVALUATING INTERBASIN WATER TRANSFERS

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D.A. Williamson<sup>2</sup>

### ABSTRACT

The movement of water between basins has long been a method to help resolve water related issues, such as meeting anticipated future water needs, and, in the case where there is too much water, moving water away to protect people and their property. Unfortunately, decisions are often made without regard to the complete social, economic and environmental costs associated with these projects. This is particularly true for projects that are proposed in one jurisdiction but where most of the risks are incurred in another jurisdiction. In such situations, the proponent typically externalizes many of the costs associated with the project while capturing the benefits in the project analysis. This problem is magnified when two sovereign countries are involved.

North Dakota is currently considering three interbasin transfer projects that could negatively impact downstream jurisdictions including the Province of Manitoba. Two of these projects, would move water from the Missouri River basin to the Hudson Bay basin to meet future water needs. The third project would move water from a closed basin to help mitigate flood conditions. To date, downstream risks have not been adequately considered by the proponent resulting in incomplete and potentially misleading information to decision-makers and the public. Given the potential enormous environmental and economic impacts that would be imposed on adjacent jurisdictions, the precautionary principle, full cost accounting, and availability of reasonable in-basin alternatives, interbasin transfer is not the appropriate solution for dealing with North Dakota's water issues.

### INTRODUCTION

The Red River basin, which is part of the Hudson Bay drainage, originates in the extreme northeast part of South Dakota and flows north, draining lands in North Dakota and Minnesota before entering Manitoba, where the Red River eventually empties into Lake Winnipeg. The Souris River, which originates in Saskatchewan, flows south into North Dakota before returning into Canada in Manitoba where it joins the Assiniboine River. The Assiniboine River eventually joins the Red River in downtown Winnipeg and is a major sub-basin to the Red. The Red River basin drains 38,300 square miles in the United States and

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additional 10,700 square miles in Manitoba, excluding the Assiniboine River basin. The Souris River basin drains about 8940 square miles in Saskatchewan, 8000 square miles in North Dakota, and 7200 square miles in Manitoba before it joins the Assiniboine River.

Flows in the Red River are highly variable, ranging at the U.S. - Canada border from nearly zero during some winter months to the peak flow observed during the 1997 flood of 132,000 cubic feet per second (cfs).

The flows of the Souris vary seasonally and annually from zero at the international crossing points to recorded peak flows of 4700 cfs and 14,800 cfs at the Saskatchewan and Manitoba crossings, respectively.

The Red River Valley, which runs approximately 315 miles from Lake Traverse, South Dakota, to Lake Winnipeg, is especially important to the economies of North Dakota and Manitoba as well as contributing significantly to the Minnesota economy. The valley has rich agricultural lands along with significant amounts of commercial and industrial production. A large portion of the population of North Dakota and Manitoba reside in the valley. In the case of Manitoba, nearly three quarters of its population live in the Valley, notably Winnipeg, the largest city in the basin, with nearly 650,000 people.

The Red River is extremely important to Manitoba. The Red River provides drinking water to about 30,000 residents in small communities and farmsteads principally to the region west of the river, irrigation to farmers, and helps support commercial and sport fisheries in the basin valued at about \$50,000,000 annually. Lake Winnipeg, the 10th largest freshwater lake in the world, by itself supports a commercial fishery estimated to directly contribute over \$25,000,000 annually to the economies of Manitoba and Canada. Many of the about 850 commercial fishing licences issued for Lake Winnipeg are to First Nations and Aboriginal peoples. Over 23,000 permanent residents, of which a majority are of Aboriginal descent, living in over 30 communities along the shore of Lake Winnipeg, derive a considerable portion of their food supply from the fishery.

### **PROPOSED INTERBASIN TRANSFER PROJECTS**

Moving water from one location to another has long been considered by governments as a way to resolve water issues, such as water shortages or flooding problems, or as a tool for economic development. These projects however can result in significant impacts to many people in both the receiving and donor basins. Currently, in North Dakota there are three projects that are being actively pursued that could have significant impacts not only to the people of North Dakota but also to the residents in other states as well as to Canada. The projects are (1) an outlet for Devils Lake; (2) transferring water from the Missouri River to the Red River valley as part of the Garrison Diversion Project, and (3)

transferring water from the Missouri River to the Souris River basin (Northwest Area Water Supply or NAWS project) also as part of the Garrison Diversion Project.

### Garrison Diversion Project

One of the largest and controversial water projects in the western United States is the Garrison Diversion Project in North Dakota. This project, if implemented, would move water from the western portion of the state in the Missouri River Basin to the Red River of the North, which is part of the Hudson Bay drainage system, in the eastern part of the state (Figure 1). The Missouri River basin has been hydraulically-separated from the Hudson Bay basin for about 10,000 years following retreat of the last major glacier. Each basin has developed a distinct aquatic biological community and water quality differs significantly.

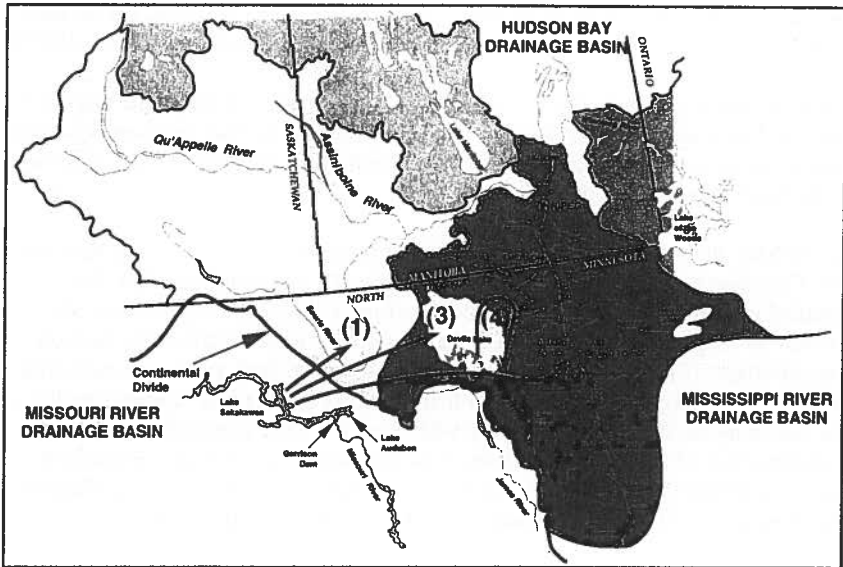


Figure 1: Missouri, Mississippi, and Hudson Bay drainage basins showing potential interbasin water transfer projects. (1) Garrison's Northwest Area Water Supply Project; (2) Garrison's Red River Valley Water transfer; (3) Inlet to Devils Lake; and (4) Outlet from Devils Lake. Projects (3) and (4) comprise North Dakota's vision for Devils Lake water level stabilization.

The Garrison Project origins go back to 1944 when Congress authorized the Flood Control Act, also known as the Pick-Sloan Missouri Basin Program. The major components of the Flood Control Act included flood control, navigation, water supply, recreation, hydropower and irrigation. Over the years the project,

which became known as the Garrison Project, has been modified many times. In 1965, Congress created the Garrison Diversion Unit legislation that, among other things, provided for irrigation of 250,000 acres, mainly on the side of the continental divide in the Red and Souris basins which flow north as part of the Hudson Bay drainage area.

Because of Canadian concerns about the portion of the Garrison Project which could affect waters flowing into Canada, both Governments referred the project to the International Joint Commission (IJC) in 1975 to make recommendations which might assist the Governments to ensure the provisions of Article IV of the Boundary Waters Treaty (BWT)<sup>3</sup> are met. Article IV states, in part, that "... boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other."

In 1977 the IJC issued its report to Governments and recommended that those portions of the project that affect waters flowing into Canada should not be built until biota transfer is no longer a concern (International Joint Commission 1977).

Environmental groups in the United States also had concerns about the Garrison project. Legal action by the National Audubon Society in 1981 resulted in a court injunction to stop construction until either Congress re-authorized the project or authorized an option for the project.

In 1986 the Reformulation Act was passed to help address a number of domestic and Canadian concerns about the Garrison Project. The Reformulation Act resulted in a significant change in the project including: (1) a reduction of the amount of irrigation lands to 131,000 acres, none of which were in the Hudson Bay drainage; (2) an increase in water supply for municipal, rural, and industrial purposes (MR&I); (3) a commitment that MR&I projects must be approved by the Secretary of State for compliance with the BWT after consulting with the Administrator of EPA and the Secretary of the Interior; (4) a requirement for a water treatment facility to treat Missouri water before it is moved to the Hudson Bay basin; and (4) a provision that requires consultation with Canada.

During the years following the 1986 Reformulation Act, North Dakota continued to push for passage of federal legislation that would allow for the completion of the larger Garrison Project. In December of 2000, their efforts culminated with the passage in Congress of the Dakota Water Resource Act (DWRA). The act authorizes (but does not appropriate) \$631.5 million to complete Garrison

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<sup>3</sup> The BWT of 1909 between Canada and the United States provides principles and mechanisms to help prevent and resolve water disputes along the boundary between the two countries. The IJC is an independent and impartial bi-national body that was established under the BWT as one of the mechanisms to help prevent and resolve disputes. The IJC has a number of roles under the BWT, including the investigation of specific issues or problems referred to it by the two governments, such as the investigation of environmental issues related to the Garrison Diversion project.

projects. The DWRA calls for a comprehensive study of water quality and quantity needs in the Red River Valley and options to meet those needs, including importing Missouri waters, to be carried out over the next three years.

While the DWRA does not provide for construction of Garrison projects, it moves the potential for a major interbasin transfer closer to reality and significantly undermines the protection provided to downstream interests in the 1986 Reformulation Act. Of particular concern to Canada is the elimination of reference to consultation with Canada and reducing federal oversight for development and operation of Garrison projects. The DWRA is also unclear on a number of significant issues, including the ultimate volume of water that may be transferred from the Missouri River basin to the Hudson Bay basin.

### **NAWS**

The Northwest Area Water Supply project (NAWS) is a \$165 M regional water supply project (Houston Engineering *et al.* 1997). Water would be pumped from Lake Audubon or Lake Sakakawea, in the Missouri basin, pretreated with chloramine, and pumped through a pipeline to the city of Minot, located on the Souris River (Hudson Bay drainage) where it would be treated to drinking water standards. Sixteen miles of the pipeline would be located in the Hudson Bay drainage. The amount of water pumped would be 10.2 million gallons per day (MGD) average flow with a peak flow of 28 MGD. From Minot the water would be distributed to 11 communities and 5 rural water supply groups.

As a MR&I project under the 1986 Garrison Reformulation Act, the Secretary of State must consult with the Administrator of EPA and the Secretary of the Interior to ensure that NAWS will not violate the BWT before the project can proceed. It is not yet clear how DWRA may affect the NAWS project.

### **Devils Lake Outlet**

Devils Lake is located in a closed basin in the semi-arid north central area of North Dakota (Figure 2). The 3,814 square mile watershed of Devils Lake is a hydrologic sub-basin of the Sheyenne River, which in turn is a sub-basin of the Red River. The lake would begin to spill to the Sheyenne River at an elevation above 1459, something that has not happened in nearly 1800 years.

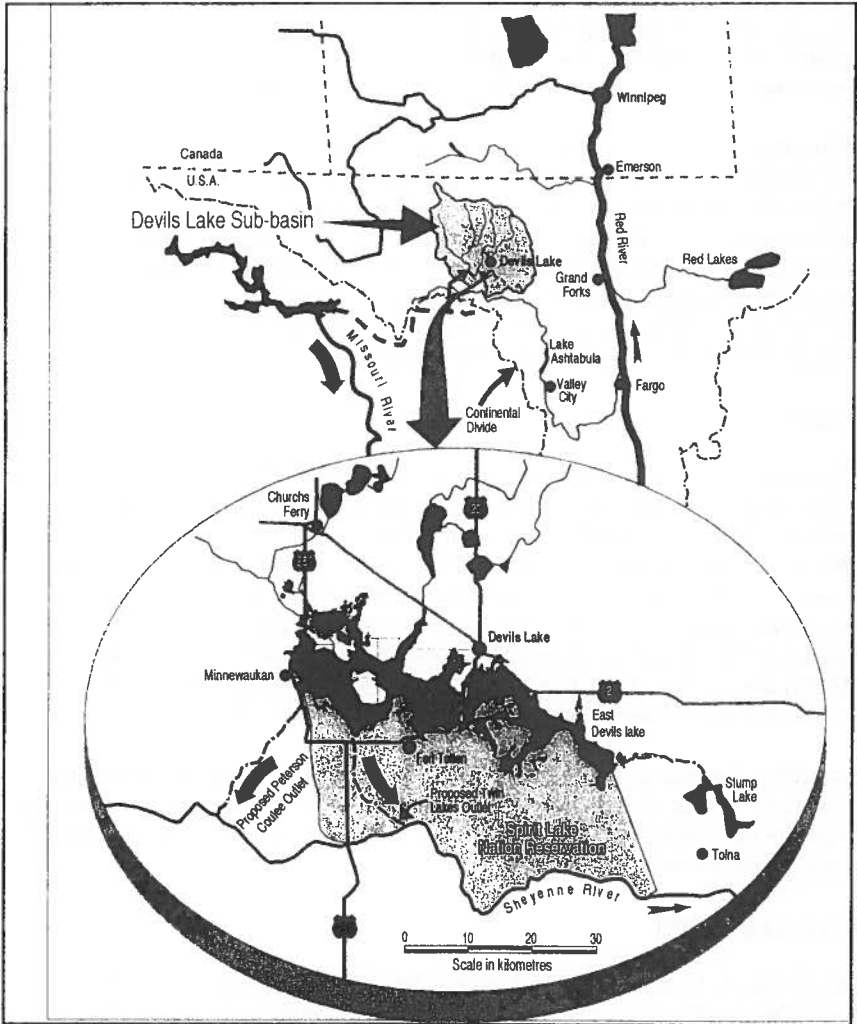


Figure 2: Proposed outlets to Devils Lake.

The lake has a long history of fluctuation (Figure 3). During the last 10,000 years, the geological record indicates that the lake was dry about six times and overflowed to the Sheyenne River also about six times, thus fluctuating over 60 feet in vertical elevation (Murphy *et al.* 1997). Of particular interest is the fact that water levels were also high during the late 1870s; a historical cairn in the centre of the City of Devils Lake shows the location where the ferry to Minnewaukan docked. Land development subsequently followed the shoreline as the lake receded. The lake was nearly dry in the 1940s and in the early 1990s.

Because of the lake's periodic low levels, the U.S. Army Corps of Engineers has investigated diverting water from the Missouri River basin to help stabilize the lake. However, when the lake started to rise in 1993, concerns changed from importing water to controlling the rising lake through, in part, construction of an artificial outlet to the Sheyenne River. Because the lake has not naturally discharged to the Hudson Bay basin for about 1800 years, an artificial outlet would represent an interbasin transfer.

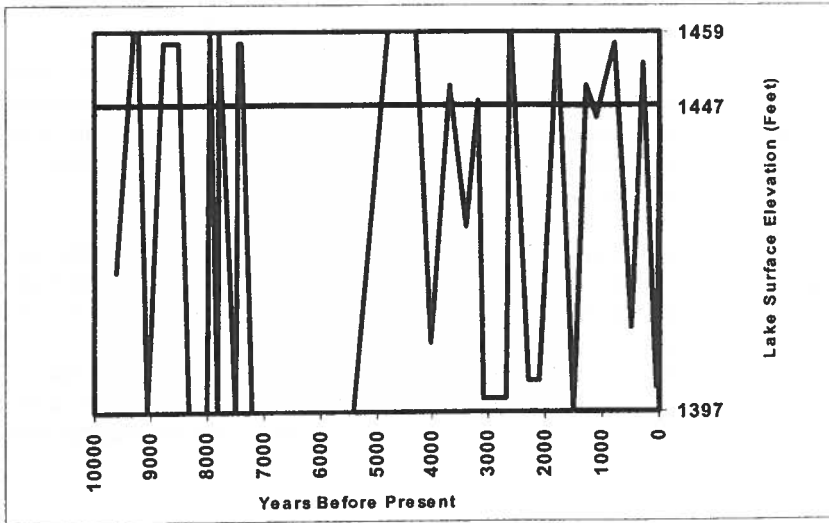


Figure 3: Historic water levels fluctuations in Devils Lake. At elevation 1397, the lake is dry, water begins to flow from Devils Lake to Stump Lake at about elevation 1447, and water begins to leave the Devils Lake sub-basin and flows to the Sheyenne River at about elevation 1459.

Since 1993 the lake has risen almost 25 feet, reaching an elevation of 1447.4 in the spring of 2001. During this period the lake has increased from about 70 square miles to nearly 195 square miles in size resulting in federal and state emergency spending of approximately \$300 million in relocation and infrastructure protection costs.

Devils Lake is naturally saline due to evaporative concentration with high levels of sulphates and total dissolved solids (TDS). During 2000, the TDS concentrations were approximately 1140 mg/L in West Bay and range to above 5000 mg/L in East Devils Lake. The lake also has elevated levels of arsenic, boron, mercury, and phosphorus.

To help mitigate the rising waters, the Army Corps of Engineers has been appropriated \$6 million by Congress to prepare an Environmental Impact Statement as well as undertake concurrent preconstruction engineering and design studies for an outlet. The water from the lake would be pumped 17 miles through pipelines to the Sheyenne River. The outlet is estimated to cost approximately \$100 million with a \$2 to \$3 million annual operating cost and will result in an annual reduction in water level of < 1 foot. This reduction would be achieved with a 300 cfs outlet that is constrained by downstream channel capacity and downstream water quality standards and objectives. More recently, the Corps has indicated it is also considering a 480 cfs outlet with no constraints in order to increase the draw-down of the lake in an attempt to make the project more viable. Such a project would not only violate water quality objectives at the international boundary but also the standards used by the state to protect its own citizens. The Corps is proposing to carry out these activities over the next two years with a final report to Congress in September 2002.

In 1997, 1998, 1999, and again in 2000, Congress established several conditions that must be met prior to any appropriation of construction funds. These include demonstrating that the project must be economically justified, technically sound, and environmentally acceptable and in compliance with the National Environmental Policy Act (NEPA) of 1969. The plans for an outlet shall also contain assurances provided by the Secretary of State, after consultation with the International Joint Commission, that the project will not violate the requirements or the intent of the 1909 BWT.

The State of North Dakota is also considering constructing its own emergency outlet. The state contends that the project is not subject to the NEPA process and will undertake its own environmental reviews. This is of major concern since Canada relies upon thorough Environment Impact Statements being conducted in full accordance with NEPA to determine compliance with the BWT rather than truncated or abbreviated assessments.

### DOWNSTREAM IMPACTS

Projects that result in interbasin transfer of water can have profound environmental, economic, and social implications both to the receiving basin as well as to the donor basin. Estimating the long-term impacts of diversion projects requires a comprehensive analysis that needs to include identification of all impacts in all basins, regardless of jurisdiction. The public needs to be actively and meaningfully involved in the assessment process.

In considering the economic viability of a project, projected water demands in the receiving basin must be scientifically and economically justified and simply not be an optimistic view that pre-determines one option over another. Too often projects are justified using methods that incorporate unlikely assumptions which



can result in erroneous forecasts. It is important that there be a true estimate of the economic demand where quantities of water withdrawals are a function of realistically-priced water supply and treatment, enhanced water conservation and efficiency programs, technical change, and other relevant variables.

In the case of the three North Dakota projects, it is imperative that the proponent not only consider the impacts within the state but also the potential impacts to downstream jurisdictions in both the donor and receiving basins to ensure a full accounting of a project implications. Some of the potential impacts that need to be considered are discussed below.

### Water Quality Impacts

Water quality impacts can be both direct and indirect. Direct effects are most easily predicted while indirect impacts are often difficult if not impossible to predict. Direct effects include the simple mixing of two volumes of differing quality. Impacts can be predicted for conservative substances such as major ions by simple modelling based upon conservation of mass. For example, preliminary modelling by Environment Canada indicates that during some years, water quality objectives established by the International Joint Commission at the Canada - US boundary on the Red River for TDS and sulphate would be exceeded by the addition of more saline waters from the proposed Devils Lake outlet. The sulphate objective would be exceeded for the first time and TDS would be exceeded more frequently and for longer periods. Such exceedances would contravene the BWT and would result in harmful impacts to water use in Canada.

Direct impacts from many substances that undergo various transformations are more difficult to predict. For example, the toxicity of many trace metals varies with valence states. As many metals move through aquatic systems, they can undergo considerable change, many of which are difficult to identify and to quantify.

Indirect water quality impacts are much more difficult to accurately predict. There are many examples of indirect water quality impacts that can occur from interbasin water transfers. It is well known that the toxicity of ammonia varies with pH and temperature. A slight change in pH due to the mixing of two waters of differing chemistry can potentially alter the toxicity of existing municipal and industrial effluents that contain ammonia. Similarly, the toxicity of many metals is related to hardness. Thus, reduction in hardness by the introduction of water with lower calcium and magnesium concentrations can increase the toxicity of existing or ambient metal concentrations in the receiving basin.

Other examples of indirect impacts from interbasin water transfers would include the dissolution of materials from newly flooded soils or from existing bottom sediments. Examples could include the well-known phenomenon of phosphorus

leaching into the water column from flooded soils. Once in the water column, phosphorus is one of the main plant nutrients that promotes the nuisance growth of rooted macrophytes and algae. Cultural or man-induced eutrophication is an important water quality issue facing much of North America, Europe, and elsewhere. Much work is underway by many water quality management agencies within the Great Plains region of central North America to better control contributions of phosphorus, nitrogen, and other plant nutrients to aquatic systems. Diversion of water from Devils Lake to the Red River systems, and subsequently to Lake Winnipeg, would provide an additional pool of phosphorus to an already nutrient-rich system.

### **Transfer of Aquatic Nuisance or Invasive Species**

Aquatic invasive or non-indigenous species are organisms that have moved beyond their natural geographical ecosystem. They may include fish, fish pathogens and parasites, invertebrates, and aquatic plants. When a new species or organism is introduced into an ecosystem, the economic and ecological consequences can be detrimental and irreversible (Mack *et al.* 2000, Morton 1997). For example, at the present time, there are 160 non-indigenous species in the Great Lakes (Muzinic 2000), a number of which were intentionally introduced such as the Pacific salmonids and rainbow smelt, while many others such as the zebra mussel, alewife, and European ruffe were accidentally introduced. While there is always the risk of some accidental introductions from man's activities, such as bait-bucket transfers, these forms of transfer present a relatively small risk compared to large-scale water diversion projects, especially where there are inadequate safeguards to treat the water. Conversely, bait-bucket transfers represent micro-scale water diversions and provide additional examples of the movement of aquatic nuisance species from one watershed to another. It was likely by this mechanism that the rainbow smelt was transferred from the Great Lakes watershed to the Winnipeg River and subsequently to Lake Winnipeg. In fact, the zebra mussel arrived in North America through a form of interbasin water transfer; the zebra mussel almost certainly was transferred from central Europe with ballast water.

However, governments in the U.S. and Canada are working jointly to minimize and eliminate many of these pathways that exist for accidental introductions. For example, in the western U.S. and Canada, the Western Regional Panel, established under the U.S. federal National Invasive Species Act of 1996, is establishing programs aimed at preventing the introduction of new non-indigenous species and at preventing the further spread of existing exotic species in the region.

Once introduced, non-native species are impossible or impractical to eradicate. Aquatic non-indigenous species can cause complex changes within their new environment as evidenced by the zebra mussel and many other species.

Populations of recently introduced non-native species often increase substantively until a new balance is reached in the aquatic system. Most non-native species have few natural predators within the new environment and, therefore, populations can expand quickly until other limits on growth or reproduction are reached. Changes to aquatic ecosystems can include a decline in the abundance of native species, extirpation of rare or endangered species, introduction of new diseases to native populations, alteration of the gene pool of native species, and reductions in reproductive success, genetic integrity, and biodiversity.

Interbasin water diversions can lead to the transfer of harmful aquatic species in a number of ways. These include direct transfer with untreated water, failure of treatment systems to inactivate organisms, increased connectivity between basins leading to greater risk of future transfers, or alteration of habitat in the receiving basin making successful colonization more likely. Increased connectivity is a critical issue since diversion of water from the Missouri basin to the Hudson Bay basin would then directly link most of the major watersheds in North America east of the Rocky Mountains. The Missouri River basin is already connected to the Great Lake system through previous diversions (*i.e.*, the Chicago Ship and Sanitary Canal from Lake Michigan to the Illinois - Mississippi river system).

Invasive species have been identified as one of the most serious environmental threats of the 21<sup>st</sup> century facing many regions throughout world (Mooney and Hobbs 2000 as cited in National Invasive Species Council 2001). Because of increasing concerns about the economic and ecological damage from invasive species in the United States, an Executive Order on Invasive Species was signed by President Clinton in February 1999 to help prevent further introduction and spread of invasive species. Among other things, the Order stipulates that Federal activities that could promote the introduction or spread of invasive species in the United States or elsewhere would not be authorized or funded unless the benefits outweigh the potential harm and all feasible and prudent measures to minimize risk are taken. Furthermore, the Executive Order directs all federal agencies to refrain from actions likely to increase invasive species problems both in the United States and elsewhere in the world. There are a number of fish species that occur in the Missouri River that are not found in the Hudson Bay drainage basin. These species include the pallid sturgeon, paddlefish, shovelnose sturgeon, shortnose gar, gizzard shad, Utah chub, smallmouth buffalo, and river carpsucker. Zebra mussels have recently been found in the lower reaches of the Missouri and are expected to invade upper reaches within the next several years. In addition, striped bass were stocked in Devils Lake in the late 1970s. This species is a large, aggressive predator that is not found elsewhere in the Red River basin. While no striped bass have been found in Devils Lake since the early 1990s, this species can live up to 35 years. If isolated fecund striped bass still survive in Devils Lake, release to the Red River basin and Lake Winnipeg could cause significant harm to the existing sport and commercial fishery. The International Joint Commission concluded in 1977 that the introduction of non-indigenous species of

fish from the Missouri River into the Hudson Bay drainage could result in 25-75% reduction in populations of commercially-valuable species in Lake Winnipeg.

In addition to harm caused by the transfer of fish species, considerable concern exists over the potential introduction of microscopic parasites and fish diseases. It is estimated that scientists have knowledge of only about 2% of fish diseases. Hence, even if an accurate and complete census of fish diseases were known in the donor basin, considerable uncertainty exists because of the lack of knowledge. It is known that the parasite responsible for whirling disease in trout and related species is present in the Missouri River but not yet in the Hudson Bay basin.

A technical review of the NAWS draft Environmental Assessment proposal by government agencies in Canada concluded in 1999: (1) there are currently no biological standards to prevent interbasin transfer of aquatic nuisance species; (2) the project was being designed to meet the 1989 federal Surface Water Treatment Rule (SWTR) as a minimum treatment requirement, but this rule cannot be met without filtration and use of both ozonation and chloramination; (3) there is a potential for high levels of trihalomethanes (THMs) at Minot that could reduce the amount of chloramine used in the pretreatment, thus increasing the risk of future failure; (4) alternatives to interbasin transfer are available; (5) at a minimum, the project should be built to the current standard required for public health facilities before water is moved to Hudson Bay. As well, the project, as any public water supply project, should be continually upgraded as knowledge and technology increases.

As in any engineered system, it is expected that sometime within its lifetime, failure will occur. A brief search revealed over 200 failures of drinking water treatment systems in the United States that resulted in human illness; about 75 of these occurred during the 1990s despite regulated monitoring requirements. Thus, the NAWS project poses significant risk of transfer of biological organisms from the Missouri River basin to the Hudson Bay basin sometime within the foreseeable future.

### **Water Quantity Impacts**

Two general types of water quantity impacts can occur. The first is a shift towards an increase in potential flooding problems in the receiving basin accompanied by an increased vulnerability for insufficient water supply in the donor basin. For example, the lower Missouri states have long expressed concern about the potential impacts on supplies for drinking water, municipal and industrial uses, recreation, fish and wildlife habitat, navigation, and commerce if water is diverted out of the basin.

The second type of impact can occur to biological communities. Biological communities in aquatic systems have evolved within existing variability. In many cases, interbasin water transfers would tend to reduce system variability. Changes in system variability could also result in shifts in the biological community since some species co-exist because of frequent disturbance. Reduction in disturbance would increase the importance of other factors that control populations, thus potentially changing species composition within the community and altering system function. This is a well-known phenomenon within ecological communities and involves shifts from communities comprised of organisms with life history strategies adapted to density-independent factors to communities structured by other factors in a less variable habitat (May 1986, Sousa 1979).

### **Biological and Ecosystem-Level Impacts**

Impacts or changes to biological systems become more difficult, and in many cases, impossible to predict especially at upper trophic levels, yet often result in the most profound system impacts (Hecky *et al.* 1984). Ecosystem-level impacts are most difficult to predict because they often involve changes in the behaviour of individual species. There are many examples of such changes, and include for example, the re-distribution of persistent organics into waterfowl once they shifted feeding behaviour to take advantage of zebra mussels in shallow regions of the Great Lakes and the increase of mercury in piscivorous fish species in the Great Lakes once they began to feed on the introduced rainbow smelt.

### **Issues Related to Transboundary Impacts and Environmental Justice**

In accordance with the 1972 Stockholm Declaration on the Human Environment and Principle 21, it is becoming more common to consider transboundary impacts and issues of environmental justice during environmental impact assessments. Environmental justice, for example, relates to the need for all parties to have equal access to the decision-making process and that disbenefits are not borne disproportionately by one population while benefits accrue to another. In the case of interbasin water transfers from the Missouri River basin to the Hudson Bay basin, it is clear that benefits of the water development projects would be realized by the residents of North Dakota, but impacts would be borne by downstream jurisdictions in both the United States (*e.g.*, Missouri, South Dakota, Minnesota) and Canada. This issue becomes even more complex when two sovereign nations are involved, as in this case. The international nature of the issue makes access to the legal and political decision-making process in the United States difficult for Canada, but access is important since Canada would bear most if not all of the project's disbenefits. A related issue of not only environmental justice but legal obligation under the both customary international and the BWT, involves the matter of responsibility and compensation should unpredictable consequences occur. In the case of the introduction of non-indigenous species, it is extremely

unlikely that mitigation and compensation could be decided in a manner that is fair and just, given the irreversible nature of the damages.

### SUMMARY AND CONCLUSIONS

The diversion of water between previously unconnected basins has been used in the past to meet real or perceived water shortages, to provide hydroelectric power production, to assist with navigation, and to provide relief from flooding. In recent years, a more mature environmental ethic has evolved both due to an improved scientific understanding of the consequences of interbasin transfer, many of which are irreversible, and to the major world-wide threat posed to aquatic systems by non-indigenous aquatic nuisance species. Despite these advances, two Garrison projects are being proposed in the State of North Dakota that would divert water from the Missouri River basin to the Hudson Bay basin, and one project proposes to move water from the Devils Lake closed basin to the Sheyenne, Red, and Lake Winnipeg systems. Environmental impacts and associated economic and social consequences from interbasin water diversion projects are difficult if not impossible to predict, and could range from (1) direct water quality impacts; (2) indirect or secondary water quality consequences, changes expressed in biological communities at the ecosystem level; (3) increased vulnerability to flooding in the receiving basin; and (4) increased vulnerability to water shortages and even drought in the donor basin. One of the major potential consequences of interbasin water diversions involves the movement of unwanted, harmful biological species from one basin to another. Proposed water diversions from the Missouri River basin to the Hudson Bay basin and from Devils Lake to the downstream Red River watershed also involve issues of international environmental law and justice; the benefits accrue to one jurisdiction, while the impacts accrue largely to another sovereign jurisdiction. Because international law and specifically, the BWT provides no clear remedies for damages to Canadian aquatic resources that may result from the proposed interbasin water transfers, the precautionary principle - a principle gaining wide acceptance in contemporary environmental management decision-making throughout North America and Europe - should prevail given the potential irreversible impacts. The environmentally - responsible approach from both a domestic and international perspective is to seek in-basin solutions to Devils Lake flooding and water needs in the Souris and Red river basins in North Dakota.

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## TRANSBASIN ASPECTS OF THE GARRISON DIVERSION PROJECT

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### ABSTRACT

The Garrison Diversion Unit (GDU) is a proposed transbasin diversion water project, located in North Dakota, which may transfer water from the Missouri River Basin and the Red and Souris Rivers. The project leads to international implications as the Red and Souris Rivers flow into Canada and eventually into the Hudson Bay as it flows northward. The purpose of this paper is to describe the project and the concerns, issues, problems, studies and proposed solutions, which have evolved during its long history as they relate to transbasin diversion of water.

The Flood Control Act of 1944 provided for the development of flood control, hydro power, irrigation, and navigation features in the Missouri River Basin. It was guided by the Pick-Sloan Plan, one of the most comprehensive river basin plans developed in the United States. The Act authorized, among other projects, construction of the GDU, which initially was proposed to develop over one million acres for irrigation in North Dakota. However, changing conditions resulted in a reauthorization in 1965, which provided for 101,000 hectares (250,000 acres) of irrigation as a first phase.

Growing concerns with the environment, land acquisition, economics and trans-basin transfer into the Hudson Bay Basin in Canada precipitated a study by an appointed GDU Commission, which resulted in a project reformulation in 1986. This reformulated project reduced the proposed irrigation development to 52,610 hectares (130,000 acres) by eliminating the proposed irrigation development in the Red River Basin. It also authorized additional funding for the construction of municipal, rural and industrial water service facilities in North Dakota.

The Dakota Water Resources Act (DWRA), a revised Garrison Project which amends the 1986 Garrison Diversion Reformulation Act, was initially introduced

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into Congress in 1997 to meet the contemporary water needs of North Dakota by authorizing municipal, rural, and industrial water projects, natural resource and recreation development, and providing water to the Red River Valley. It does not authorize funding for irrigation development. The DWRA was passed by Congress on December 15, 2000, and then signed by the President.

There are several issues concerning transbasin transfer of water embodied in the history of the GDU. The Province of Manitoba, and the state of Minnesota, have raised major objections to the project over concerns of unwanted "biota transfer". Numerous attempts and millions of dollars have been expended to alleviate their concerns, which remain elusive and ever-changing. One of their first concerns in the early 70s was the danger of trash fish (fish and fish eggs, disease, and parasites) being transferred and also the degradation of water quality; this was followed by an added concern of "virus" transfer. These concerns were addressed first by the development of a very fine screening process for all diverted water and later with the offer to disinfect all transferred water with ozone and/or chloramine. Tests showed that the disinfection processes was 99.99 percent effective. The trend seems to be that each solution by project sponsors is met with another new problem from Canada. Whirling disease in fish is one of the latest problems suggested by the Canadians as a biota transfer concern. These are listed as concerns without regard to the degree of risk that actually exists. As reported in an unpublished manuscript *Science and Policy: Inter basin Water Transfer of Aquatic Biota*, risk assessment studies and a review of the historical and geological fish distribution data have shown that the natural process has a much greater risk for biota transfer than planned project activities.

Considering those concerns, it is ironic that Canada has developed and implemented numerous transbasin diversion projects, some of which have flows in the magnitude of  $45\text{m}^3/\text{sec}$ . (1,575 cfs) compared to less than  $8.6\text{m}^3/\text{sec}$ . (300 cfs) for DWRA planned flows. It is logical to believe that the much lower flows contemplated for the DWRA will pose almost an insignificant threat for biota transfer compared to those transbasin flows being proposed in Canada.

It has become apparent that the foundation for biota transfer concerns is primarily a political position, which is not supported by scientific data. Concluding remarks of Canadian representatives confirm this when stating, "It is not the known, but the unknown that concerns us." This is in contrast to the requirements of the Boundary Waters Treaty (BWT), which under normal and historic circumstances presume some real and present threat or evidence of injury to the other's waters should be found before a serious claim under the BWT is made.

The fundamental effect of this type of resistance or efforts to ban transbasin diversions of any kind, under any circumstances, promotes an international abyss and a barrier to cooperation within the regions on many fronts. In the opinion of the authors, it makes it more difficult to foster the cooperation that both countries

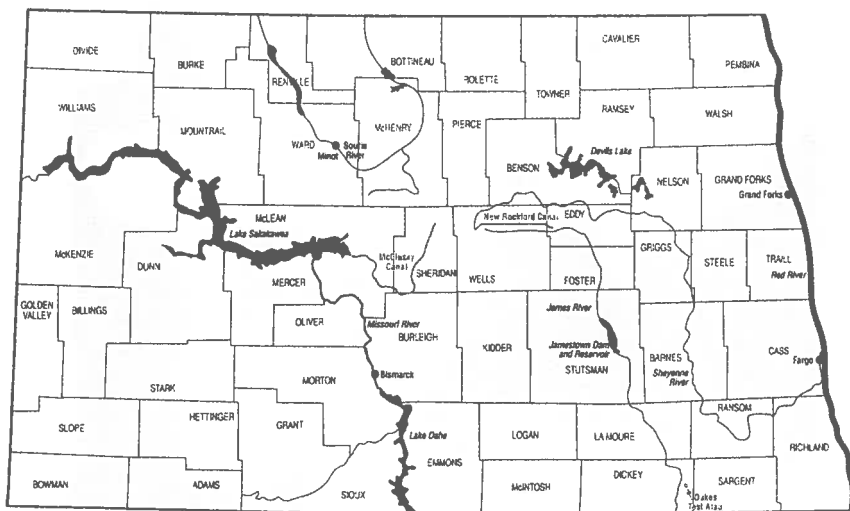
need in order to go forward on a variety of issues critical to their respective futures.

## INTRODUCTION AND BACKGROUND

### Introduction

The purpose of this paper is to describe the Garrison Diversion Unit (GDU) Project in the state of North Dakota and the concerns, issues, problems, studies and proposed solutions, which have evolved during its long history, as they relate to potential transbasin diversion of water. The GDU was authorized by the Flood Control Act of 1944, which was passed for the primary purposes of flood control, navigation, irrigation, and hydro power production.

North Dakota's most reliable and high quality water supply is the Missouri River, which flows through the southwestern part of the state. However, two thirds of North Dakota's population is in the Red River Basin in the eastern part of the state, which has an inadequate water supply during drought cycles. Consequently, the transfer of water from the Missouri River Basin to the Red River Basin is one of the options to meet the contemporary water needs of North Dakota (See Figure 1).



The GDU Project has evolved from an irrigation project, which proposed to irrigate more than one million acres in 1944 to a municipal, rural, and industrial (MR&I) water supply project in the 1990s. The water needs have been reduced dramatically; however, the potential need for transbasin transfer still exists to fully develop North Dakota's water resource. This concept was first mentioned in the North Dakota State Constitution prior to 1906.

The project has international transbasin implications, as the Red and Souris Rivers flow into Canada and eventually into the Hudson Bay on its journey northward (See Figure 2). Canada and the Province of Manitoba have historically objected to the transbasin diversion of water, which has resulted in major roadblocks and problems in completing the Garrison Project despite many honest efforts and extensive funding by the United States. Primarily because of this transbasin transfer issue, the project has a very long, tortuous history and has never been completed.

The following discusses the background and history of the project, along with problems, roadblocks, probable solutions and issues relating to the possible transbasin diversion of water.

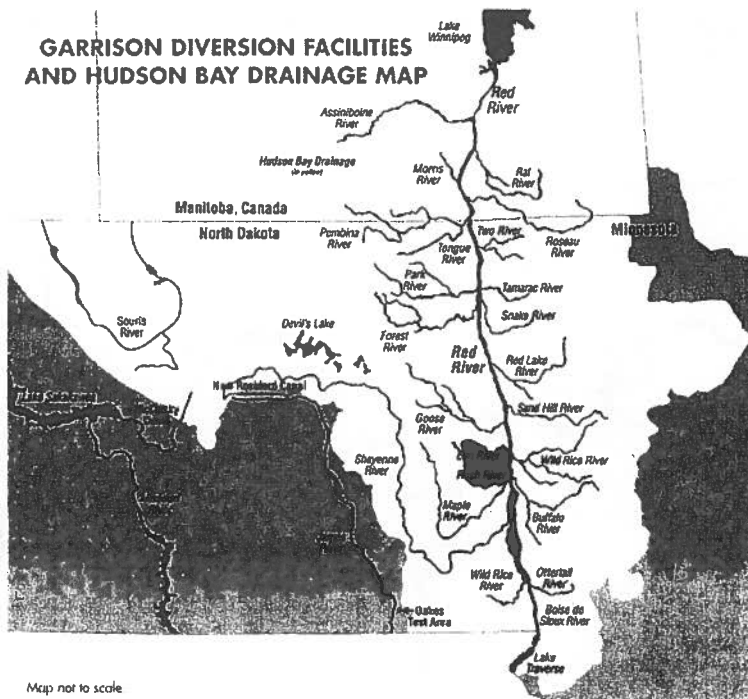


Figure 2 - Red River drainage area

## **Project Background**

Disastrous floods in the early 1940s and the need for economic development precipitated the need for the development of the water resources of the Missouri River. The Bureau of Reclamation (Reclamation) and the Corps of Engineers collaborated on a study, which resulted in the writing of the Pick-Sloan Plan, one of the most comprehensive river basin plans in the United States. The Flood Control Act of 1944 authorized many facets of the Pick-Sloan Plan, including the construction of six major dams on the main stem of the Missouri River along with the GDU. The Act authorized these projects for the primary purposes of flood control, irrigation, navigation, and hydro power generation.

The six dams constructed on the main stem of the Missouri River are: Fort Peck Dam in Montana, Garrison Dam in North Dakota and Oahe, Big Bend, Fort Randall, and Gavins Point Dams in South Dakota. The reservoirs formed behind two of these dams, Garrison and Oahe, have inundated 222,580 hectares (550,000 acres) of prime North Dakota farmland. About 95 percent of North Dakota's water supply is available in the Missouri River, which is a high quality and reliable supply of water. Consequently, transbasin diversion of water from the Missouri River is a realistic solution for providing an adequate water supply to the Red River Basin.

This has been a concept since the early 1900s when the first attempts were made to study this problem; however, no projects to divert transbasin water were seriously contemplated until the GDU Project was authorized in 1944. This issue, however, was indirectly addressed with the passage of the "Boundary Waters Treaty of 1909 (BWT)". Article 4 of this Treaty provides "that neither country will take any action which will cause water pollution resulting in harm or injury of health or property." The International Joint Commission (IJC) was established for the purpose of resolving disputes over the terms of the BWT; it has repeatedly ruled that the Treaty's intent was not to preclude development of natural resources.

The GDU was authorized to develop irrigation on over one million acres of land in North Dakota in the Missouri, Souris and Red River Basins in part to mitigate the farmland inundated by those reservoirs. Between 1944 and 1965, surveys and studies were performed to assess the feasibility of irrigating this land using Missouri River water. Results of those studies and other factors changed the project significantly, and reauthorization was required before development could begin. In 1965, legislation was passed, which authorized initial irrigation development of 101,000 hectares (250,000 acres), municipal and industrial water development, fish and wildlife development and recreation. Construction of the principal supply works was started in 1968 and continued until the mid 1980s, when it was halted because of environmental issues, private land acquisition, economics of irrigation, and Canadian concerns about transbasin transfer of water

from the Missouri River to the Red and Souris River Basins. The amount of water proposed for transfer at that time was about 2,000 cfs.

The matter was referred to the IJC in 1975, and in 1977 they issued their report entitled "Transboundary Implications of the Garrison Diversion Unit". The Conclusions and Recommendations in that report were based upon an analysis completed by the International Garrison Diversion Study Board wherein they examined whether or not the Garrison Diversion Project, as planned at that time, would violate the terms of the BWT. The Study Board report contained a series of recommendations including one that recommended the project be modified to eliminate any direct transfer of fish, fish eggs, fish larvae and fish parasites, and to reduce the risk of transfer of fish diseases to the Hudson Bay drainage.

Fish screen research was subsequently conducted by the Bureau of Reclamation, and a prototype fish screen facility was tested using Missouri River water. Four years of testing showed conclusively that the screening facility was capable of removing all viable fish, fish eggs, fish parasites and larvae from the project water. A fish screen structure, which has not been used, was also constructed in the McClusky Canal for the installation of screens.

In 1984 the National Audubon Society, an environmental organization, caused legislation to be introduced in the US Congress, which became Public Law 98-360 and established the GDU Commission to conduct an independent review of the project. The Commission was appointed by the Secretary of the Interior in 1984 to recommend changes of direction for the project. In their December 20, 1984, report, the Commission, after considering the IJC report and other related information, recommended development of the GDU significantly different from the project described in the 1957 feasibility report and the project authorized in 1965. The major recommendations relating to the transbasin concerns were:

- \*Proposed irrigation development reduced from 101,000 to 52,610 hectares (250,000 to 130,940 acres), none of which would be in the Hudson Bay drainage. (In the meantime, irrigation development continued unabated in Manitoba.)

- \*Construction of a water treatment facility to treat Missouri River water that would be transferred into the Hudson Bay drainage to comply with the BWT

- \*Designation of the Lonetree Reservoir site as a Wildlife Management Area

- \*Authorized the transfer of 2.8 meter<sup>3</sup>/sec (100 ft<sup>3</sup>/sec) to the Red River Valley for municipal, rural and industrial purposes, a relatively small amount of water compared to most transbasin transfers.

\*The Secretary of Interior may authorize delivery of water to the Hudson Bay drainage only after the Secretary of State and the Administrator of the Environmental Protection Agency have determined that adequate treatment has been provided to meet the requirements of the BWT

Clearly, the modifications more than met the recommendations of the 1977 IJC report. After review of the newly authorized project, the Canadian government delivered Diplomatic Note No. 201 dated March 26, 1985. The note stated that the plan provided by the Commission, "as a package does not pose a threat to Canadian waters and, once approved by Congress, should resolve a longstanding problem on the Canada-United States agenda." We can only imagine that officials in the United States believed the message contained in Diplomatic Note No. 201 and heaved a sigh of relief as the 1986 Act passed, believing that at long last they had resolved the issue. It proved to be a premature sigh.

Among the activities that followed passage of the Act was the preparation of a Draft Environmental Impact Statement (DEIS) for the reformulated project. The release of that document prompted yet another Diplomatic Note No. 177 from the Canadian government, which expressed additional concerns beyond those previously considered and addressed in the IJC report; thereby reversing their previous position and raising the question of when can we believe their diplomatic statements.

In addition to the preparation of the DEIS in 1987, the Bureau of Reclamation, the North Dakota State Water Commission and the Garrison Diversion Conservancy District began contributing funding to an independent research effort to determine the potential impacts of a transbasin diversion as recommended by the GDU Commission. From 1987 to 1995, twenty studies were conducted involving scientists from both the United States and Canada. An unpublished draft manuscript of the studies reports that the species previously identified as species of concern are either already in Lake Winnipeg or cannot survive in the Hudson Bay environment. One study concludes that the risk of biota transfer is much greater from bait bucket transfer and fish hatchery operation than from the proposed Garrison Project.

Nevertheless, in response to Diplomatic Note No. 177, the two governments, acting through a consultative group, established a Joint Technical Committee, (JTC) on September 26, 1989. In 1994 the JTC, while studying the Northwest Area Water Supply project, determined that .. "If actual studies demonstrate that Giardia and viruses can be inactivated to levels required for drinking water (i.e., 3 log inactivation for Giardia and 4 log inactivation for viruses) at the Continental Divide, then the water can be considered adequately treated for purposes of mitigating biota transfer."

Tests were conducted to determine whether or not two specific proposals for disinfection would meet the standard. Both tests successfully met the standards. Nevertheless, the Canadian government continued to oppose the transfer of water into the Hudson Bay drainage for reasons not previously expressed. This time the concern was expressed in terms of an unknown species with unknown impacts. They suggested that the United States should meet yet undeveloped standards. The target was moving so fast that United States officials were given to questioning the sincerity of the process.

In 1997 the Dakota Water Resources Act (DWRA) was drafted to again pursue legislation which would meet the identified water needs of the state. The DWRA is a new authority and direction for the Garrison Project, one purpose of which is to address the concerns of Canada in a responsible manner. The major provisions of this legislation were state MR&I, Red River Valley MR&I, and Indian MR&I water development, in addition to natural resource and recreation development. This legislation has been pursued persistently since 1997, and on December 15, 2000, it was passed into law as the "Dakota Water Resources Act". Technical and environmental studies will continue to support this legislation, along with environmental assessments for this work.

### **TRANSBASIN DIVERSION UNDER THE DAKOTA WATER RESOURCES ACT OF 2000**

#### **Red River Valley Water Supply Needs Study**

The DWRA calls for a study of the means to meet the water supply needs of the Red River Valley and if the recommended means of meeting that need involves a transfer of Missouri River water to the Hudson Bay drainage, the Secretary of Interior is to submit the report to Congress for approval before proceeding. The studies will include a comprehensive evaluation of present water uses and possible conversion, conjunctive use of surface and groundwater, conservation, desalinization, treatment and other appropriate issues. The complex issues of the Corps of Engineers on Devils Lake and Lake Ashtabula projects will also be addressed relative to their combined impacts on this project.

A Programmatic Environmental Impact Statement (PEIS) is being considered to address all broad issues at an early date, along with another PEIS relating to specific project conditions. An economic evaluation will also be made to determine financial viability of the project.

The alternatives will consider three broad categories: 1) no action, 2) inbasin and 3) transbasin.



The no action alternative analyzes the possibility of no further federal funding. It will look at the existing capabilities and options available to the State and local communities as well as the impacts of the limitations that this alternative naturally imposes on the region. This alternative will serve two very important purposes. One purpose is to define the problem and the other is to establish the need for federal involvement. Whenever a program is proposed in Washington, one of the first questions to answer is "What is the federal interest? This will establish the need for federal assistance or not."

The inbasin alternative, analyzes the options and impacts of meeting the water supply needs from inbasin resources. This option will include a look at an aggressive conservation program, the potential for reclamation of saline and/or waste water sources, as well as the potential for the conversion of existing uses such as irrigation water to municipal use. Because this option could eliminate the need for transbasin transfer of water, some may be tempted to rush to a judgement on this option. For purposes of this analysis, all reasonable options will be thoroughly analyzed on an equal footing.

The transbasin alternative would result in a transfer of Missouri River water to the Red River Valley. The water crossing the divide between the Missouri River drainage and the Hudson Bay drainage will be treated to the level necessary to assure that injury does not occur to downstream receiving streams and uses. A thorough examination will need to be conducted to determine how any plans for routing Devils Lake flood waters into the Sheyenne River would have on any means of meeting the water supply needs of the Red River Valley.

### **SPECIFIC CONCERNS EXPRESSED BY CANADA**

Perhaps some sense can be made out of this matter by discussing some of the Canadian's specific objections to the DWRA as we understand them. Following are objections along with our response to each, which seem to be the most prevalent.

- ★ The DWRA is not specific about what project or features might ultimately be authorized.

The DWRA provides for a full-scale investigation into options other than the transfer of Missouri River water. We are currently evaluating and will continue to evaluate the technical, economical and environmental feasibility of other inbasin alternatives. This opens up the possibility that no transfer will be necessary. This is different than past plans, which guaranteed an transbasin transfer.

- ★ The DWRA does nothing to reduce the significance of the potential for biota transfer.

The maximum amount of water required under the DWRA is very small compared to that originally proposed for the Garrison Project. The water required for the original Garrison Project was about 3 million acre feet as compared to that required for the DWRA, which is only 72,000 acre feet.

- ★ The DWRA does not include a requirement to consult with Canada or other process safeguards that are presently part of the GDU Reformulation Act.

The following language is included in Section 1 of the DWRA, "Prior to construction of any water systems authorized under this Act to deliver Missouri River water in the Hudson Bay basin, the Secretary, in consultation with the Secretary of State and the Administrator of the Environmental Protection Agency, must determine that adequate treatment can be provided to meet the requirement of the BWT". The timing of consultation to determine compliance with the BWT was changed from "prior to delivery of water to prior to construction of facilities". It is clear that amendments (DWRA) to the 1986 Act provide greater protection and assurance rather than less. The feature of concern at that time was the Lonetree Reservoir, and it no longer requires consultation because it was taken out of the project. The timing of consultation to determine compliance with the BWT was changed from "prior to delivery of water" to "prior to construction". It is hard to imagine how these changes are harmful to Canadian interests. This should alleviate Canadian concerns relative to timing.

- ★ The DWRA assumes that the focus on MR&I water supply rather than irrigation eliminates much of the objection to transbasin transfer—this is not the case since the risk remains due to pipeline breaks, failure of treatment systems, etc.

The shift to MR&I water supply was viewed by the project sponsors as an action that would remove much of the objection to the project. This appears logical simply from the viewpoint of the amount of water now proposed for transfer for MR&I is 40 times less than that originally proposed for irrigation. The shift of the focus from irrigation to MR&I is a major concession by project sponsors to what have proved to be unfounded and exaggerated fears. The concession by North Dakotans to give up the irrigation portion of the GDU is major in terms of emotions and potential benefits. They are deprived of major potential agricultural benefits, while irrigation continues to proliferate in Manitoba. In fact, since the IJC study, irrigation acres in Manitoba has increased by over 100

percent. In any case, the potential harm from the reformulated MR&I project is logically lower.

- ★ The DWRA includes the authority for an inlet and outlet on Devils Lake as a project feature.

The DWRA specifically deauthorizes a study of the Devils Lake area that addresses stabilized lake levels through an inlet or outlet.

## CONCLUSIONS

Movement of water between Canada and the United States is governed by the BWT, which stipulates quite simply that water movement across the borders will not result in harm to either country. The full development of North Dakota's water resources depends strongly on transbasin water diversion from the Missouri River to the Hudson Bay drainage basin for the Northwest Area Water Supply Project and, likely, the Red River Valley components of the Garrison Diversion Project. The District has shown good faith to Canada by explicitly eliminating the authority for an inlet and outlet to Devils Lake from the Garrison Project.

The BWT specifically states "waters herein and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other side". While North Dakota is in full agreement on this language, the Canadian government apparently is not. Their only acceptable position has been of "no risk". This exceeds the wording of the Treaty and is untenable to North Dakota. The Canadian position is not a requirement of the Treaty and limits any progress in resolving the issues.

A large number of transbasin diversions that exist today are in Canada. Ironically, the Great Lakes issue of greatest concern in recent years has been a proposal by Canada to export water from the Great Lakes not to the neighboring water basin, but to another country for profit.

Logical solutions to identified or potential problems are usually met by a requirement from Canada for more studies on "as yet unidentified issues". It is clear that potential biota transfer, resulting from transbasin diversion of water has become an emotional and political issue in Canada rather than a technical problem that has a finite solution. A new fish, a new disease, a new treatment, have all been used to delay the North Dakota project. To say that most North Dakotans are frustrated with the Canadian objections would be an understatement.

It is somewhat ironic that the intent of the Dakota Water Resource Act was to analyze thoroughly the best means to meet the water supply needs of the Red

River Valley. We should not prejudge the outcome. The preferred means for meeting those needs is not known. Lets not prejudge them before the facts are in.

The District recognizes a legal and ethical commitment to Canada to assure that biota transfer will not harm Canada's water resources and feels that all practical measures have been taken and will be to protect Canada's waters in pursuit of its much needed water resource development.

It is critical to the future of North Dakota that its water resource is effectively developed; this includes providing a high quality, reliable water supply to the Red River Valley. We are also sincere in our efforts to implement all practical measures to prevent harm to Canadian water resources.

It is our hope that the Canadians realize the sincerity and persistence by North Dakota and allow the analysis to proceed in a timely manner. The BWT recognizes the right of each country to develop its water and other resources, and we, in North Dakota, view that as a basic right that we will not relinquish. Nowhere on either border has a dispute of this nature been framed as a concern about an unknown species with unknown impacts.

An off-handed comment by one of the Canadian officials may be the key to resolution. He asked why should Canada settle at all? We (Canada) are exposed to the risk however small, and we get nothing for it. The answer to that question is simple. A continuation of the bitterness associated with this issue will further separate a region that needs to work in cooperation. Cooperation on issues of commerce are vital to each country's future and the required cooperation is made more difficult by allowing this issue to fester.

## WATER DEVELOPMENT ISSUES IN THE COLORADO RIVER HEADWATERS

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### INTRODUCTION

The Denver Board of Water Commissioners believes that cooperative arrangements with metropolitan water suppliers outside Denver's service area is good public policy and may provide benefits to its own customers. Accordingly, the Board's 1996 Resource Statement directs Denver Water staff to evaluate cooperative water development proposals by other metropolitan area water suppliers based on certain criteria. One such criterion requires that the proposing entity gain acceptance for a water development proposal, including appropriate mitigation measures from those who might be impacted by the proposal. This paper reviews criteria to be considered for cooperating with entities outside Denver's service area and discusses some of the water supply issues, potential impacts and mitigation opportunities associated with developing water from the Colorado River headwaters for use in the Denver metropolitan area.<sup>1</sup>

#### Transition To Current Cooperative Policies

In 1918, the citizens of Denver elected to purchase a water system and create, by Charter, a five-member Board of Water Commissioners. Since that time there have been abundant opportunities for changes in the service area and conditions for service that the Board was willing to assume. But in 1991, the Environmental Protection Agency's veto of the proposed 1,100,000 acre-foot Two Forks Reservoir served as perhaps the decisive event in the Board's transition to its current policies.<sup>2</sup> Until the veto, raw water development at Denver Water was relatively predictable and effective. It consisted of estimating future demand, then building the structural projects necessary to capture, store, convey, treat and deliver water to meet those increasing demands. Under that mode of planning, the Board was willing to assume a larger responsibility for the area it was willing

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<sup>1</sup> For the purpose of this paper, the Colorado River headwaters are defined as the Colorado River and its tributaries upstream of the U.S. Geological Survey gage "Colorado River at Kremmling." This area encompasses all of Summit and Grand counties.

<sup>2</sup> One acre-foot (af) is a volume of water equal to one foot in depth covering an area of one acre, or 43,560 cubic feet. There are approximately 325,851 gallons in an acre-foot. Roughly two-thirds of an acre-foot serves the needs of a typical family for a year. One acre-foot equals 1,234 meters<sup>3</sup>.

to serve. The federal veto for a locally-sponsored project caused the Board to reexamine its water service mission.

In 1992, then Denver Water Board President, Hubert A. Farbes, Jr., made the following statement:<sup>3</sup>

“Denver’s role in developing any new projects will focus on protecting and developing its water rights to meet future needs of Denver citizens and suburban residents of Denver’s contract service area. Denver will still need to develop new water supplies—but only to bridge the gap between its current water reserves and the reasonably expected needs for ‘build-out,’ over the next 30 to 50 years, of the center city and its contract service areas.

Denver’s Water Board will continue to cooperate with others who initiate new water supply proposals... Denver’s system is... the ...most important component of any major water development proposal for the metro area; and we will continue to make Denver’s system work for the benefit of others so long as Denver’s rights, requirements, and abilities to develop water for its own citizens and service area are not impaired.”

Thus, Denver Water would focus its energies on serving its service area and furnish water supplies to other entities where it was beneficial to Denver’s customers.<sup>4</sup> The Board’s position raised a number of questions: What were the current and future demands of customers in Denver’s service area? How much additional supply did Denver need for buildout of the service area?<sup>5</sup> How could Denver successfully pursue developing those supplies? What would be the best approach to accomplish its goals? And what policies should govern uses of resources outside the service area?

### **Integrated Resource Planning**

To answer these questions Denver Water staff began working in 1993 on a long-range planning effort using the process and techniques referred to as Integrated Resource Planning (IRP). As opposed to focussing on a single project such as construction of a new reservoir, the IRP process uses a broad-based approach to water supply and demand management (conservation) planning. The basic result

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<sup>3</sup> Hubert A. Farbes, Jr., A New Path. 1992.

<sup>4</sup> The Board’s full geographic service area, sometimes referred to as the combined service area, consists of the City and County of Denver and the Board’s existing contract distributors in areas surrounding Denver. Approximately 50% of Denver Water’s service area is outside of the City and County of Denver boundary.

<sup>5</sup> Buildout (or Build-out) refers to the circumstance where the Board’s service area is fully developed. Denver Water’s ultimate supply needs are to provide for buildout of its combined service area.

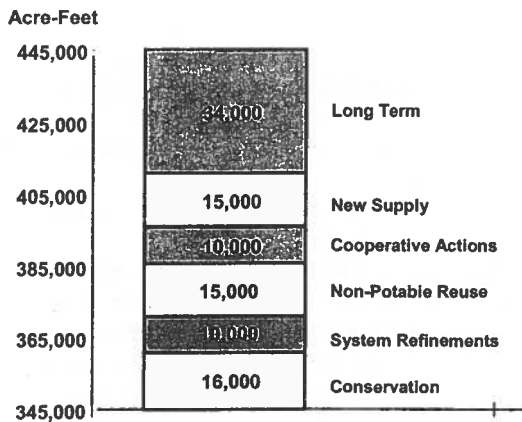
of this process is information that can be used to make reasoned decisions among resource options.

By 1997, the IRP process provided some essential information. It was established that the Board's existing system could reliably provide 345,000 af of supply, whereas the existing demand of its service area is 265,000 af. In other words, the Board has an 80,000 af surplus. However, to fulfill its obligations to buildout demand of the service area, projected to occur in about 50 years, Denver will need to develop an additional 100,000 af of water as outlined below:

Water Supply (1997)	345,000 af
Future Additional Supply Needed	70,000 af
Safety Factor <sup>6</sup>	<u>30,000 af</u>
Buildout Supply	445,000 af

In the IRP process, over 200 options were examined to meet the supply shortfall including conservation, enlarging existing reservoirs, constructing new reservoirs, groundwater development, new river diversions, and non-potable reuse. Conservation, non-potable reuse of effluent, and small-scale system refinements were identified in the IRP as the best methods for efficiently using Denver's water supplies for meeting future water demands in the near term. The Board committed to the following combination of demand management and supply options:

### Near-Term Strategy



<sup>6</sup> The Board maintains a safety factor to protect against risks the Board faces in meeting its customer needs. Risks include catastrophic events, unexpected buildout demand, lower than expected yields from its system, and longer than anticipated drought.

As shown, the Board anticipates developing 10,000 af of new supply through cooperative actions with entities outside its service area.

### Cooperative Action Policies

Throughout the IRP process, the Board struggled with the issue of how to define its relationship with water supply entities outside of its service area. Although the Board does not accept regional responsibility for meeting the water needs of the entire metropolitan area, it recognizes that cooperative arrangements with other metropolitan water suppliers may benefit Denver Water customers. Through the policies contained in its Resource Statement, the Board opted for a cooperative role, rather than one involving responsibility or leadership. As a result, the Board issued policies for those cooperative actions efforts and stated, in part that:<sup>7</sup>

*"...cooperative arrangements with existing metropolitan water suppliers outside the service area may benefit customers within the service area and may improve provision of water service within the Denver Metropolitan Area. Accordingly the Board's Resource Statement directs Denver Water staff to evaluate potential Cooperative Actions that may be proposed by other metro area water suppliers."*

As outlined in the policy, the Board is willing to use its infrastructure to cooperate with and assist other entities in mutually beneficial projects that meet certain conditions. To receive serious Board consideration, a proposal should:

- Provide significant water and financial benefits to the Board's customers;
- Minimize the Board's regulatory, financial, legal, and political risk;
- Limit the Board's obligation to the proposing agency to a limited amount of water;
- Assure that the proposing agency will implement an effective water conservation program;
- Ensure that the proposing agency will pursue available non-potable reuse options to maximize the efficient use of water;
- Maximize the use of the Board's existing water rights;
- Consolidate proposals from the same geographic regions;
- Foster environmental protection and enhancements;
- Demonstrate an effort by the proposing entity to gain acceptance of the proposal from those outside the Denver Metropolitan Area who might be impacted by the proposal, including efforts to mitigate those impacts;
- Ensure that groundwater resources are sustainable if the proposal relies on groundwater.

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<sup>7</sup> Denver Board of Water Commissioners. Cooperative Actions with Metropolitan Water Suppliers Outside the Board's Service Area, October 15, 1996.



In addition, the Resource Statement states that “Any future structural projects located on the West Slope should be developed cooperatively with West Slope entities for the benefit of all parties...”<sup>8</sup>

### Cooperative Action Proposals

Following the Board’s directive, Denver Water staff moved forward to consolidate water supply proposals by geographic region. The metropolitan area was grouped into the Northwest, Northeast and Southern regions.

In addition to Denver Water, entities in the Northwest metropolitan area include the cities of Arvada, Broomfield, Westminster, and Consolidated Mutual. Proposals include construction of new reservoirs and enlargement of existing reservoirs, as well as exploring ways to reuse supplies more efficiently.

Entities in the Northeast metropolitan area include the cities of Brighton, Thornton, and Aurora, South Adams County Water and Sanitation District, Metro Wastewater Reclamation District, the Rocky Mountain Arsenal, and Farmer’s Reservoir and Irrigation Company (FRICO). In this area, Denver and South Adams County are cooperating on construction of new reservoirs that will be used to recapture and more efficiently reuse supplies. Denver and FRICO have developed an agreement that improves water supply and water quality. In addition, Denver Water is developing a 15,000 af non-potable reuse project. Other potential cooperative actions may include facilities for potable or non-potable reuse.

Entities in the Southern metropolitan area include the town of Castle Rock; Centennial, Parker, East Cherry Creek, Inverness, Stonegate, and Cottonwood water and sanitation districts; Castle Pines North, Roxborough Park, and Meridian metropolitan districts; Pinery Water and Wastewater District, Arapahoe County Water and Wastewater Authority, and Douglas County. This group has recently embarked on a two-year, \$1,000,000 study to examine their future demands and potential water supply shortages. After fully examining conservation, reuse, and local ground and surface water supplies, potential cooperative actions may include using Denver’s excess supplies in above average runoff years in conjunction with the groundwater system.

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<sup>8</sup> The Continental Divide generally runs north and south through the Rocky Mountains, separating rivers that flow west to the Pacific Ocean from those that flow south and east toward the Gulf of Mexico and the Atlantic Ocean. In Colorado, land to the west of the Continental Divide is commonly referred to as the Western Slope or West Slope.

In addition to the regional efforts described above, Denver Water and the City of Aurora, the second largest water supplier in the metropolitan area, are jointly studying reservoir enlargement options in South Park.

### **HYDROLOGICAL ISSUES IN THE COLORADO RIVER HEADWATERS**

Cooperative actions, especially those in the Northwest and Southern metropolitan areas, have the potential for increasing importation of water from the Colorado River headwaters. (As previously noted, for the purpose of this paper, the Colorado River headwaters are defined as the Colorado River and its tributaries upstream of the U.S. Geological Survey gage "Colorado River at Kremmling." This area encompasses all of Summit and Grand counties.) The Colorado River is an important source because most of the state's water supply originates as snow melt in the Rocky Mountains on the west side of the Continental Divide. The Colorado River system drains nearly two-fifths of the state and 75% of the state's available water. In contrast, about 90% of Colorado's population is concentrated along the east slope of the Rocky Mountains. Due to the proximity to Denver, tributaries to the Colorado River headwaters have historically been a primary source for such diversions. These headwater streams currently provide Denver Water customers with about 115,000 af/year, or 45% of their water supply. This water is diverted from streams in the Blue, Williams Fork, and Fraser River basins and conveyed through the Continental Divide via the Gumlick, Vasquez, Roberts, and Moffat tunnels. As demand increases, the headwater streams will provide about 190,000 af/year, or 55% of Denver's water supply with existing water rights and diversion facilities. Projects under consideration for cooperative actions would draw water from these streams primarily during years with average and above average snowmelt runoff.

As previously discussed, Board policy requires an effort to gain acceptance of the proposal from those outside the Denver metropolitan area who might be impacted by the proposal. Summit and Grand counties include the towns of Breckenridge, Frisco, Silverthorne, Winter Park, Fraser, Grand Lake, and Granby, as well as the Arapahoe Basin, Keystone, Breckenridge, Copper Mountain, and Winter Park ski areas. It is fair to assume that a proposal would have to address impacts caused to these entities.

To better understand and address these issues, numerous entities on both sides of the Continental Divide have begun the Upper Colorado River Basin Study (UPCO). Sponsors include Summit County, Grand County, Northwest Council of Government's Water Quality/Quantity Committee, Colorado River Water Conservation District (CRWCD), Middle Park Water Conservancy District (MPWCD), Northern Colorado Water Conservancy District (NCWCD), and Denver Water (DW). Several ski areas in Summit and Grand counties have also been invited to participate. The results of this analysis will be used in a collaborative fashion with the participants and other stakeholders to find solutions

to identified problems. The following discusses most of the major issues and some potential mitigation opportunities to be addressed by the UPCO study and critical to any cooperative action proposal.

### Water Supply

Between 1990 and 1997, Summit County's population grew by more than 43% and Grand County by 24%. Facing tremendous development pressures of their own, the counties are looking for ways to develop new water resources while maintaining the environmental assets that make these areas so desirable. Any competition for water from a cooperative action proposal further intensifies the issue.

Entities in Summit and Grand counties are primarily short of water for municipal uses and snowmaking during the winter months and in years with low snowmelt runoff. Existing water rights, including those owned by Denver Water, have senior priority to much of the limited runoff at those times. New water supplies that rely on junior water rights would be in priority to divert water only during times of high flows primarily in May, June and July.

As compensation for a cooperative action project that would divert more water to the Denver metropolitan area, a mitigation measure could be to divert somewhat less water in dry years or in the winter season when flows are most critical to water supply needs in these headwater counties. Another possible type of mitigation would be to have the proposing cooperative action entity develop small, but locally important, water supply projects in Summit and Grand counties that could provide water to all participants. Examples include construction of new reservoir storage, new diversions, or the purchase and transfer of senior water rights to new uses.

### Water Quality

Water quality problems in Summit and Grand counties include discharges from abandoned mine sites, stormwater runoff, and runoff from development activities. Water quality problems are often aggravated by depleted flows resulting from diversions. Several stream reaches in the counties are on the state's 303(d) list of impaired waters, meaning that these segments do not (or may not) meet designated uses due to abandoned mine site drainage or other non-point pollution sources.<sup>9</sup>

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<sup>9</sup> Section 303(d) of the Federal Water Clean Water Act requires States to identify waters which do not or are not expected to meet applicable water quality standards with technology-based controls alone. This identification of water quality-limited waterbodies is presented in a document called the 303(d) list, which is updated biennially.

Another water quality concern in the headwater counties is the increased wastewater treatment costs as water quality regulations become more stringent and as streamflows decrease. One focus of the UPCO study is to determine to what extent flow reductions may affect water treatment costs to Summit and Grand counties 19 wastewater treatment facilities. The potential cooperative action proposals, as well as the future water quality needs in the headwater counties, will be analyzed to quantify the extent and locations of potential problems. To the extent that a cooperative action further increases treatment costs, a mitigation measure could be for the proposing entity to contribute resources to offset those costs.

Snowmaking by the ski areas in the headwater counties is another activity that may also contribute to water quality problems. For example, Keystone Resort has used water from the Snake River for 28 years and the practice may contribute to the presence of heavy metals in the river and in Dillon Reservoir. The resort and the U.S. Forest Service are studying whether snowmaking is contributing to the pollution in the Snake River. The ski areas are generally at a higher elevation in the watershed than the potential points of diversion for any cooperative action proposal. Although a cooperative action is unlikely to alter the impacts that snowmaking has on water quality, a mitigating measure would be to assist the ski areas in whatever mitigation options are needed.

### **Dillon Reservoir Water Quality**

Located in Summit County, Dillon Reservoir is Denver's largest storage facility and an important asset to Summit County.<sup>10</sup> In 1997, the phosphorus and chlorophyll concentrations in Dillon Reservoir were studied. The three factors that potentially affect phosphorous and chlorophyll concentrations, 1) land use, 2) hydrology, and 3) reservoir operations, were analyzed for existing conditions and potential conditions for the years 2015 and 2045. Of these factors, the study showed that the anticipated land use changes due to development of the watershed above Dillon Reservoir has by far the greatest potential impact. Natural variation in hydrology has the second strongest effect. In general, the hydrology in dry years produces the lowest concentrations in Dillon Reservoir, while the wet year runoff produces the highest concentrations. The study also concluded that reservoir operations have little effect on phosphorous and chlorophyll concentrations. This conclusion holds for existing conditions and in the future when Dillon Reservoir is used more extensively as the demand on Denver's water supply increases.

Because development of land in the watershed above Dillon Reservoir is the greatest contributor of phosphorus and chlorophyll concentrations in Dillon Reservoir, zoning and permit requirements for development are an important

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<sup>10</sup> Completed in 1964, Dillon Reservoir has an active capacity of 254,036 af.

mitigation tool. Whereas cooperative actions are not expected to influence the problem significantly, this is a matter that Denver Water will need to address with Summit County in the latter's zoning and comprehensive planning.

### **Dillon Reservoir Water Levels**

Although the purpose of Dillon Reservoir is water supply, the reservoir is an important recreational amenity for Summit County. In addition to the aesthetic values, recreation activities at the reservoir include boating, windsurfing, fishing, camping, picnicking, shoreline hiking and biking. One activity directly affected by water levels is access to the lake for boating. This activity is served primarily by two marinas, one near the town of Frisco and one near the town of Dillon.

At full capacity, the water surface of Dillon Reservoir is at an elevation of 9,017 feet. At 93% full, Dillon Reservoir is at an elevation of 9,011 feet. Even at this relatively high level the Frisco Marina becomes unusable. At an elevation of 9,002 feet (82% full), the Dillon Marina becomes unusable. The major recreation season for these marinas is from about Memorial Day through Labor Day, with some activity occurring as late as mid-October. As the demand in Denver Water's service area increases, water levels will be drawn down more than it has in the past. Cooperative actions could cause even lower levels.

One form of mitigation of lower reservoir levels resulting from a cooperative action would be to extend the walkway further out into the reservoir, or to use "star docks" with taxi service. This option would be preferable to dredging of the marinas. The marinas could then remain in operation with elevations to as low as 8,997 feet (77% full). Another option would be for Denver Water to rely on its other reservoir facilities during the recreation season, keeping Dillon levels high, then make greater use of Dillon during the fall and winter months. The water supply risks, recreation, and environmental impacts to Denver Water's other reservoirs would need to be considered in relation to this scenario. The relative costs and benefits of the various mitigation options need to be evaluated in terms of the frequency that the reservoir is expected to be above the various levels during the major recreation season.

### **Stream Flows**

Various rates of stream flow are desired for different uses. For example, the high flows desired by white water rafters are detrimental to those wishing to wade into the stream for fly-fishing. Other flow needs include protection of wetlands, wildlife, riparian habitat, and a wide-range of flow requirements for different fish species at varying life stages. Often these desired flows are in direct competition with each other and with the administration of water rights for municipal, industrial and irrigation uses.

White Water Rafting. The white water rafting interests below Dillon Reservoir would like to have outflow from the reservoir in the range of 800 cfs -1,500 cfs during the summer months.<sup>11</sup> These releases may also benefit rafters further downstream on the Colorado River below the Blue River. A cooperative action project would tend to divert water from Dillon Reservoir in the high runoff season, primarily May through July, and thereby affect whitewater rafting. However, similar to the issues of maintaining higher levels in Dillon Reservoir during the summer recreation season, there may be opportunities in some years to divert water later in the season.

Minimum Stream Flows. The Colorado Water Conservation Board (CWCB), working in cooperation with the Colorado Division of Wildlife, is responsible for establishing the minimum instream flow necessary to "preserve the natural environment to a reasonable degree."<sup>12</sup> Since the creation of the state's Instream Flow Program in 1973, the CWCB has appropriated water rights for approximately 130 stream segments in the Colorado River headwaters. Although these water rights are relatively junior and unable to call water past senior upstream users, there may be mitigation opportunities to bypass water to meet the minimum streamflows in all but the driest runoff years. For example, the minimum instream flow right below Dillon Reservoir is 50 cfs. Even when the total inflow to Dillon goes below 50 cfs, Denver Water has agreed to maintain 50 cfs under specific, limited conditions.

Fish Habitat. In addition to minimum flow, aquatic life benefit from periodic high flushing flows during the spring that move the streambed sands, gravel and cobbles and assist in aquatic habitat formation and maintenance. As previously mentioned, water for new projects with junior water rights is available only in the May through July period. Although flushing flows and use of water for expanding municipal purposes compete with each other, there may be opportunities to periodically bypass high flows without significant loss of yield to municipal water supply. For example, under the Windy Gap diversion agreement, once in every three years, if equivalent flushing flows do not occur past the diversion, the Windy Gap diversion releases a total of 450 cfs of water for 50 hours during the period of April 1 through June 30 for flushing flow purposes.<sup>13</sup> In addition to minimum and flushing flows, selective placement of boulders could improve habitat as a mitigation measure.

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<sup>11</sup> Cubic Foot per Second (cfs). A rate of flow of water passing a given point, amounting to a volume of one cubic foot for each second of time. Equal to 7.48 gallons per second, 448.8 gallons per minute, or 1.9835 acre feet per day. 35.3 cfs equals 1 meter<sup>3</sup> per second.

<sup>12</sup> Colorado Senate Bill 97, 1973.

<sup>13</sup> The Windy Gap diversion is at the confluence of the Fraser and Colorado rivers.

Whirling Disease. Shallow, muddy, warm water is an ideal environment for the tiny tubifex worm that carries Whirling Disease. Whirling Disease was found in the upper Colorado River drainage in the fall of 1988. Whirling Disease spores are difficult to kill, and individual spores can remain viable for up to 30 years.

The Colorado Division of Wildlife has asked the Northern Colorado Water Conservancy District to consider building a \$1.5 million dam-within-a-dam at the Windy Gap diversion dam. Biologists say the new dam could change the reservoir's status as an incubator of Whirling Disease. Building a 2,400-foot berm through the middle of the reservoir would isolate Whirling Disease spores in a settling basin inside Windy Gap and prevent them from flowing downstream. The 2,400-foot berm would take up substantial space inside the reservoir, and could prevent the NCWCD from using its full legal water right. The new dam also could clog part of the reservoir with tons of sediment, which would have to be removed in expensive dredging operations. Another more expensive option would be to construct a bypass channel around the diversion to isolate the problem. As mitigation for cooperative actions, funding of the best alternative could be aided by the proposing entity.

Reservoir Releases. Fluctuation in flow releases from a reservoir is referred to as "ramping rates." For example, the ramping rate goals for Dillon Reservoir are as follows:

<u>Flow (cfs)</u>	<u>Max. Change/Hour (%)</u>
0-50	38 %
51-100	27%
101-200	35%
201-400	22%
401-600	18%
601-800	15%
> 800	11%

One recently stated goal is that at low flow the change in releases from Dillon Reservoir should not exceed 10% over a 24-hour period. Operating under these criteria, it would take five days to change the outflow from 55 cfs to 100 cfs. Under Colorado's water rights system,<sup>14</sup> if a senior water right needs water, the junior upstream right must bypass water as needed to satisfy the senior right. Thus, the proposed release schedule may not allow the Dillon Reservoir to meet its obligations to downstream senior water rights. However, there may be opportunities to create or modify ramping rate for reservoirs in a way that is

<sup>14</sup> Prior Appropriation Doctrine. Under the prior appropriation system, the first person to appropriate the water and put it to beneficial use has the first right to use water from that source. Colorado's system is administered according to priority or seniority. The owner of a senior water right is entitled to be completely satisfied before a junior right may divert or store any water.

acceptable to the reservoir owners, senior water rights holders, and the State Engineer.<sup>15</sup>

**Flood Control.** The water supply reservoirs in the headwaters area are generally kept as full as possible in anticipation of municipal water needs. There is some pressure, especially with Dillon Reservoir, to operate as a flood control facility. Indeed, Dillon Reservoir is typically drawn-down during the winter months and not full at the start of the spring runoff season. In some years this provides substantial flood control benefits. In the Silverthorne area below the reservoir, flows above 1,800 cfs are a considerable threat to property and aquatic life. In recent years, the spring runoff without the reservoir would have exceeded 2,650 cfs. Given the capricious behavior of nature especially in the spring, and competition for water, it would be unreasonable to assume that the water supply reservoirs in the headwaters can always be relied on to provide flood control. The best remedy in this instance may be for the counties to ensure that property is not developed within the floodplains, and that desired fish species are re-stocked in the streams after adverse flooding events. Cooperative actions that divert more water from Dillon reservoir will inadvertently improve flood control.

### SUMMARY

Denver Water has numerous options to meet the anticipated 100,000 af water supply shortfall within its service area. One option is to develop 10,000 af of new supply through cooperative actions with entities outside of its service area. The operative term here is "cooperation." The Denver Water Board seeks to establish cooperative relations built upon solid, two-way communication with its customers, distributors, other water providers, Western Colorado, the environmental community, federal and state agencies, and the public at large. The Board believes that in all its actions, good environmental practices make good public and water policy. Accordingly, the Board's 1996 Resource Statement directs Denver Water staff to consider numerous factors when evaluating potential cooperative actions proposed by other metropolitan area water suppliers. The proposing entity must also make an effort to gain acceptance of a proposal from those who might be impacted by it, including efforts to mitigate those impacts. As outlined in this paper, there are many complex water resources issues and potential impacts, but many mitigation opportunities associated with developing water from the Colorado River headwaters for use in the Denver metropolitan area.

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<sup>15</sup> Water rights are administered by the Office of the State Engineer, Colorado Department of Natural Resources.



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# INTERBASIN WATER TRANSFER AND CHANGES IN RURAL WATER MANAGEMENT INSTITUTIONS: A CASE STUDY FROM THE MELAMCHI RIVER BASIN IN NEPAL

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## ABSTRACT

Recently, the Nepal Government has launched a mega scale interbasin and intersectoral water transfer scheme to divert Melamchi river water through a 26.5 Km long tunnel to meet the growing water needs of its capital, the Kathmandu City. This case study focuses on local water institutional issues involved in the mega scale interbasin and intersectoral water transfer project, often key to the success of projects in developing countries. In particular, this paper describes the evolution of water management institutions in the face of growing water demands in the remote mountain areas of Nepal. Rural water users have developed over centuries time tested water allocation mechanisms to meet the local needs. These institutions may provide a means to buffer the increasing stress brought about by the diversion of water out of the Melamchi, but they are at present insufficient to deal with issues of formal water rights, river water allocation, and negotiation with Kathmandu city agencies. The present institutions however could provide the building blocks to carry out these functions. The Melamchi Water Supply Project represents a situation that is common worldwide. Increasing demands from cities will pull water from rural water users. These users often will not have the institutional arrangements during the water transfer process to negotiate and manage water adequately after the water transfer has taken place. Adequate and reliable data may not be available to know the extent to which changes will affect local users. The Melamchi Project has correctly paid a lot of attention to the affected area in the donor basin. This interbasin diversion may be an excellent opportunity to catalyze institutional development for managing water resources in the donor basin where competition will increase.

## INTRODUCTION

The Melamchi Water Supply Project is the first of such mega scale intersectoral and interbasin water diversion project being implemented in this Himalayan

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kingdom. The project costs are estimated to be US \$464 million, spread over six years, almost half of the annual budget (GDP) of the Himalayan kingdom. A successful project will surely benefit Kathmandu, but is likely to stress water management arrangements along the Melamchi. A major question is whether present rural institutions in Nepal can cope with such a change, and how institutions might evolve to better manage cross-sectoral, cross-basin water resources. The major objective of this paper is to analyze the institutional changes and evolution of new institutions during the initiation of the Interbasin Water Transfer (IWT) project in Nepal to meet the growing urban water demand of Kathmandu valley.

Urban water demand is escalating everywhere in the developing countries, particularly more in South Asia due to extensive urbanization in the recent past. Only about 85% of the urban population and 76% of the total population in South Asia has access to improved water sources (World Bank, 2001). Moreover, a smaller percentage of the population has access to piped supply drinking water in the region. The safe drinking water supply situation in Nepal is precarious as only 44% of total population has access to improved water sources (World Bank, 2001). The dry season piped water supply in Kathmandu City is sufficient to meet the basic water requirement (demand) for only half of the city population. Therefore, the interbasin water transfer (IWT) for Kathmandu may be the only feasible option for supplying enough water, given the rising population, and already an acute water shortage situation.

This paper focuses on the evolution of water management institutions in the rural donor basin, the Melamchi. The major question is whether present institutional arrangements in the Melamchi, are sufficient to deal with the stress brought about by the interbasin transfer. The objectives of the paper are to provide a case study on institutions to understand how institutions evolve, and to give an indication of what types of institution building can help to cope with changes. The paper first explores the present institutional arrangements within the Melamchi Basin. Next, a brief description of the project is given with an indication of the magnitude of the change that will take place in the donor basin. A description of the process of negotiation and institution building is given to show how the problem is being coped with. Finally, some general conclusions are drawn.

### WATER MANAGEMENT – THE PRESENT STATUS

The *Melamchi* River basin, a sub-basin within the larger *Indrawati* River basin (Figure 1) has a long history of complex water use practices.

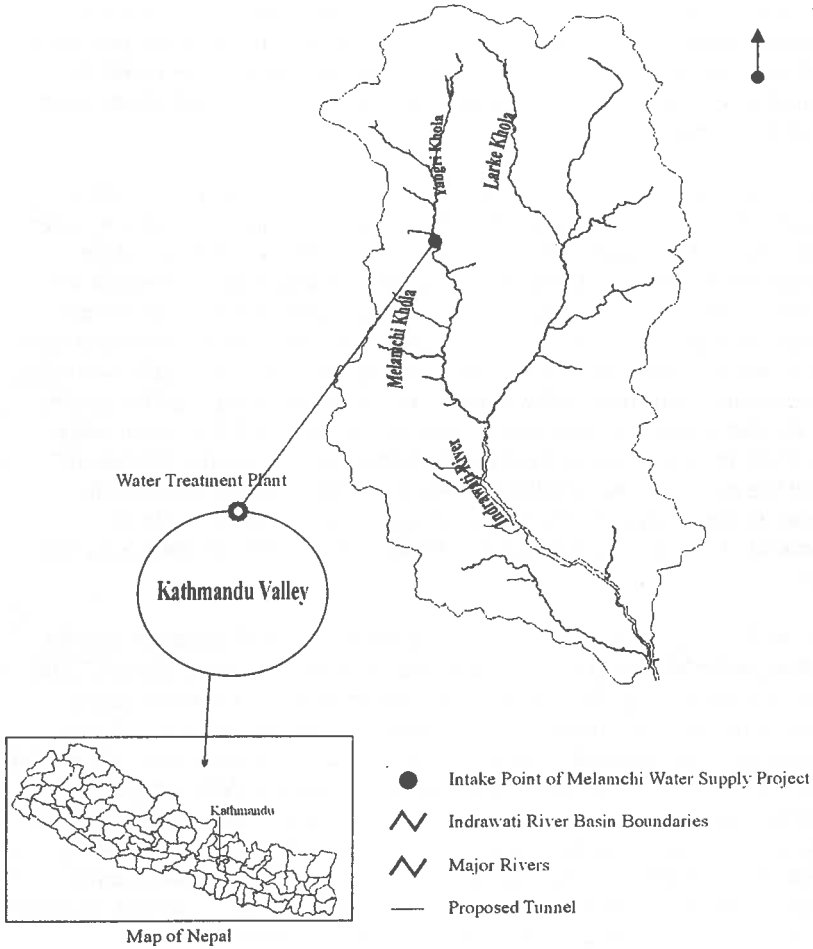


Fig. 1. Map Showing the Melamchi River Basin watershed, Nepal

The local communities have developed several formal and informal water sharing arrangements and water suited to local conditions. (Also described in Pradhan, 1989; Yoder, 1994, and Pradhan, 1990). Removing a large volume of water is likely to change the hydrologic characteristics, and create more stress on institutional mechanisms for allocation and conflict resolution. The question is whether these existing community level institutional arrangements can cope with

the institutional crises brought by this level of external shock. It is believed that these century-old community developed and practiced innovative water use institutions could somewhat buffer the extent of shock, and also could provide a sound basis for developing Integrated Water Resource Management (IWRM) at the basin level. The concept of building on existing institutions deserves merit and further exploration.

Local water users have been diverting water from the Melamchi River and its tributaries by constructing temporary intake at different places for various water use activities, like irrigation, grain milling<sup>3</sup>, and micro-hydro power and for drinking water. The installation of micro-hydro is a recent development in the area, only since 1999. As a perennial river basin, these water use systems are operated throughout the year. The present water allocation in the Melamchi river basin is mainly within canals that serve both irrigators and water mills. According to the customary practices followed in the area, drinking water gets first priority over all other water uses, followed by irrigation systems, and then water mills. Most of the present drinking water needs of the donor community (Melamchi project site area) is being fulfilled from the perennial streams and waterfalls tributary to the Melamchi surrounding the community. Hence, the local community is not directly dependent on Melamchi river flow for drinking water needs.

There are 22 water mills and 18 locally community managed irrigation systems operating in the Melamchi River basin as shown in the diagram of Figure 2. The irrigation systems range from as small as 2.5 ha to larger of 150 ha irrigation scheme, providing year round irrigation access to about 500 ha of land. Two micro-hydro power turbines (with water mills) are also operating in the river basin to provide electricity to the local communities. In addition, there is a plan to rehabilitate an irrigation system and to provide irrigation to an additional 210 ha of lands. Government (DOI) as well as some INGOs and NGOs are providing support for maintenance and performance improvement of these communities managed irrigation systems. The water mills are mostly privately owned, whereas the irrigation systems are community managed and owned by the local community stakeholders (FMIS), as common property resources.

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<sup>3</sup> Milling is carried out by traditional *Ghattas* where the turning of a grinding stone is driven by the force of water, and more recently by water powered turbines connected to mills.

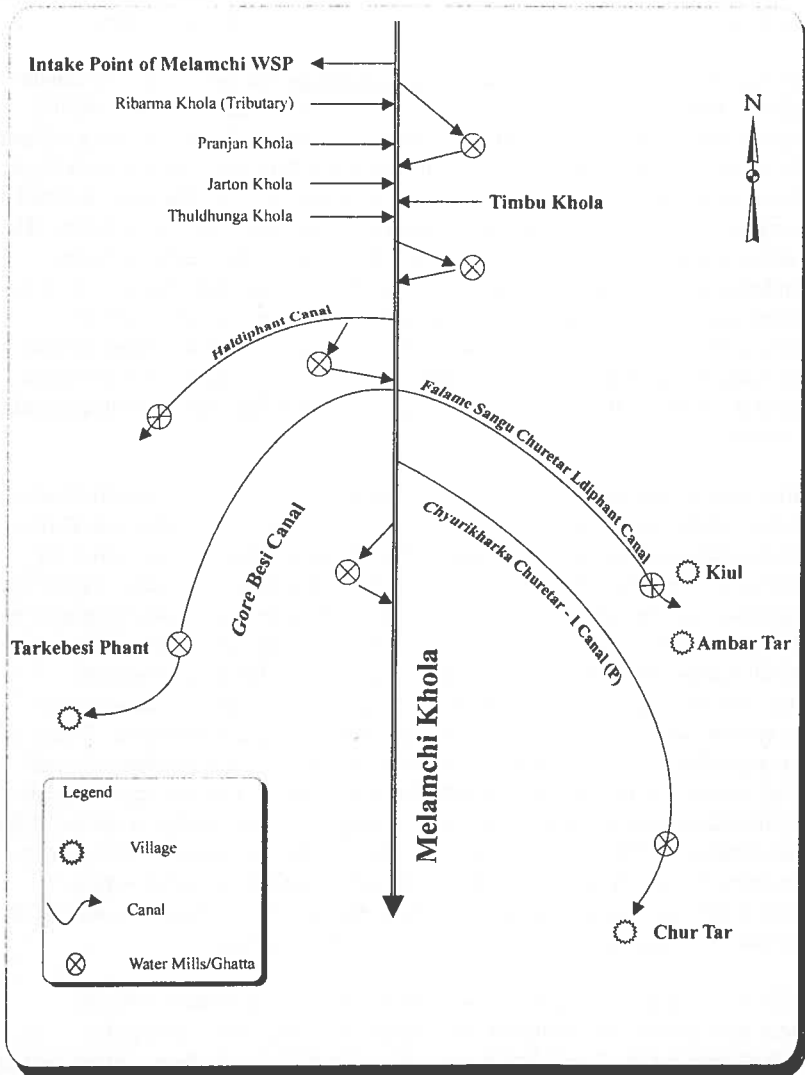


Fig. 2. Schematic Diagram of Water Use Practices in Melamchi WSP Intake in Melamchi Khola, Nepal. (Not in Scale)

The water allocation systems followed are based on the customary water practices and informal traditions, without use of any formal rules and regulations.

Typically, diversion structures made of stones and wood, direct water to canals that bring water to water mills and irrigators. The irrigated areas are usually located at the upstream of the canal whereas the water mills operate at the tail end of the canal. The mill owner usually constructs the temporary headwork with an earthen canal, and also maintains the canal up to the mill. By doing so, the mill owner usually obtains the rights on the land on which the water canal passes. The understanding between the mill owners and irrigators is that the farmers get unhindered access to the water for irrigation. Sharing the water rights among the different users based on the mutual negotiation and customary practices is followed. Before construction of the water canal and mills, the farmers used to divert water from small seasonal rivulets, which were mostly seasonal in nature (monsoon). A mutually beneficial arrangement has evolved to deal with irrigation and milling.

Another interesting facet of the water sharing mechanism is that the mill owner performs all the operation and maintenance of the canal without any cost sharing and compensation from irrigation users, though the benefits of canal water are shared by both groups. The mill owner has relatively larger individual stakes in the operation of the canal due to the larger scale of investment, and its location at the tail end position of the canal. Any reduction of canal water flow has a relatively larger investment risk on water mill owner. This gives a positive incentive to the mill owner for timely repair and maintenance of the irrigation canal system, which are in general common property natural resources. Plenty of water is available for all during the monsoon, so there is little problem of water sharing. However, the situation is different in the dry season (January to April). The mill owner usually needs unhindered supply of 180 to 200 lps in the canal for smooth operation. There were occasions in the recent past when the mill owners had to even shutdown the mill for 2-3 hours at the request of the farmers to provide water for irrigation needs. In some cases, the irrigation is done during the night while leaving the water uses to the mill in the daytime.

Usually, the mill owner negotiates with the farmers to try to obtain written consent with the farmers for unhindered access to canal water. Except for providing land for the canal, the farmers obtain water free of charge. Even though it is informal, complex water rights sharing mechanism exists. The irrigation users get first priority for the use of water even for the dry season crops, despite the fact that the mill owner bears the canal construction and maintenance costs. This may seem an unfair arrangement from the outsiders' observation, but this kind of informal arrangement is socially desirable with low transaction costs leading to smooth operation of the irrigation systems. Otherwise, involvement of larger number of smallholder farmers, instead of a single mill owner, would be time consuming and incur large transaction costs for collective choice decisions.



Timely repair and maintenance of the canal is the critical factor in the adverse mountain environment, where flash flood and landslide are daily phenomenon during the monsoon.

The available water is barely adequate both for irrigation and water mill operating simultaneously during those dry months. The competition for water use is growing as new water use activities emerge. The water allocation practice followed in the area is to start irrigation at the head reach first, then middle, and then the tail reach last. Adequate availability of the water at the source (Melamchi River), and the construction of new canals at the downstream has to some extent eased the local water disputes, but these may worsen with short supplies.

Some water related disputes occur when the irrigation users disrupt the water flow to the mill (*Ghatta*), without informing the mill owner (Ghatta). This happens especially for the winter and spring season crops, when the water flows in the canal is reduced at minimum level. Moreover, these water disputes between the irrigation users and the mill owner are usually resolved through the mutual dialogue between the two parties, only occasionally such water disputes are brought to Village Development Council (VDC). In the recent past, one of the VDCs resolved such a water dispute between two irrigation systems (farmers) in one of the tributaries (*Jageswor kulo*) of *Melamchi Khola* by allocating the water between the upstream and downstream users proportionate to the land holding, and also in the rotational system. The *water* was allocated for four days (*Jageswar Kulo*) to one group, and three days to another (*Tarshera phant kulo*). Both the upstream and downstream users have been abiding the VDC decision.

Other than that there is no serious water conflicts so far noticed among the different water users in the community. Different factors help to reduce such water-related frictions, some of them are:

- Abundance of water availability in river basin compared to the water use activities.
- Existing flexible customary practices for water sharing between the mill owner and the irrigation users based on the need and urgency.
- All the turbine mills, except few of the water mills are at the downstream of canal, thus, the mill owner takes responsibility for operation and Maintenance of the canal.
- There is a customary practice of maintaining at least 200 meter distance between the upstream and downstream intakes; thus the downstream users would not allow a new construction if upstream user do not follow this practice.
- Availability of micro sources of irrigation to cater to the need of the scattered area.

In summary, the institutional framework has evolved adequately and ingeniously to manage local water supplies. Fortunately, there is ample water available in the river except in a few dry months that help to "lubricate" conflicts. Along the river, there is little need for upstream-downstream coordination because of the sufficient amount of water in the river, but there have been cases where local institutions have resolved the matter. The source of water for drinking is different than that for irrigation, minimizing cross-sectoral local water conflicts. The mill owners and irrigators have adapted an effective operation and maintenance system for the canal networks. Informal water rights and enforcement mechanisms have evolved to match the local situation. Locally derived operation and maintenance procedures exist and are fairly well adapted to the rough mountainous conditions.

If water is reduced in the Melamchi, will this type of institutional arrangement suffice? With this setup, can people adequately negotiate with the urban water users from Kathmandu? Can they manage potential upstream-downstream conflicts that may arise when water supplies are less? What changes are needed in the present institutional setup? Part of the answer lies in how much water will remain in the river after the transfer, and in the institutional development efforts of the Melamchi project. Let us first give some more details about the water transfer project.

### THE MELAMCHI INTERBASIN WATER TRANSFER (IWT) PROJECT

The Melamchi Water Supply Project is designed to transfer water from the Upper Mountain range to meet the urban water needs of Kathmandu Valley. This kind of commercial use water transfer is first of its kind in Nepal. At present, the average daily water demand of Kathmandu Valley is 180 million-liter per day (MLD<sup>4</sup>), equivalent to 150 liters per capita per day. The Nepal Water Supply Corporation (NWSC), a government owned agency, has capacity to supply only 120-140 (MLD in the rainy season (100 to 116 liters per capita per day). This is reduced to 80-90 MLD during the dry season (i.e., 66 to 75 liters per capita per day). The water demand<sup>5</sup> in Kathmandu city is projected to increase to 510 MLD in 2018 (MWSB, 2000). Considering all these factors, there is clearly an urgency to identify a suitable alternative for a continuous supply of drinking water.

After studying several options, the Nepal government decided to transfer water from a nearby Melamchi river basin to Kathmandu Valley through the implementation of Melamchi Water Supply Project (MWSP). The details of project descriptions are given in Table 1, 2 and 3. Moreover there is also an additional provision to supplement the water flow in the project intake canal

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<sup>4</sup> 1 million liter per day (MLD)=0.01157Cumecs

<sup>5</sup> Based on the Kathmandu valley population, 1.2 million now, which is growing at the rate of 3.3 percent per year.

diverting water from other nearby river and tributaries if it is later required for the growing population of Kathmandu City. The first stage of the project is designed to divert 170MLD (1.97 cumecs of water from Melamchi River. In the second and third stages it is proposed to supplement an additional 170 MLD of water by diverting it from Yangri and Larke tributaries of Indrawati River to the same Project intake canal. Thus, it is expected that this project least would be able to meet the long-term (more than 30 years) water demand of the Kathmandu City.

**Table 1: Melamchi IWT Project Salient Features.**

	Features	Unit	Description
1	Project name		Melamchi Water Supply Project (MWSP)
2	Executing Agency		Government of Nepal, Ministry of Physical Planning and Works, Melamchi Water Supply Development Board (MWSDB)
3	Project Duration	Year	6 year (July,2001-July,2006)
4	Estimated cost	US\$	464 Million
5	IRR	%	13.5
6	Financiers/ Donors	No:9	Asian Development Bank -US\$ 120 million; World Bank- US\$ 80 millions Other Bilateral donors - US\$ 146 millions Government of Nepal - US\$ 118 millions
7	Source of Water	No:3	Stage I: Melamchi River (perennial) in HELAMBU VDC of Sindupalchowk District located 40 KM north east of Kathmandu  Stage II & III: Yangri and Larke (tributaries of Indrawati)
8	Major Components of Project	No:5	<ul style="list-style-type: none"> <li>• Melamchi Diversion Scheme (MDS): Included access road and tunnel adit, a diversion weir dam 5-7 m high, control system and sediment exclusion and 26.5 Km long tunnel starting from Ribarma to Mahankal, Sundarijal VDC in Kathmandu.</li> <li>• Water Treatment Plant (WTP): Conventional gravity water treatment plant will treat the water for WHO drinking water standard through the process of chemical flocculation, sedimentation, filtration and chlorination. The plant will be located at Sundarijal VDC, outskirts of Kathmandu City.</li> <li>• Bulk Distribution System (BDS): Treated water will be conveyed by network of peripheral distribution system of ductile iron pipe of dia.300-1400 mm to the reservoirs built at high locations.</li> <li>• Distribution Network Improvement (DNI): Distribution to the consumers by rehabilitated and extended network ensuring quality and equitable distribution, and reduction of leakage and wastage.</li> </ul>

Langtang National Park and the Helambu area both famous eco-tourism trekking routes are located in the upper water catchment area of the Melamchi River basin. Several environmental impact assessment reports and detailed feasibility studies conducted in the past have not reported any project related adverse environmental impacts on these sectors. The Melamchi IWT project is still a complex and costly adventure in Nepal. It involves construction of a 26.5 Km long tunnel. The total project costs are estimated at US\$ 464 million. About 30 percent of the project financing is committed by the multilateral and bilateral donors as grants, about 45 percent by the World Bank and the Asian Development Bank as loan financing, and remaining 25 percent project costs are financed by the Nepal government (Table 1). Private sector involvement during the construction phase as well as management of the water supply system in Kathmandu City, through privatization of the Government owned Nepal Water Supply Corporation, are some of the preconditions of the donor financing on the project. By involvement of the private sectors in the construction and city water supply and management in the future, the project is planned as a (nearly) full cost recovery type of infrastructure project.

Considering the nature and scale of the water diversion project, it has also brought several other institutional changes in Nepal, particularly in the infrastructural development and related project-financing sectors. The experience gained during planning and implementation of the Melamchi project, inclusion of wider stakeholders in the project decisions, are solid foundations upon which the future mega-scale water projects planning in Nepal can be built upon. Likewise, the government's experience on negotiating with several multilateral and bilateral donors together on this project, which lasted more than a decade, could be a valuable information base, and experiences for any future large scale water resources project planning and development in Nepal. Figure 3 shows the average flow pattern in the Melamchi as reported by several studies. It is important to note that one of the difficulties in the analysis of water availability has been the paucity of data available leading to some uncertainty in the results. The line at the bottom of the graph represents the constant  $1.97 \text{ m}^3/\text{demand}$  of Kathmandu that will in the future be subtracted from discharge in the Melamchi.

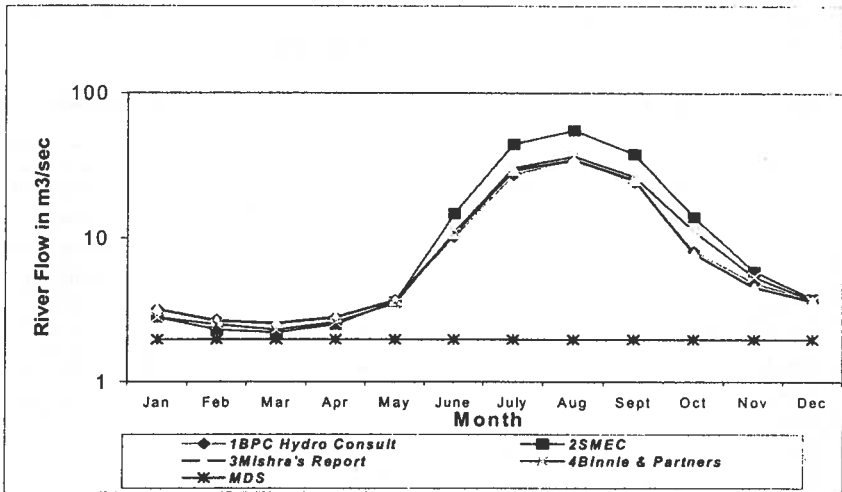


Fig. 3. Comparison of Average Monthly Flows with Respect to Water Diversion from the Proposed Project.

The graph above indicates that March is the driest month with an average river flow being  $2.5 \text{ m}^3/\text{s}$  at the MDS intake. According to the project authority, the Melamchi project is designed to leave at least  $0.4 \text{ m}^3/\text{s}$  even in the driest season downstream of the intake (HMGN/MWSDB, EIA report, 2000). The figure suggests that the existing and future water use activities in the Melamchi river basin could face increased water stress, especially from February to May. The affect on water use activities would be felt in the immediate downstream stretch of MDS intake. In dry years, there would be more stress.

In the lack of extensive long time series data reporting and water accounting status study in the basin, there are several uncertainties on the future water balance situation in the river basins. It was observed that the greatest source of tension was around discussions about the water remaining in the river after the project.

### THE LOCAL RESPONSE TO THE PROJECT

The Melamchi Water Supply Project (MWSP) was conceived at the higher political and administrative level in Nepal. Supply of adequate drinking water to in the Kathmandu City, has been a major political agenda in Nepalese politics for more than three decades. Considering the nature and scale of the project, its implementation would not have been materialized without strong political commitment, which involves huge investments and several institutional reforms

in Nepal. This has been a dream project of each successive government in Nepal for the last several years. Likewise, negotiation with the prospective donors for funding and convincing the local people were other major tasks for which higher level political commitment was required to materializing the project.

**Table 2: Comparison of Average Monthly Flow (m<sup>3</sup>/sec) at MDS Intake.**

Month	SOURCES				
	<sup>1</sup> BPC Hydro Consult	<sup>2</sup> SMEC	<sup>3</sup> Mishra's Report	<sup>4</sup> Binnie & Partner	Proposed water diversion (MDS)
January	3.2	2.8	3.2	2.8	1.97
February	2.7	2.3	2.6	2.5	1.97
March	2.5	2.2	2.6	2.3	1.97
April	2.8	2.5	2.8	2.6	1.97
May	3.7	3.6	3.7	3.5	1.97
June	10.2	14.8	10.8	11.0	1.97
July	27.4	44.4	29.3	30.5	1.97
August	34.4	55.3	34.8	36.7	1.97
September	24.4	38.0	25.5	26.6	1.97
October	8.2	14.1	7.9	11.3	1.97
November	4.9	5.9	4.6	5.4	1.97
December	3.7	3.8	3.7	3.7	1.97
Average	10.7	15.7	11	11.6	1.97

Sources: From the several project feasibility studies conducted by following companies.

- (1) BPC - Butwal Power Company, Nepal; 1997.
- (2) SMEC - Snowy Mountain Eng. Corp. Australia; 1992.
- (3) Mishra Report - Researcher, IWMI/Nepal. Water Accounting Study, 2000.
- (4) Binnie & Partners - International Consultant, United Kingdom; 1998.
- (5) Proposed MDS - Proposed water diversion from the Melamchi river.

Melamchi Project plan has assigned concerned District Development Committee (DDC) of Kathmandu and Sindhupalchowk for coordinating the local NGOs' activities in the project areas, known as NGO Participation Plan (NGOPP). The DDC is a local elected institution in Nepal responsible for coordination and implementation of all the governmental local development activities in the district. Likewise, concerned Village Development Councils (VDCs) are also assigned for coordinating and monitoring the activities implemented by the NGOs in their respective jurisdiction. This project has given consideration in involving local elected entities in the project implementation activities. Likewise, a Local Consultative Group at Melamchi valley has been formed to facilitate better participation of the local people in the project activities, consisting of 15-member

committee (representatives of line agencies, high school principal, women representative, and the Melamchi project field officers.

**Table 3: The Physical Characteristics of Melamchi River Basin.**

SN	Description	Unit	Quantity
1	Total Length of River: Main stream	km	41
2	Tributaries	No	14
3	Catchment area of MDS intake	km <sup>2</sup>	157
4	Catchment area of River	km <sup>2</sup>	330
5	Catchment area of the nearest River gauge	km <sup>2</sup>	122
6	Elevation at Intake from Mean Sea level (msl)	m	1445
7	Elevation at tunnel end from msl	m	1410
8	Elevation at confluence with Indrawati river from msl.	m	820
9	Elevation of the river origin from msl	m	5863
11	Average monthly max flow at Intake	m <sup>3</sup> /s	10.92
12	Average monthly min. flow at Intake (March)	m <sup>3</sup> /s	2.55
13	Average monthly max. flow at confluence	m <sup>3</sup> /s	76.00
14	Average monthly min. flow at confluence	m <sup>3</sup> /s	5.62
15	Slope of the river	%	12
16	Distance at Intake from Confluence	km	20
17	Average annual rainfall in intake of catchment	mm	3212
18	Average Annual rainfall in the Melamchi basin	mm	3050

Source: HMG/NWSDB, 2000; and Mishra, 2000

Emergence of NGOs and local pressure groups in the project area is one of the important developments and institutional changes brought by the Melamchi project in the infrastructure project sectors as a whole in Nepal. 65 NGOs have already been officially registered in the project area, however, not all of these NGOs are all equally effective to look after the interests of the local communities. These NGOs have until now focused more on getting involved in implementation of economic packages under the project, rather than looking at the basin level water management as a whole, and its impact on the livelihood of local people. Nevertheless, the NGOs have played an important role in raising awareness and concerns in the communities about the project. Some of the NGOs have already been assigned to the role of facilitator for the implementation of various social development components of the project compensation package.

According to the recent water acts of Nepal (1992 and 1993), the ownership of all the water resources in the country is vested in the central government. The water law has prioritized the use of water in the following order: first drinking water, then irrigation and agricultural uses (animal husbandry), hydropower, cottage industry, industrial enterprises including mining, navigation, recreational use and then other uses. Moreover, the governmental civil code of 1963 has also

guaranteed the customary use right and prior appropriation right of water uses in Nepal. According to this, the local water use practices should not be adversely affected by any water diversion from the river basin without due compensation, since community water users have the first right over the water resources. In the absence of adequate information on how much water will be left in the river after diversion, however it is not sure whether the customary water use right, or the legal water rights of the present user will be protected.

In the absence of the any formal rule and regulation for a bulk water transfer scheme, it is the governmental agency to decide how it is going to compensate to the donors communities for its decisions for such water transfer scheme. Nepal government has proposed to spend US \$18.33 million for the general welfare improvement activities in the communities as a compensation package to mitigate some of the environmental, social and economic adverse effects imposed by the project. Considering the present development stage and socioeconomic activities in the donor communities, this level of compensation package represents a considerable sum. Included, \$15 million is allocated for Resettlement Action Plan (hospital, road, and school services in the local communities, etc) and the remaining US \$ 3.33 millions are for social upliftment programs in the local communities (poverty reduction and equity related project programs).

Viewing the on-going project activities, and the involvement of local NGOs and even international agencies like UNDP for implementing some of the mitigating activities, the local community may get due compensation. However, actual distribution of the benefits of the project compensation package, within the community disproportionate to the actual project's affected sector due to skewed land holdings. Since, most of the mitigation expenditures are concentrated on provision of public goods like school construction, road constructions, hospital buildings, benefits of which can be obtained by the people permanently residing there, and not by the people directly affected. While certainly these programs are worthwhile, there seems to be little effort to develop local water management institutions.

## DISCUSSIONS AND CONCLUSIONS

The existing formal and informal institutions for water management in the Melamchi River basin are adequate to cope with local canal water management. Local institutions have evolved to resolve within canal system water allocation and disputes. There have been limited examples of resolving problems of neighboring canal systems. But these same institutions have not been put to the test of negotiating formal water rights along rivers and large-scale water transfers with a powerful neighbor like the city of Kathmandu. They are likely to be adequate to help buffer additional water allocation and competition problems brought about by a reduced supply. There seems to be an opportunity to use these existing institutional structures to develop better arrangements to manage



water resources in the Melamchi River. The project could be a good catalyzing event to bring stakeholders together in the area to improve their water management arrangements to better deal with less resource, and to better negotiate with Kathmandu.

Had there been firm water rights for the Melamchi users, the negotiation for transfer of water may have been much different, with the negotiation between those with water rights and the city. Unlike in the western USA and other developed countries, there is no such formal (or informal) rule and regulation related to bulk water transfer in Nepal (and in much of South Asia). This is one reason for a lack of direct negotiation between different stakeholders. This is particularly relevant in the face of growing urban drinking water crises worldwide, more in the context of developing countries. Here, Nepal government has brought a one time project compensation package to mitigate some of the negative impacts of the Melamchi project, and due compensating the donor communities for their loss of water rights. The compensation was materialized after several years of project related discussion in the nation. The importance of the compensation package is quite important and should not be understated. In our view though, more could be done to use the situation to stimulate institutional development for water management. Rather than negotiate with entities set up by the project authority, it would perhaps be better in the long run to negotiate through upgraded institutions.

The Melamchi river basin is in average years a water surplus basin considering its present water use activities and annual water flow in the river basin. From March to April the area faces more stress with low flows during the dry season. The different water balance studies in the recent past have provided mixed results. In the absence of enough hydrological information shared and discussed among different stakeholders of the river basins, there is still unease among the current water users in the basin. Some of the recent studies (based on existing scant data) have reported it is likely that there will be adequate water left over in the Melamchi River even after the proposed diversion (Mishra, 2000) in average years. But there remains a large uncertainty in the absence of adequate information provided from the project implementation authority, and inadequate scientific validation of the hydrological facts and figures.

Uncertainty in information about streamflow reduction has been an area of dispute between local stakeholders and those implementing the project. This underscores the need for good hydrologic information, transparency about what information exists, and straightforward reporting about uncertainties and what is not known.

Unlike other infrastructural project in Nepal, various activities are proposed to benefit the local people in this project. The Melamchi project board has recently allocated a compensation package of US \$ 18.33 million for the various programs

and project activities in the local communities to mitigate some of the project adverse impacts. Several NGOs and local organizations are also being involved in the project implementation process. The successful completion of these activities will certainly benefit the local people, however, it is not sure whether these activities would provide adequate and due compensation to those most affected. Largely, it also depends upon how these activities will be implemented and how local community concerns are included in the long run operation of the project

While ample attention on general development was given precedence, development of local water management institutions could be given more prominence. The project does provide a unique opportunity to develop people to better manage their local water resources. Given the large numbers of current stakeholders and water users in the Melamchi River basin, and large scale of interbasin transfer of water involved, adoption of an integrated River Basin Management arrangement might have been a better option to resolved some of these issues raised earlier. Such integrated River Basin level Planning and Management practices, if initiated earlier could provide better arrangement for the integration of the watershed, land-use, river use regulation, community's overall welfare improvement, and meeting urban water needs at he same time. However, such opportunity may not yet been completely missed, and there still is opportunity to use the project for some institution building.

The Melamchi Water Supply Project represents a situation that is common worldwide. Increasing demands from cities will pull water from rural water users. These users often will not have the institutional arrangements to negotiate and manage water adequately after the water transfer has taken place. Plus adequate and reliable data may not be available to know the extent to which changes will affect local users. The Melamchi Project has correctly paid a lot of attention to the affected area in the donor basin. This interbasin diversion may be an excellent opportunity to catalyze institutional development for managing water resources in the donor basin where competition will increase.

**Acknowledgement:** The financial support for carrying out the case study in the Melamchi River basin in Nepal was provided by Ford Foundation, New Delhi. The research is conducted by a team of scientists of the Water and Energy Commission Secretariat (WECS) in Nepal and the International Water Management Institute (IWMI). IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).

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## TRINITY RIVER TRANSBASIN DIVERSIONS IN A CHANGING ENVIRONMENT

Franklin E. Dimick<sup>1</sup>

### ABSTRACT

The Bureau of Reclamation constructed the Trinity River Division (TRD) of the Central Valley Project, California in the mid 1950's. The TRD was to divert water from the Trinity River in Northern California to the Sacramento River in order to supply irrigation, municipal and industrial water to users within the Central Valley of California.

The TRD, authorized by Congress in 1955 started diverting water from the Trinity River to the Sacramento River in 1964. During the next 10 years, an average of 1,234,000 acre-feet (1,522,139 cubic dekameters) of water (approximately 88% of the total flows of the Trinity River at Lewiston Dam) were diverted to the Sacramento River, producing electrical energy for the CVP as it moved between the rivers. At the same time, the river suffered a significant decline of salmon and steelhead populations.

In 1981, the U.S. Fish and Wildlife Service (FWS) was directed by the Secretary of the Interior to conduct a study to evaluate the flows necessary for the restoration and maintenance of the Trinity River fishery. That study was started in 1984.

In 1991, the Secretary of the Interior issued a decision that no less than 340,000 acre-feet (419,390 cubic dekameters) of water remain in the river, reducing diversions to the water users.

On October 30, 1992, the Central Valley Project Improvement Act was signed into law. Section 3406(b)(23) of this law required the FWS to complete their study and the Secretary of the Interior to make a final decision on the amount of water that must remain in the Trinity River for restoration and maintenance of the Trinity River fishery.

In 1999, FWS completed their study and issued the Trinity River Flow Evaluation with recommended flows for the Trinity River. The FWS has completed an Environmental Impact Statement for implementing the recommended flows. The recommended action in the EIS would reduce transbasin diversions from the Trinity River to the Sacramento River by an average of 254,500 acre-feet

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(313,926 cubic dekameters) per year. This would mean a loss of irrigation, municipal and industrial water available to CVP users as well as a significant loss of electrical energy. It will also have an adverse effect on threatened and endangered fish species in the Sacramento River. The Secretary of the Interior made a final decision and signed a Record of Decision December 19, 2000. The Record of Decision required implementation of the recommended alternative in the EIS/EIR. Westlands Water District and several other entities filed a lawsuit against the Secretary to halt the implementation on the grounds that the EIS was inadequate and did not meet NEPA requirements.

### HISTORY

The Reclamation Act of 1902 was passed to encourage people to settle the arid west by providing irrigation water to those lands. The passage of that act started an era of dam building and water project construction. The Bureau of Reclamation (formerly the Reclamation Service) was the Federal agency charged with carrying out the directives of that act and overseeing the construction of the water projects. One of the projects constructed by Reclamation was the Central Valley Project (CVP) in California.

The CVP was constructed to provide agricultural and municipal water as well as to provide flood control and electrical power. The project is located in the Central Valley of California. It covers an area extending from near the Oregon-California border on the north to the Tehachapi Mountains on the south and from the summit of the Sierra Nevada Mountains on the east to the coastal range of mountains on the west. The CVP provides water to over 2,000,000 acres (809,371 hectares) of land. It also provides approximately 1,000,000 acre-feet (1,233,500 cubic dekameters) of municipal water to 40 different entities. Project power plants produce approximately 5,169 Gigawatt hours of electrical energy each year.

The CVP is divided into 8 divisions: 1) Pit River Division (proposed); 2) American River Division; 3) Delta Division; 4) Friant Division; 5) Sacramento River Division; 6) San Felipe Division; 7) West San Joaquin Division; and 8) Shasta/Trinity River Division.

Congress in 1955, with the passage of Public Law 84-386 (1955 Act), authorized the Trinity River Division (TRD). The purpose of the TRD was to divert surplus water from the Trinity River to the Sacramento River for use within the Central Valley area. The 1955 Act authorized and directed the Secretary of the Interior (Secretary) to "... adopt appropriate measures to insure the preservation and propagation of fish and wildlife ..." The U.S. House of Representatives report on the 1955 Act states:

"... there is available for importation from the Trinity River, water that is surplus to the present and future needs of the Trinity and Klamath River

Basins, and that surplus water, in the amount proposed in the Trinity River division plan (704,000 acre-feet or 868,380 dekameters), can be diverted to the Central Valley without detrimental effect to the fishery resources.”

### TRINITY RIVER DIVISION - PROJECT DATA

The TRD is located in the Northwest corner of the state of California as shown in Figure 1.

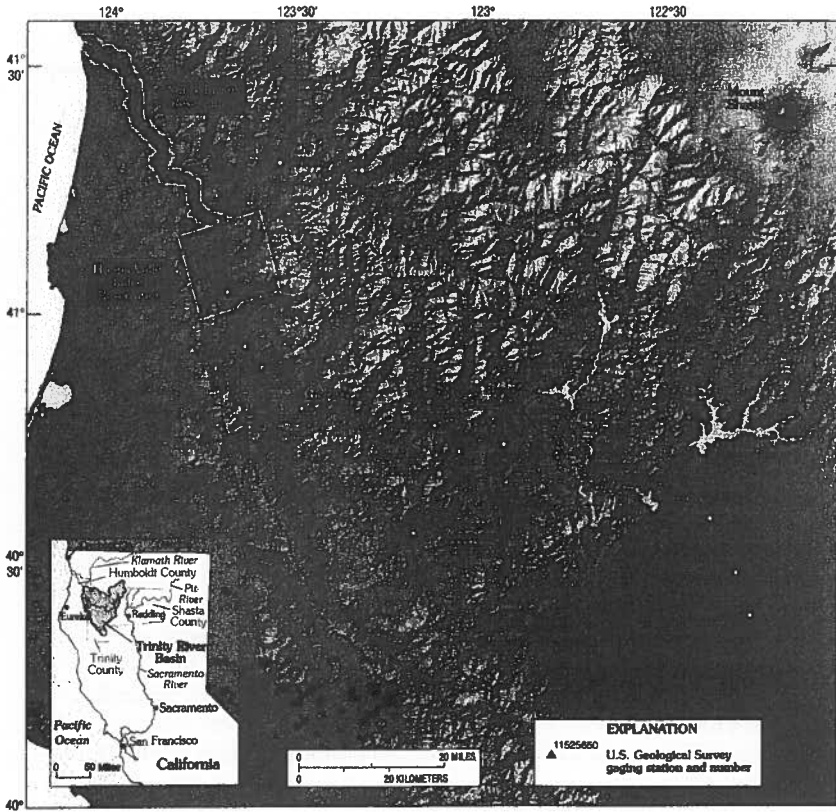


Figure 1. Trinity River Basin

The Trinity River is approximately 220 miles (354 kilometers) long and is a tributary to the Klamath River. The Hoopa Indian Reservation is bisected by the Trinity River at its confluence with the Klamath River. The Yurok Indian Reservation lies on both sides of the Klamath River from its confluence with the Trinity River to its outfall into the ocean.

Diversions from the Trinity River were to be accomplished by constructing three dams. The first dam is Trinity Dam and is located approximately 112 miles (180 kilometers) upstream from the confluence of the Trinity and Klamath Rivers. Trinity Dam is an earthfill structure 538 feet (164 meters) high with a crest length of 2,450 feet (747 meters). The reservoir formed behind the dam has a capacity of 2,448,000 acre-feet (3,019,600 cubic dekameters). Water is stored in Trinity Reservoir primarily during winter rain events and the spring snowmelt period. The average annual flow of the river at Trinity Dam is 1,396,000 acre-feet (1,722,000 cubic dekameters).

The second dam, Lewiston Dam, was constructed on the Trinity River approximately 3 miles (4.8 kilometers) downstream from Trinity Dam and serves as a regulating dam for releases from Trinity Dam. Lewiston Dam is also the diversion point for water diverted from the Trinity River Basin to the Sacramento River Basin. The third dam, Whiskeytown Dam, is located on Clear Creek, a tributary to the Sacramento River, a few miles south and east of Trinity Dam.

The TRD is operated and maintained by the Bureau of Reclamation. Central Valley Project Water Users have contracted to repay the reimbursable costs of constructing, operating and maintaining the TRD.

## BACKGROUND

Transbasin diversions from the Trinity River to the Sacramento River began in 1961 with significant diversions commencing in 1963. During the first 10 years of operation (1964-1973) an average of 88 percent (1,234,000 acre-feet or 1,522,139 cubic dekameters) of the annual flow at Lewiston Dam was diverted to the Sacramento River. This resulted in a flow in the river downstream of the diversion of about 12 percent (168,300 acre-feet or 207,600 cubic dekameters) of historical flows. Studies supporting the 1955 Act determined that annual instream fishery flow volumes of 120,500 acre-feet (148,600 cubic dekameters) were necessary to maintain or improve the fish and wildlife resources in the Lower Trinity River. The diverted water was delivered to CVP customers, primarily those south of the Sacramento – San Joaquin Delta area. Supplemental water was provided to an additional 475,828 acres (192,560 hectares) of land in the Central Valley.<sup>2</sup>

In 1971, the Trinity River Basin Fish and Wildlife Task Force was created to develop a program to stop the degradation of the fish and wildlife in the Trinity River Basin and to formulate a long term program for the Trinity River.

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<sup>2</sup> United States Department of the Interior, Water and Power Resources Service, Project Data Book, 1981, pg 221.



By 1973, a decline in the fishery populations below Lewiston Dam had been documented.<sup>3</sup> Although sufficient water was being released downstream for fish survival, the reduced flows were causing a change in the river morphology, which caused a degradation of fish and wildlife habitat. It was found that the reduced flows did not scour the sediments from gravels used by the fish for spawning and rearing habitat. Additional studies showed that the reduced flows were also creating a narrow, steep sided channel that reduced the amount of feathered edges, riffles and pools available for spawning and rearing habitat.

In 1980, Congress enacted the Trinity River Stream Rectification Act to control sediment deposition from the degraded Grass Valley Creek watershed, a tributary to the Trinity River. This act authorized the construction of Buckhorn Dam to capture sediments in the Grass Valley Creek prior to reaching the Trinity River. Land use practices on the Trinity River watershed was causing significant amounts of sediment to enter the river.

Because of the growing concern over the reduced fish populations, particularly salmon and steelhead, in the lower Trinity River below Lewiston Dam, Secretary Cecil Andrus issued a Secretarial Decision in January 1981. The decision provided for reducing diversions from the Trinity River in order to provide at least 340,000 acre-feet (419,390 cubic dekameters) of water annually in the Trinity River below Lewiston Dam in normal and wetter water years. It also provided that 220,000 acre-feet (271,370 cubic dekameters) of water in dry years and 140,000 acre-feet (172,690 cubic dekameters) of water in critically dry years would remain in the river. An Environmental Impact Statement prepared by the FWS in 1980 supported the decision.<sup>4</sup> The EIS addressed the Department of the Interior's proposal to restore salmon and steelhead populations in the Trinity River by increasing streamflow. The EIS concluded that the primary cause of the decline of the fishery in the Trinity River was the reduced streamflow and that increasing the flows would immediately improve the fish habitat and fish runs. This decision resulted in reduced transbasin diversions to water users in the CVP and reduced power production by the affected powerplants.

The 1981 decision also directed the U.S. Fish and Wildlife Service to conduct a study to assess the results of habitat and watershed restoration due to the increased flows in the river. The FWS did not initiate the study until 1984.

The Fish and Wildlife Service and the Bureau of Reclamation (known then as the Water and Power Resources Service) signed an agreement in December of 1980 that was approved by the Secretary of the Interior in January of 1981. This

<sup>3</sup> Hubbel, P. 1973. A program to identify and correct salmon and steelhead problems in the Trinity River Basin. California Department of Fish and Game.

<sup>4</sup> Environmental Impact Statement on the Management of River Flows to Mitigate the Loss of Anadromous Fishery of the Trinity River, California. Volumes I and II. U.S. Fish and Wildlife Service.

agreement required the Bureau of Reclamation to release the flows called for in the 1981 Secretarial Decision. It also required the FWS to submit a report to the Secretary at the end of 12 years that summarized the effectiveness of restoring flows and other measures including intensive stream and watershed management programs in rebuilding the Trinity River salmon and steelhead stocks.

In 1984, the Trinity River Basin Fish and Wildlife Management Act, P.L. 98-541 was passed by Congress to aid in the restoration of the Trinity River. The 1984 Management Act required the Secretary to develop a management plan to restore fish and wildlife populations in the Trinity River Basin to those levels that existed prior to the construction of the TRD. The act also created the Trinity River Task Force, which became a group that was chartered under the Federal Advisory Committee Act to make recommendations to the Secretary on restoration activities on the Trinity. The Act also directed that the restoration program developed by the Secretary would include "efforts aimed toward the rehabilitation of fish habitat in the Trinity River and its tributaries, modernization and increased effectiveness of the Trinity River Fish Hatchery, monitoring of fish and wildlife populations and the effectiveness of rehabilitation work, advising the Pacific Fisheries Management Council on salmon harvest management plans, and other activities as the Secretary determines to be necessary to achieve the long-term goal of the program."<sup>5</sup>

The FWS initiated work on the Trinity River Flow Evaluation Study in 1984. However, four years of the first 6 years of the study were drought years and consequently, pursuant to the 1981 Secretarial Decision, only low flows were available for study. In 1990, the Hoopa Valley Tribe filed an administrative appeal with the Secretary of the Interior, seeking his help in resolving the problems related to the low flows during the drought years. The Secretary, in July 1990, directed the FWS to review the flows prescribed in the 1981 Decision. The FWS reviewed the flows and in January 1991 the FWS developed an Environmental Assessment tiered off the 1980 EIS. This new Environmental Assessment evaluated the impacts of a proposal to provide at least 340,000 acre-feet (419,390 cubic dekameters) of water in the Trinity River, downstream of Lewiston Dam, each dry and wetter water year and 340,000 acre-feet (419,390 cubic dekameters) in critically dry water years if at all possible. The 1991 Environmental Assessment was adopted by the Secretary and a 1991 Secretarial Decision on Trinity River Flows was issued. The 1991 Decision included the 340,000 acre-foot (419,390 cubic dekameters) proposal of the Environmental Assessment. The Decision was immediately implemented by the Bureau of Reclamation. The increase of flows downstream of Lewiston Dam further reduced transbasin diversions of water to users in the CVP and also further reduced the amount of power produced by the CVP.

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<sup>5</sup> Trinity River Flow Evaluation Final Report, June 1999, pg. 10. U.S. Fish and Wildlife Service and Hoopa Tribe

The Central Valley Project Improvement Act (CVPIA), Title 34 of P.L. 102-575, was signed into law on October 30, 1992. The purposes of the CVPIA are:

- 1) To protect, restore, and enhance fish, wildlife, and associated habitats in the Central Valley and Trinity River basins of California;
- 2) To address impacts of the Central Valley Project;
- 3) Improve the operational flexibility of the CVP;
- 4) To increase water-related benefits provided by the CVP to the State of California through expanded use of voluntary water transfers and improved water conservation;
- 5) To contribute to the State of California's interim and long-term efforts to protect the San Francisco Bay/Sacramento-San Joaquin Delta Estuary;
- 6) To achieve a reasonable balance among competing demands for use of CVP water, including the requirements of fish and wildlife, agricultural, municipal and industrial and power contractors.

Section 3406(b)(23) of the CVPIA requires the Secretary of the Interior, in order to meet the Federal trust responsibility to the Hoopa Valley Tribe, to complete the Trinity River Flow Evaluation Study required by the Secretarial Decision of 1981 in a manner that insures the development of recommendations based on the best available scientific evidence regarding permanent instream fishery flow requirements for restoration and maintenance of the Trinity River fishery. The Secretary was required to forward the recommendations of that study to the Congress by December 31, 1996. The CVPIA further states that if the Secretary of the Interior and the Hoopa Tribe agree with those recommendations, any increase in the minimum Trinity River instream flows from the 1991 Secretarial Decision shall be implemented.

Two interesting things should be noted about the language of the CVPIA. First, the Flow Evaluation Study will be completed prior to December 31, 1996 and second; flows resulting from the recommendation of the Flow Evaluation Study will be permanent.

When the CVPIA was passed in 1992, 12 years had already passed from the time the Bureau of Reclamation and the FWS had signed their agreement providing for a 12-year study. However, since the FWS did not begin the study until 1984, Congress was giving them the full 12 years from the date the study was actually started in order to complete it.

Congress reauthorized and amended the 1984 Act in 1996. The amendment clarified that the management program was intended to assist in the resumption of fishing activities. It also provided that restoration would be measured not only by the number of returning salmon and steelhead spawners but also by the ability

of Tribal and non-tribal fishers to participate fully in the benefits of restoration through enhanced harvest opportunities.<sup>6</sup>

The Trinity River Flow Evaluation study was not completed until June of 1999, 15 years from its start and 19 years from its original authorization. The study resulted in recommendations that could have far reaching impacts to water and power users and the environment. The study recommended that instream flows downstream of Lewiston Dam be increased above those required in the 1991 Secretarial Decision. The quantity of water needed each year was to be based on the type of water year it is. The Study recommended that the minimum release downstream be 368,600 acre-feet (454,670 cubic dekameters) in a critically dry water year and that the maximum release downstream (excluding flood releases) be 815,200 acre-feet (1,005,550 cubic dekameters) in an extremely wet year. The weighted average of these recommended releases downstream is 594,500 acre-feet (733,300 cubic dekameters) of water annually. This is 426,000 acre-feet (525,470 cubic dekameters) more than what was released prior to 1981 and 254,500 acre-feet (313,925 cubic dekameters) more than was required in the 1991 Secretarial Decision. The water released downstream would serve two basic purposes. One purpose would be to maintain appropriate temperatures in the river necessary for good fish habitat. The second purpose would be to provide flows sufficient to cause natural changes in the riverbed to provide additional spawning and rearing habitat. The higher flows would be released to scour and transport sediments, clean gravel beds, scour deep pools, create riffles, remove vegetation from the riverbed, etc. and thereby create additional spawning and rearing habitat.

The Trinity River Flow Evaluation Final Report also recommended the establishment of an Adaptive Environmental Assessment and Management program to carry out the provisions of the Final Report. The Final Report defines AEAM as a "formal, systematic, and rigorous program of learning from the outcomes of management actions, accommodating change, and improving management."<sup>7</sup> This type of management program was recommended because the FWS recognizes that the data on which their recommendations were based was not complete and the desired results may not be achieved as projected. Therefore they recommend adaptive management of the program to ensure that modifications of the recommended flows are made as necessary to achieve restoration of the Trinity River Fishery. Although the timing and rate of flows specified in the Record of Decision can be changed through the AEAM process, the maximum annual volume for each water year cannot be exceeded.

The FWS, Bureau of Reclamation, Hoopa Valley Tribe and Trinity County completed a draft Environmental Impact Statement/Environmental Impact Report in October 1999 using the recommendations in the Trinity River Flow Evaluation

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<sup>6</sup> Ibid

<sup>7</sup> Ibid, Appendix N, pg N-2.

as the preferred alternative. The document was provided to the public for a review and comments through a notice in the Federal Register on October 19, 1999. The comment period was scheduled to close on December 8, 1999, a total of 50 days. Many of the parties to be impacted by this proposal complained about the short review period. They indicated that it was unreasonable to require responses to a set of documents more than a foot (.304 meters) high that describe impacts that result from a 15 year study in only 50 days. Due to these concerns, the comment period was extended another 18 days to December 20, 1999. There was still a major concern by reviewers on the length of time they had to comment, so on December 27, 1999 the FWS reopened the comment period until January 20, 2000. There were many reasons that the FWS wanted to keep the comment period short, including the hope that they could get a final Record of Decision in time for implementation in the spring of 2000. However, because of the number of comments received and the scope of those comments, a final EIS/EIR was not completed until late in 2000. There were 6,445 written comments on the draft EIS/EIR from individuals and organizations (1,009 letters and 5,436 pre-printed postcards).<sup>8</sup>

The adverse impacts described in the EIS/EIR are numerous and significant. Ceasing the transbasin diversion of an average of 254,500 acre-feet (313,926 cubic dekameters) of water each year, in addition to that which was stopped in 1981 and 1991, will have significant impacts to the environment and water users. Some of the listed impacts are:

1. Increasing mortality to listed species of fish in the Sacramento River due to increased temperatures.
2. Reduced water deliveries to CVP contractors.
3. Reduced power production.
4. Reduced recreation in the Sacramento River basin.
5. Loss of jobs.
6. Retirement of prime agricultural land in the Central Valley and Pajero Valley.
7. Increased groundwater pumping in areas where groundwater is already being pumped in excess of natural and artificial recharge.
8. Land subsidence in the San Joaquin Valley due to excessive groundwater removal
9. Reduced water quality in areas of the San Joaquin Valley due to lower flows and use of lower quality groundwater.

Because of potential adverse impacts to several species of fish in the Central Valley due to the proposed reductions in transbasin diversions, the FWS entered into Section 7 consultation under the Endangered Species Act on the proposed actions. Consultation on non-anadromous species was with the Fish and Wildlife

<sup>8</sup> Trinity River Mainstem Fishery Restoration Final Environmental Impact Statement/Report, October 2000, Fish and Wildlife Service, Bureau of Reclamation, Hoopa Valley Tribe, and Trinity County.

Service and consultation on anadromous species was with the National Marine Fisheries Service (NMFS). The Biological Opinions resulting from these consultations were released at the same time as the Record of Decision (ROD) described below.

The Biological Opinion for the anadromous species states that "it is NMFS' biological opinion that the action, as proposed, is not likely to jeopardize the continued existence of Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, or Central Valley steelhead."<sup>9</sup>

The Biological Opinion on other species states that "After reviewing the current status of the delta smelt, splittail, the environmental baseline, and the cumulative effects, it is the Services biological opinion that the proposed action is not likely to jeopardize the continued existence of these species..."<sup>10</sup>

On December 19, 2000, Secretary of the Interior Bruce Babbitt, as one of his last acts in office as the Secretary, signed a ROD for the Trinity River Environmental Impact Statement. The Secretary signed the ROD during a ceremony on the banks of the Trinity River at the Hoopa Reservation. Upon signing of the ROD, the Hoopa Valley Tribe ruling body passed a resolution which concurred with the ROD, thereby putting Section 3406(b)(23)(B) into effect, requiring the implementation of the flows recommended by the Trinity River Flow Evaluation Final Report.

Prior to the signing of the ROD, Westlands Water District, a CVP Contractor, had filed suit against the Secretary, requesting the court to issue an injunction prohibiting the Secretary from signing the ROD. The purpose of this suit was to clarify that Westlands, and others, were not prohibited from filing and/or pursuing lawsuits related to the flows after the Secretary signed the ROD, since the signing and subsequent approval by the Hoopa Valley Tribe initiated a section of a Federal Law. The court refused to issue an injunction stopping the Secretary from signing the ROD but after agreement by Federal lawyers, also ruled that Westlands and others could pursue lawsuits against the Secretary after the ROD was signed. Therefore, immediately after the ROD was signed, Westlands Water District filed a suit against the Secretary of the Interior and directors of the Fish and Wildlife Service and the Bureau of Reclamation. Several other entities have

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<sup>9</sup> National Marine Fisheries Service, Biological Opinion for the Trinity River Mainstem Fishery Restoration EIS and Its Effects on Southern Oregon/Northern California Coast Coho Salmon, Sacramento River Winter-run Chinook Salmon, Central Valley Spring-run Chinook Salmon, and Central Valley Steelhead, October 12, 2000.

<sup>10</sup> U.S. Fish and Wildlife Service, Biological Opinion of the Effects of Long-term Operation of the Central Valley Project and State Water Project as Modified by Implementing the Preferred Alternative in the Draft Environmental Impact Statement/Environmental Impact Report for the Trinity River Mainstem Fishery Restoration Program.

joined with Westlands in the lawsuit. The suit claims that the EIS and ESA work was inadequate and therefore the Secretary should not have signed the ROD.

Trinity County, as the lead entity for the State of California, is required to certify the EIR before those actions requiring action by entities within the State of California can commence. The County has not yet certified the EIR because of fear of being sued. The County indicated that they did not have the financial resources necessary to defend the EIR in a lawsuit.

### ACTIONS TO BE TAKEN

The Bureau of Reclamation and the Fish and Wildlife Service have begun to implement the recommendations of the Flow Study as required by the ROD. Design work is being completed to rebuild three bridges on the Trinity River downstream of Lewiston Dam so that the higher flows necessary for moving rocks and brush and cleaning the spawning gravels of sediment can be released from the dam. Efforts have commenced on implementing the AEAM program and staffing of the Trinity Management Council. Staffing of this group and the AEAM program staff will be delayed due to a hiring freeze imposed on all Federal agencies by the Bush administration. The implementation of the ROD is expected to have a budget of approximately \$15 million per year for the known future.<sup>11</sup>

Trinity County must certify the EIR. If they certify the EIR before the lawsuit over the EIS is settled, the entities filing suit over the EIS will likely file suit against the County.

If the suit by Westlands Water District and others against the Federal Government is successful, implementation activities will be suspended or abandoned until additional NEPA and ESA work can be completed or other actions required by the court are taken. The final outcome is unknown.

If the suit is not successful, the Department of the Interior will continue to implement the recommendations of the Flow Study and the ROD. The diversions of water from the Trinity River to the Sacramento River will be significantly reduced and impacts to agricultural water users, municipal water users, the economy, recreation users, fish and wildlife and the environment will occur. Additional water will flow down the Trinity River in an attempt to create additional spawning and rearing habitat through natural processes. If it does occur, whether or not the creation of additional spawning and rearing habitat will restore the fishery in the Trinity River is the big unknown in this whole issue. Biologists and environmentalists believe it will while water users and others are

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<sup>11</sup> Statements of USBR Mid-Pacific Region Regional Director at a Trinity River Task Force Meeting on February 8, 2001 in Sacramento, CA

skeptical. Only time and nature will provide the answer. If the fishery is restored, then only history will tell whether it was worth the adverse impacts to society of reducing established diversions of water from the Trinity River.

### SUMMARY AND CONCLUSIONS

The Bureau of Reclamation constructed the Trinity River Division (TRD) of the Central Valley Project, California in the mid 1950's to divert water from the Trinity River to the Sacramento River in order to supply irrigation, municipal and industrial water to users within the Central Valley of California.

Within 10 years of the start of diversions, degradation of the fishery in the Trinity River downstream of Lewiston Dam was noted. Efforts commenced to determine the cause of the degradation and appropriate corrective actions needed to restore the fishery. After almost 30 years of studies and several attempts to correct the situation by relatively small reductions of diversions, the FWS completed a study that recommended significantly reducing diversions to the Central Valley and thereby increasing flows in the Trinity River below Lewiston Dam.

In December, 2000 the Secretary of the Interior signed a Record of Decision that approves the EIS and requires the implementation of the recommended flows from the Trinity River Flow Evaluation Study. Trinity County has not yet certified the EIR for the same actions.

The Westlands Water District has filed a lawsuit challenging the adequacy of the EIS and accompanying ESA documents. They have been joined by other entities in that lawsuit.

Despite this lawsuit, the Department of the Interior has commenced implementation of the actions required by the Record of Decision.

Whether or not the actions of reducing the diversions from the Trinity River as spelled out in the Record of Decision will actually restore the fishery as planned is yet to be determined.

The future of the water supply to hundreds of thousands of people and many acres of land is now unknown.

The final conclusions of this issue cannot be written until all issues have been resolved. However, based on the Trinity River activities, it can be concluded that even though transbasin diversions have been implemented, well established and have created an industry and society dependent upon those diversions, they are not guaranteed in the future.



## INTERSTATE WATER BANKING THROUGH GROUNDWATER RECHARGE

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### ABSTRACT

With the establishment of the Arizona Water Banking Authority in 1996, Arizona is able to store its unused portion of the Colorado River allocation and save it for future uses, especially in times of drought. In addition, the underground storage facilities can be marketed as interstate water banking facilities to store any pre-agreed amount of Nevada's unused share of Colorado River water or to provide water to communities in Nevada and California, as well as to the downstream communities in Arizona by means of wheeling water through the Central Arizona Project (CAP) aqueduct.

To seize this opportunity, Vidler Water Company, Inc. has constructed an underground storage facility in La Paz County, Arizona; approximately 90 miles west of Phoenix. The site is ideally situated to receive and store the Colorado River water due to its proximity to the CAP aqueduct. The facility consists of a turnout structure, a metering vault, over 3 miles of concrete lined canals, approximately 120 acres of recharge basins with numerous control structures and gates, and a number of vadose zone recharge wells. The design capacity of the facility is 157,500 acre-feet per year, which is equivalent to 220 cfs.

Water depths in recharge basins are monitored by ultrasonic sensors in the basins. The groundwater table is monitored by a number of monitoring wells around the perimeter of the facility. The facility is automated to operate through a telemetry system communicated by satellite.

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### INTERSTATE WATER BANKING AND TRANSFER

In addition to Mexico, water in the lower reach of the Colorado River is shared by three states: Nevada, California and Arizona. According to an interstate agreement, Arizona is entitled to receive 2.8 million acre-feet of water per year from the Colorado River. Based on the projected water demand, however, it was estimated that Arizona would not be able to use its full allocation until the year 2030. The accumulated volume of water left in the Colorado River would amount to approximately 14 million acre-feet. Most of this unused water would go to southern California.

Since leaving a hefty portion of the allocation in the river is really a lost opportunity, the Arizona Legislature created the Arizona Water Banking Authority (AWBA) in 1996 in order to store the unused allocation from the Colorado River and save it for future uses, especially in times of drought. A five-person commission directs the activities of the AWBA, and the Director of the Arizona Department of Water Resources (ADWR) chairs the commission.

Each year, the AWBA would pay the delivery and storage costs to bring Arizona's unused Colorado River water into central and southern Arizona via the aqueduct owned and operated by the Central Arizona Project (CAP). The water would be stored underground in existing aquifers (direct recharge), or used by irrigation districts in lieu of pumping groundwater (indirect recharge or in-lieu recharge).

The AWBA could contract with similar authorities in California and Nevada to allow these states to acquire, on a year-to-year basis, a portion of Arizona's surplus of Colorado River water and store it in Arizona as a credit. When there is a need in the future, the contracting state would be able to draw that amount of water from the Colorado River directly.

In addition, through contractual and financial agreements, the AWBA is able to "deposit" any pre-agreed amount of Nevada's unused share of Colorado River water in Arizona's storage facilities each year on Nevada's behalf. When Nevada needs the water, it would initiate a "bank transaction" by informing Arizona of the amount it wants to withdraw. Nevada could take that amount directly from the Colorado River, instead of from its underground storage in the downstream areas. Arizona would then receive water credits that could be withdrawn at any time and transported down the CAP aqueduct to the downstream communities.

### THE VIDLER UNDERGROUND STORAGE FACILITY

To seize this opportunity, Vidler Water Company, Inc. received a permit from the Arizona Department of Water Resources (ADWR) to construct an underground

storage facility and market it as an Interstate Banking Facility. The Vidler underground storage facility is located at MBT Ranch in La Paz County, Arizona; approximately 90 miles west of Phoenix. The site is ideally situated to receive and store the Colorado River water due to its proximity to the CAP aqueduct (Figure 1).

The facility consists of a gravity turnout structure, a metering vault, over 3 miles of concrete lined ditches, and approximately 120 acres of recharge basins with numerous control structures and gates. The design capacity of the facility is 157,500 acre-feet per year, which is equivalent to 220 cfs. The layout of the facility is shown in Figure 2.

### **Site Description**

The site is located near the center of the Harquahala Basin, with an approximate elevation of 1,400 feet above mean sea level. Temperature ranges from an average daily maximum of 65°F in January to 106°F in July. Mean annual rainfall is about 6 inches, with a third occurring in the months of August and September.

The site is dominated by alluvial sediments composed of very fine grained silts. Coarser grained sands and gravels are not found at the surface. However, they are present at depth. Driller's logs from existing wells at MBT Ranch indicate of a conglomerate unit occurring at a depth of approximately 850 feet below land surface. The depth to bedrock in this area is thought to be greater than 1,000 feet.

The water table is approximately 430 feet below the land surface. Lateral movement of groundwater in the vicinity of the site is relatively slow due to the flat water table gradient. The transmissivity value ranges from 38,000 gpd/ft to 99,000 gpd/ft.

### **The Pilot Recharge Facility**

Prior to the design and construction of this underground storage facility, a permit was obtained by Vidler from the ADWR on June 1, 1998 to construct a pilot recharge facility to evaluate state-of-the-art recharge methodology which coupled shallow basins and vadose zone recharge wells. Three shallow basins, each with an approximate surface area of 4 acres, were constructed and tested for a period of 60 days to observe the average infiltration rate of the soil. Inside one of the three basins, two vadose zone recharge wells were installed.

Water was pumped at a rate between 3,000 and 3,500 gallons per minute (gpm) from the CAP aqueduct to the pilot recharge site through a 15-inch PVC pipeline approximately 6,000 feet in length. Hourly performance data, including water level and flow rate for each of the three basins, were collected by a programmable

logic controller and transmitted via satellite back to the office of HydroSystems for analysis. Soil resistivity and neutron logging data as well as groundwater level and water quality data were used in evaluating the efficiency of the water migrating to the aquifer. A total of 486 acre-feet of water was recharged during the 60 day test, that amounts to an average recharge rate of 0.67 foot per day per acre.

### **The Headwork**

The headwork of the storage facility consists of a gravity turnout structure at the bank of the CAP aqueduct, a concrete metering vault, and a junction structure which directs the water into two separate ditches. These three structures are interconnected by 84-in diameter reinforced concrete pipes.

The inside width of the turnout structure is 14 feet and the length at the top of the structure is 17 feet. A steel rack is placed at the entrance to prevent trash and fish from entering the recharge system. An 84" x 84" cast iron sluice gate with electrical actuator is provided at the outlet of the structure. A steel stop log is also provided at the structure so that the structure can be isolated for maintenance or repair.

The inside dimensions of the metering vault are 14 feet in length and width, and 19 feet in depth. The flow measuring device is of the sonic type, consisting of eight acoustic transducers mounted on an 84-in steel pipe that is placed through the center of the vault. Access hatch, ladders, lights and ventilation system are provided in the vault.

The inside dimensions of the junction structure are 16 feet in width, 22 feet in length, and 17 feet in depth. A concrete weir is placed in the middle of the junction structure to ensure that the 84-in pipe in the metering vault is always submerged. The junction structure has two 60-in pipe outlets which direct the flow to two separate ditches. Gates with electrical actuators are provided at the outlets for flow regulation and control.

### **Recharge Basins**

A total of twenty recharge basins are constructed at the site. Each basin, having long-thin shape, has approximately 5 acres in surface area. Every five basins forms a single recharge pod. The five basins in each pod share the same floor elevation and are interconnected with 18-in pipes. The side slopes of each basin is 6 horizontal to 1 vertical. The basins are oriented in north-south direction to minimize erosion of basin embankments due to westerly winds that blow almost each afternoon.

At the head of the twenty basins, there are two sediment basins to allow settlement of soil particles carried in the water. Each sediment basin is approximately 11 acres in size. Provisions are made at the sediment basins so that one of them can be isolated for maintenance and cleaning.

### **Conveyance System**

Two concrete lined main ditches are constructed at the site to convey the water from the CAP aqueduct to the sediment basins. Each main ditch has a trapezoidal cross section, with a bottom width of 2 feet and side slopes of 1.25 horizontal to 1 vertical. The depth of the main ditches is 4 feet, with a longitudinal slope of 0.0020 ft/ft.

At each sediment basin, the main ditch is branched out to two lateral ditches to feed the recharge basins. The lateral ditches are also concrete lined, with the same cross section and longitudinal slope as the main ditches, except the depth of the laterals is 3 feet. A concrete delivery structure is installed to deliver water from the lateral ditch to each recharge basin.

The total length of the main and lateral ditches is approximately 3 miles. The system also consists of a number of structures and gates for the purpose of flow bypass, regulation and control.

### **Recharge Wells**

At the present time, two vadose zone recharge wells have been installed at the site to collect site specific data for future operation references. Each recharge well is drilled to a depth of 180 feet. The borehole is 48 inches in diameter for the upper 150 feet. The diameter of the hole is reduced to 30 inches for the remaining 30 feet. The hole is backfilled with coarse gravel. A perforated PVC manifold is placed on top of the well to bring water from the basin to the well. As the demand for recharge increases in time, more vadose zone recharge wells will be installed at the site to increase the recharge rate.

### **Monitoring and Instrumentation**

The impact of recharge on water table in the aquifer is monitored by several existing and new wells around the perimeter of the recharge basins. Currently, the water table is approximately 420 feet below the natural ground.

The conveyance system and the basins are equipped with instrumentation for automated water level sensing that monitors water levels and flow data for permitting requirements. These data are also utilized for remote operation and control of the entire recharge system.

### CONCLUSION

With the completion of this underground storage facility, Vidler Water Company is able to market it as an interstate banking facility to store water on behalf of communities in Nevada and to supply water to the downstream communities in Arizona by means of wheeling water through the CAP aqueduct.



NOT TO SCALE



**FIGURE 1 - PROJECT LOCATION**

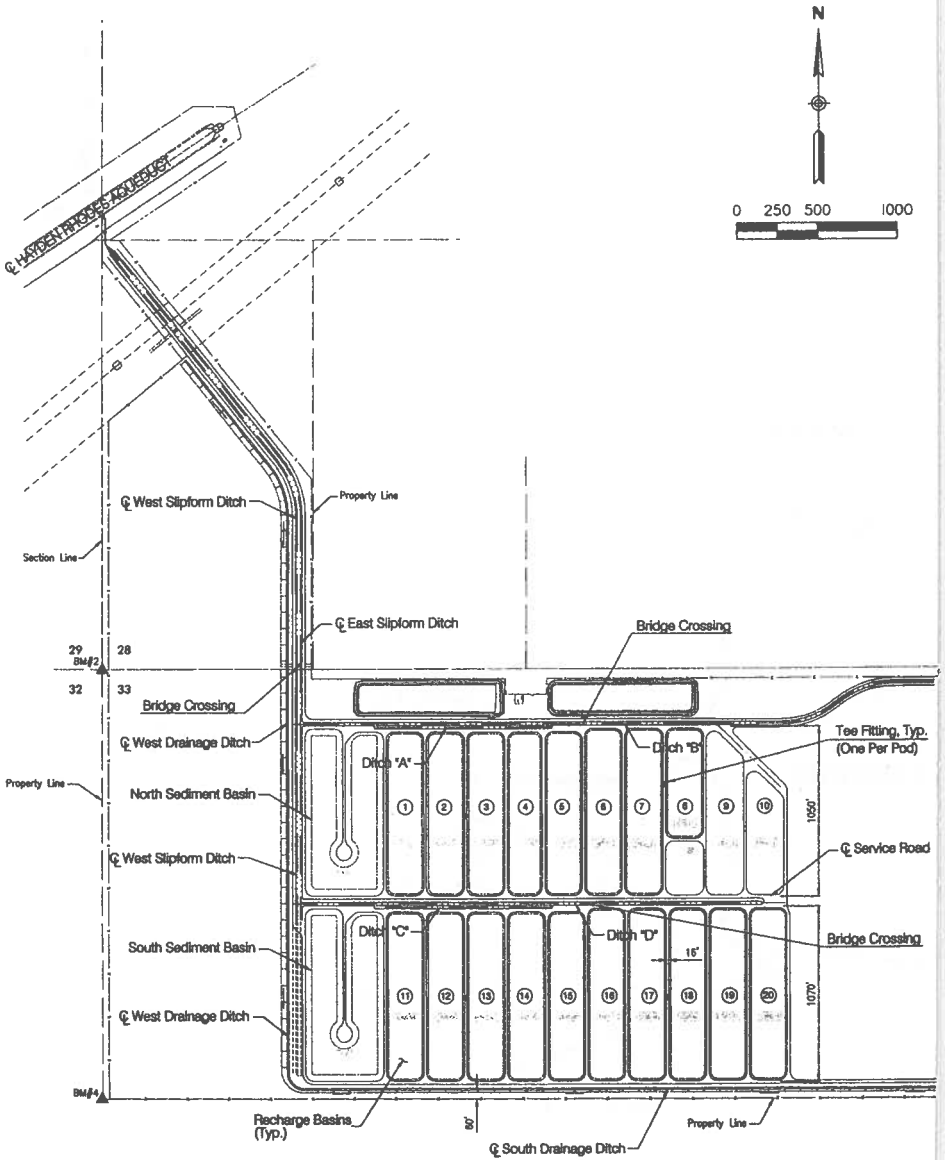


FIGURE 2 - VIDLER UNDERGROUND STORAGE SITE



# HOW DO WE DETERMINE THE REAL AMOUNT OF WATER AVAILABLE FOR TRANSFER FROM ONE BASIN TO ANOTHER?

by Maurice Roos<sup>1</sup>

## ABSTRACT

Development of a water market has resulted in an abundance of schemes to move water from one region to another. In California most of the natural supply of water is in the north while major needs are in the south. A review of the 1991 California Department of Water Resources (CDWR) drought water bank report showed three categories of water: (1) water from fallowing of irrigated land, (2) surface water stored in reservoirs, and (3) use of ground water in lieu of surface diversions. The major source area of bank water was the Sacramento Valley and the Sacramento-San Joaquin Delta; most users were in the south, in the San Joaquin Valley, the San Francisco Bay region and southern California. These users took their water (minus conveyance losses transferring water across the Delta) via the California Aqueduct.

The paper will review how net new water made available from these three categories can be estimated and what some of the issues are that need to be considered, relying on the drought water bank experience and the author's personal experience in hydrology and reservoir operation studies.

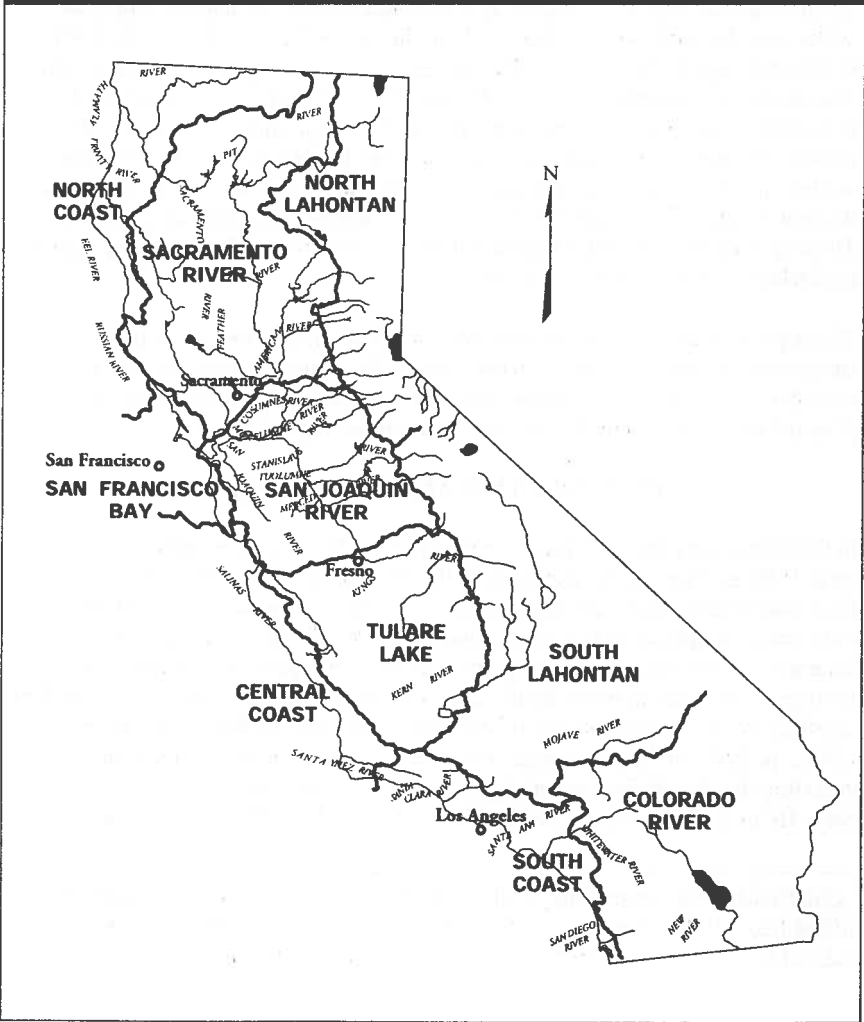
## INTRODUCTION AND BACKGROUND

In California very few new water supply facilities have been constructed since the early 1980's. One notable exception is the 800,000 acre-feet ( $987 \times 10^6 \text{ m}^3$ ) Diamond Valley off-stream reservoir (formerly named Eastside) in southern California, completed in late 1999, which will provide significant drought insurance to that area. But to keep this amount in perspective, compare it to average water demand in the South Coast region (see Figure 1 map) of 5.2 million acre-feet ( $6.4 \times 10^9 \text{ m}^3$ ) per year (California Department of Water Resources, 1998). In 1995, the total estimated statewide water use in an average year, including that for environmental purposes, was 79.5 million acre-feet ( $98 \times 10^9 \text{ m}^3$ ). Of the supply, about 65 million acre-feet ( $80 \times 10^9 \text{ m}^3$ ) was

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Figure 1. California's Hydrologic Regions



surface water, which is most likely to be diminished during a drought. Groundwater supplied around 14 million acre-feet ( $17.3 \times 10^9 \text{ m}^3$ ), of which approximately 1.5 million acre-feet ( $1.85 \times 10^9 \text{ m}^3$ ) were overdraft. Most groundwater basins in California have enough storage capacity to provide multiyear, sometimes multidecadal, supply out of storage. At the 1995 level of development, dry year statewide shortages were estimated to be around 5.1 million acre-feet ( $6.3 \times 10^9 \text{ m}^3$ ) including the 1.5 million acre-feet of groundwater overdraft. Some of the deficit could be made up by water transfers. The State has had some experience with such transfers with the Drought Water Banks of 1991 and 1992. Except for 1994, California has had good water years since then and therefore no need for a state-run water bank. Water year 2001 has again turned dry and a voluntary water bank has been reinstated.

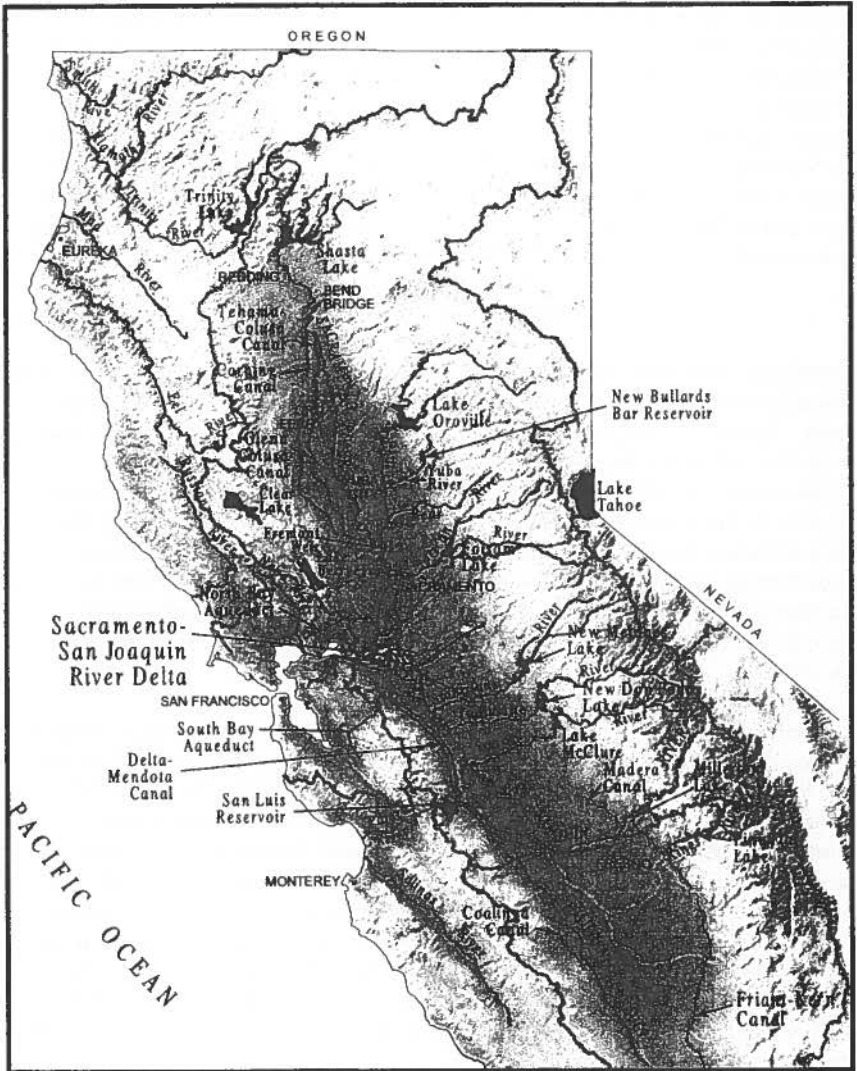
### TRANSFER AMOUNTS

Historically, there have been many trades or exchanges of water within major California service areas, for example along the Friant Kern and Delta Mendota canals. (See map on Figure 2). These are not usually controversial because uses are similar and within the control of a single operating agency. Interbasin transfers from one hydrologic region to another are more complicated. One has to consider the impact on other parties; often this includes water use changes, for example from agricultural to urban. During the irrigation season in a source region like the Sacramento Valley of northern California, all water is used for something; if not consumed by evapotranspiration, the excess diverted water either returns to the river via drainage canals or percolates to recharge ground water bodies.

California has another unique measure of control. Most areas receiving a transfer have to convey the transferred water via the California Aqueduct operated by the State Water Project (SWP) or in the canals of the Central Valley Project (CVP). As such, the operators of these two major water projects have a strong lever to insure that water accounting for transfers is reasonable and technically sound. The federal Central Valley Project serves water, mostly to agriculture, within the Central Valley and to urban portions of the San Francisco Bay region. The State Water Project primarily serves Southern California, the Tulare Lake region in the southern end of the San Joaquin Valley, and the San Francisco Bay region; the major share of SWP service is urban. Also the State Water Resources Control Board, which administers water rights, including place of use, has strong authority in the transfer arena.

Often the water to be transferred cannot be used or conveyed directly as furnished because of diversion or export constraints during the time of the season it is being generated. Here, too, the storage works of the two major water projects can be reoperated or adjusted to provide temporary regulation.

Figure 2 Location Map



## THE 1991 AND 1992 EMERGENCY DROUGHT WATER BANKS

The 1991 California Department of Water Resources drought water bank was an important pioneer effort in regional water transfers. Water year 1991 was the nadir of the six year 1987 – 92 drought, probably the worst overall sustained period of drought in the State's history, although not much worse than an earlier six year dry period from water year 1929 through 1934 (Roos, 1992). The first five months of the 1990 – 91 water year were extremely dry; California was only saved from a severe calamity by a "miracle March" with about three times normal precipitation (See Figure 3). The water year eventually closed with about three-fourths of average precipitation statewide and 43 percent of average runoff. The emergency water bank was created by a Governor's Executive Order in early February 1991 after half the rainfall accumulation season had passed and statewide precipitation was only 25 percent of average for the date.

Approximately 820,000 acre-feet ( $1.01 \times 10^9 \text{ m}^3$ ) of water were purchased for the 1991 water bank from those willing to sell at a price of \$125 per acre-foot. About 655,000 acre-feet was available for allocation to users with severe deficits, after 155,000 acre-feet were deducted for Delta water quality requirements (Figure 4). Thirteen percent of the amount was allocated for agricultural purposes in the San Joaquin Valley. Forty-seven percent was provided to urban users in the South San Francisco Bay area and southern California. The remaining leftover 40 percent went into State Water Project reservoir storage. The export cost was \$175 per acre-foot at the Delta, plus pumping and conveyance costs. In 1992, the supply situation was a little better in southern California and the Central Coast region. The 1992 bank purchased 193,000 acre-feet ( $238 \times 10^6 \text{ m}^3$ ) and delivered almost 159,000 acre-feet after about 20 percent was deducted for Delta water quality requirements. About 60 percent went to agriculture in the San Joaquin Valley. The export price at the Delta in 1992 was \$72 per acre-foot. Some 15 percent went to the California Department of Fish and Game for fish and wildlife uses and 25 percent to urban agencies in the South San Francisco Bay and South Coast regions.

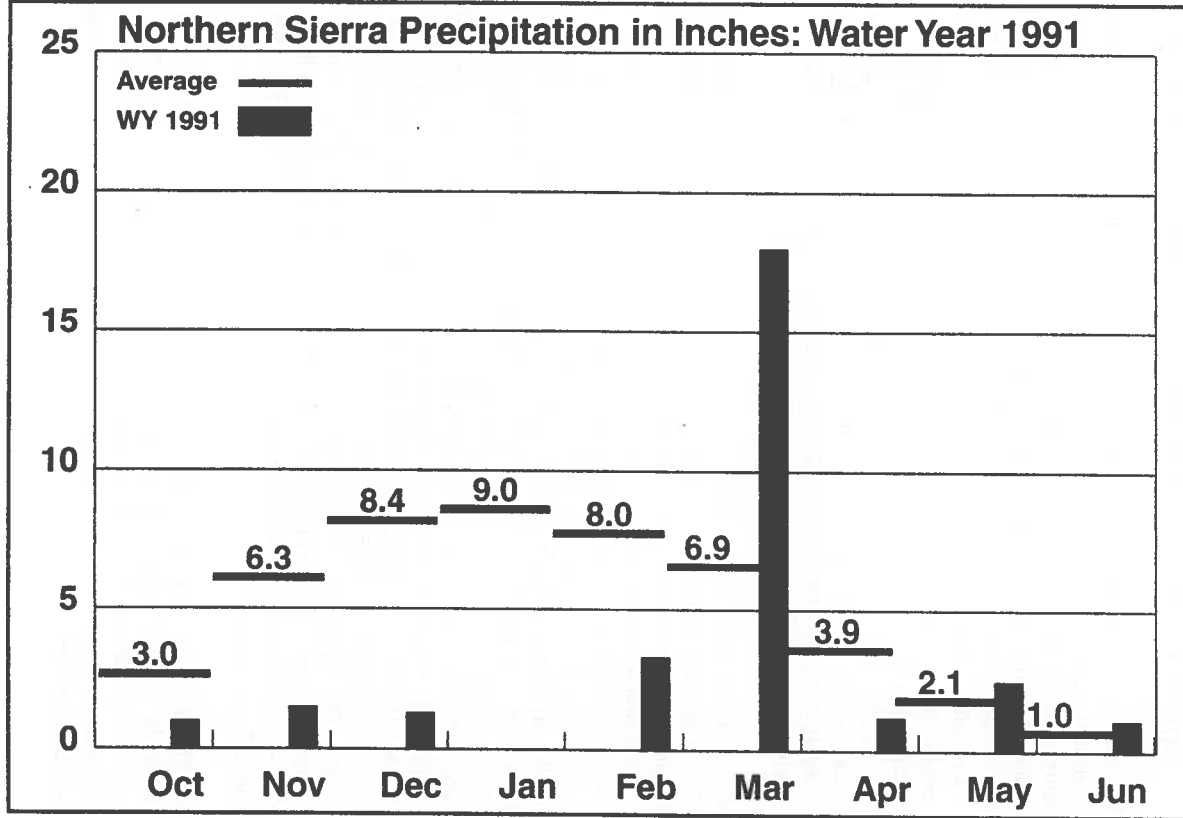
In addition to the State water bank, the U. S. Bureau of Reclamation furnished "hardship" water to some of its Central Valley Project users where economic losses would have otherwise been large. The amount provided in 1991 was nearly 66,000 acre-feet ( $81 \times 10^6 \text{ m}^3$ ). Some additional federal water was also provided to wildlife refuges.

### Generation of Transfer Amounts

Three components of source water were available for the bank in 1991:

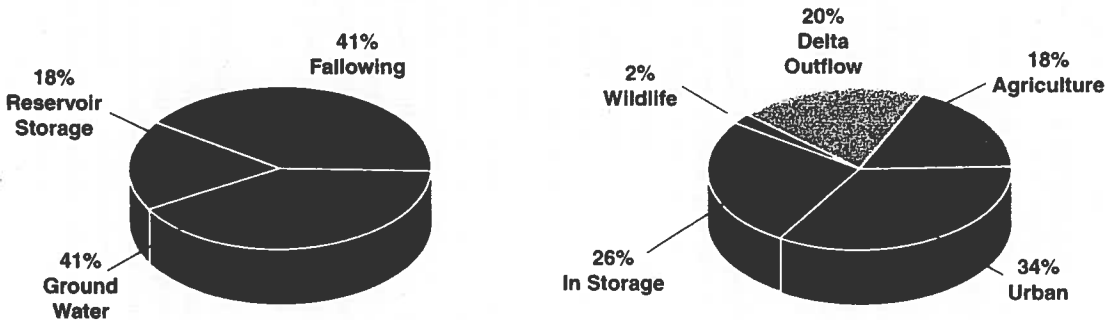
- (1) water from fallowing irrigated land,
- (2) surface water stored in reservoirs, and
- (3) use of ground water in lieu of surface diversions. Of these three, the most

Figure 3



**Figure 4**

**Water Sources and Allocations of the 1991 and 1992  
State Emergency Drought Water Bank  
(thousand acre-feet)**



**Sources of 1991 and 1992 Supplies**

	1991	1992
Following	415	0
Ground Water	259	161
Storage	147	32
<b>TOTAL</b>	<b>821</b>	<b>193</b>

**Allocations of 1991 and 1992 Supplies**

	1991	1992
Agriculture	83	95
Urban	307	39
Fish and Wildlife	0	25
Delta Outflow	165	34
In Storage	266	0
<b>TOTAL</b>	<b>821</b>	<b>193</b>

direct and easiest to measure was stored water in certain Sacramento River region reservoirs where the owners felt there was more water than needed by their normal customers. Most of the stored water purchased for the bank came from Yuba County Water Agency's New Bullards Bar Lake on the North Yuba River (Figure 2). This agency had built a large reservoir in 1970 with 966,000 acre-feet ( $1.2 \times 10^9 \text{ m}^3$ ) capacity, but had not yet fully developed the distribution system to use the supply and, therefore, had stored water left over for sale.

For water stored in a reservoir above the Delta, the net new supply for the water bank is fairly easily determined. It is the amount released downstream over and above what is required without the sale; usually this would be the amount exceeding the minimum fishery flow below their primary point of diversion at the eastern edge of the valley.

Measurement of the increase in downstream releases for the bank during the dry season is relatively easy. But that is not the end of the story. In a multiyear drought, the refilling of the additional vacated reservoir space may reduce export water supply in the Delta for the two major water projects, the State Water Project and the Central Valley Project. This is solved by a bookkeeping water balance at the reservoir, assuming the reservoir refills (to flood control limits). One looks at the period of time when refilling occurs of the increment which was sold the previous season. If this supplemental gain in storage comes at a time when the water can be used by the two big water projects, the projects would get a credit for water to be subsequently released or a monetary refund. In this case there would be no need to actually release water until later, because if San Luis reservoir (on the west side of the San Joaquin Valley) fills anyway later in the season, the net export loss is erased. Much of the winter reservoir filling, even in drier years comes during a few wet weeks when surplus Delta flows are available; usually the impairment of subsequent major project export supply is not large. In the event of a wet winter, the deficit is easily erased.

Use of stored groundwater, either by direct pumping, or more commonly as a substitute (in lieu use) for normal stream diversions, would theoretically follow the same rules as surface reservoir storage. In this case, however, the recharge is not directly measurable. When groundwater is used in lieu of surface diversions, the reduction of surface diversions has to be consistent with the history of such diversions and take into account of the likelihood that a deficient surface supply might be all that is available because of dry year conditions on the local watershed. But the net new water for transfer is basically still the difference between the actual diversions and what the diverter would have taken. Fortunately California summers are virtually rainless, so there is normally little need to adjust for weather and precipitation impacts on farm consumptive use.

In a multiyear drought, there may also be an impact on the water supply of the major project exports in the Delta as groundwater levels are restored, as typically



happens during the winter. Care needs to be exercised that the cone of depression of a well field does not induce added river seepage losses or that these losses can be determined satisfactorily. In 1992, for example, an aquifer performance test suggested that 30 percent of the water being pumped in nearby wells in Yolo County may have been induced Sacramento River seepage (CDWR, 1993, page 122). The 30 percent was then accounted for in the transfer amount. Wells much further from the river had a negligible effect at least during that season of transfer. There may be an effect during subsequent rainy seasons which would be difficult to quantify. Because of the increased reliance on the ground water option expected in future water banks, this element of doubt would be significant in multiyear droughts. Additional losses could become a burden on the two major water projects because winter season supplies in the Delta may be decreased.

The third option, that of fallowing land, depends on a theoretical estimate of reduction in water consumption. Direct measurement of depletion by fields is difficult; hence, unit seasonal evapotranspiration rates were calculated for the various crop types, and these figures were the basis for determining water transfer amounts. A variant was substitution of a lower water use crop with credit given for the difference. (Crop history records can be used to guard against a claim that a high water use crop was intended in a field.) Unit rates for reduced water use varied from 1 to 3.5 feet (0.30 to 1.07 m) for the season depending on the crop, with most crops falling in the 2 to 2.5 foot (.61 to .76 m) range. Somewhat lower rates were used in the Sacramento San Joaquin Delta because of cooler summer conditions there. In 1991, as March turned wet, rates for irrigated grain were reduced in recognition of reduced requirements for applied water. The major crop fallowed in 1991 was corn, which accounted for 36 percent of the fallowed acreage. Contrary to initial expectations, rice acreage was only about five percent, about 8,000 of the 166,000-acre (67,200 ha) total. Fallowing land was controversial because it has more third party impacts. The smaller 1992 water bank program did not include fallowing nor did a similar sized water bank in 1994.

#### **INVOLVEMENT OF THE CENTRAL VALLEY PROJECT (CVP) AND THE STATE WATER PROJECT (SWP)**

Although some have proposed a privatized buyer-seller water market, both of these two major governmental water projects are necessarily involved, primarily because of the need for conveyance space for the transferred water in the aqueduct system for many buyers. Space is not available in all months, sometimes because of export pumping rate limitations to protect Delta fisheries, although there is more flexibility during drought years because of water shortages. So there is a need to coordinate with regular CVP or SWP operations.

Another aspect that impacts interbasin transfers from the Sacramento and

San Joaquin River hydrologic regions to coastal and southern California regions is that the CVP and SWP share in the water requirements, including outflow to the ocean, needed to meet water quality and flow objectives in the Sacramento San Joaquin Delta. Excess water, when it occurs, is available for export. During dry water years there is no surplus Delta outflow in most months. Typically only one or two winter months then show surplus water. This means that errors in calculating the net available new water supply developed by transfer agreements will affect CVP and SWP water yields. Stored water releases can be timed to occur when usable. But there may also be local fishery problems from an upstream tributary reservoir with changing, especially lowering, upstream releases too rapidly during a temporary time of surplus in the Delta. This would result in some loss of stored water. The amounts can be measured, but it could be disconcerting to a buyer to see some shrinkage in amounts of water expected. Such operational losses are not likely during the dry season but could be a risk if the transfer from upstream storage extends into winter months.

Groundwater transfers involve some of the same problems in that recharge replacement generally continues during the subsequent water year. Distinguishing between recharge to replace local usage and the incremental portion to replace export transfer can be difficult. Most of the recharge would occur during the wetter periods when surplus flows are likely. Nevertheless, there may be a residual recharge (additional streambed loss) from the upstream rivers which could adversely affect low flow water supplies of the two water projects. To the extent this occurs, the water projects assume the risk. One solution could be a recharge loss percentage mutually agreed on by all parties. If the groundwater well fields are quite far from the major rivers, such losses are probably small, as long as the drought period is not too long, say not over two years.

Indirectly the two big water projects provide the buffer reservoir storage regulation needed to make a water transfer from north to south work. After the rains of March 1991, not all the purchased water in that year was taken and the leftover 265,000 acre-feet ( $327 \times 10^6 \text{ m}^3$ ) of unused water bank water was purchased by the State Water Project. Since the drought continued into 1992, all of the leftover purchased water was used. If 1992 had been wet, Project contractors probably would have objected to being the fallback position.

### WATER CONSERVATION

Agricultural water conservation, in the traditional sense of reduced application, can help individual farmers in a service area stretch their allocations, which are often reduced from normal amounts, during droughts. Unless evapotranspiration can be reduced, such measures do not add to the regional supply. Depletion remains essentially the same even with greater application efficiency, because these potential watershed source areas in the Sacramento and San Joaquin Valleys

are like closed basins with all irrigation season water accounted for somewhere in the hydrologic system either within the valleys or in the Delta. The only exception is during the few months of excess outflow. In recent history, the definition of excess outflow is shrinking, too, as outflow requirements for the environment and fisheries go up.

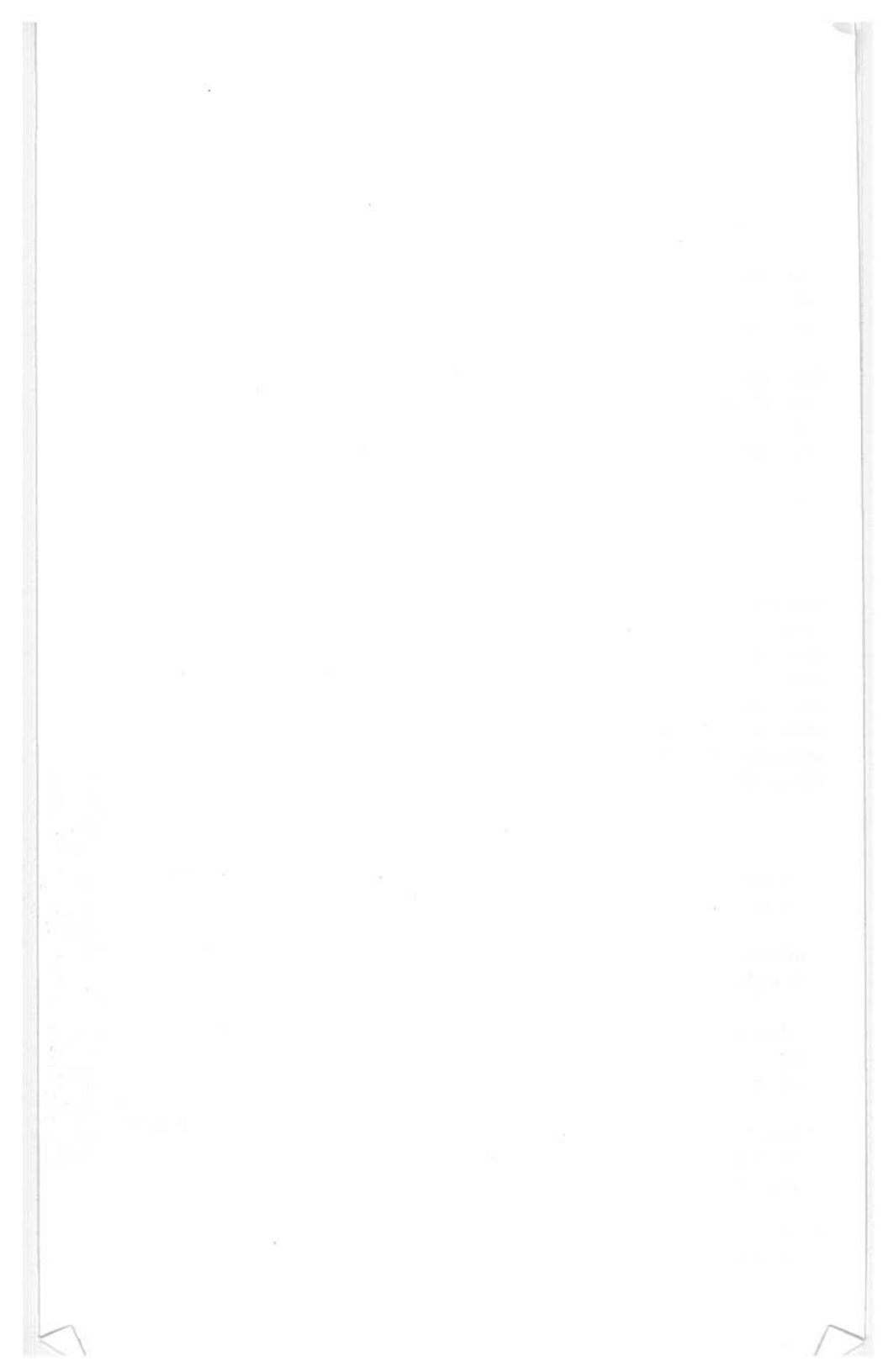
There may be some value in reduced field water applications (applied water savings) enabling greater rates of flow in certain river reaches. Also, occasionally reduced diversions may provide some advantage in upstream storage operations. The potential depends on where the physical controlling requirements for flow or water quality happen to be at the time. But the general rule is still valid; unless depletion changes there is no real water savings available for transfer.

### SUMMARY

This paper has been an attempt to outline the factors involved in determining the real amount of water available in a water transfer from one region to another. Sources of supply boil down to three basic categories: use of stored reservoir surface water, use of ground water storage, and use of water made available from fallowing or otherwise reducing the depletion on irrigated lands. Each situation is different, but the principles outlined can be used anywhere to make a determination of the actual quantity of water made available. Often the amounts will be less than proponents of the transfer will claim.

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# A CASE STUDY OF THE WATER RIGHTS, PURPOSES, OPERATIONS AND OBLIGATIONS OF THE BUREAU OF RECLAMATION'S SAN JUAN-CHAMA PROJECT

Jaci L. Gould<sup>1</sup>

Connie L. Rupp<sup>2</sup>

## ABSTRACT

The initial stage of the San Juan-Chama project was authorized by Congress in 1962. This transbasin project diverts water from the Navajo, Little Navajo and Blanco Rivers in the Colorado River basin to Willow Creek, a tributary to the Rio Chama in the Rio Grande basin in New Mexico. The project must be operated with sufficient water accountability to insure compliance with the Colorado River Compact, the Upper Colorado River Basin Compact, and the Rio Grande Compact. Additional limitations on water management flexibility stem from federal legislation and state water laws. As managers, we consider multiple conflicting requests for water. On this project, the state of Colorado often wants more water left in the Colorado streams instead of diverting it for the San Juan-Chama project. However, the use of this transbasin supply in New Mexico for multiple purposes has allowed us to literally escape disaster in the Rio Grande basin. The water budget in the middle Rio Grande valley is operating in the red with the demands for water already exceeding the available supply. Urbanization and population growth along the Middle Rio Grande valley is changing the use and increasing the demand for water. Ground water is being depleted at an alarming rate. The native Rio Grande water supply budget may be further reduced in the future by prior and paramount pueblo claims which as yet are unquantified. In addition to this already overwhelming demand for water, we must address the needs of the endangered Rio Grande silvery minnow for instream flow. Questions regularly arise on how the San Juan-Chama project waters can be managed and used within the middle Rio Grande valley. In the past there have been efforts to take advantage of modified operations to provide additional benefits such as rafting, fish and wildlife, and water exchanges among contractors. As more of the San Juan-Chama contract water is requested from storage and consumptively used, there will be changes in how the system of storage and water conveyance can be operated. There may be some opportunity to increase multiple use benefits, but in some cases there will be reduced options. Nevertheless, there will be changes in the operational flexibility of the project. This paper will sort

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through the web of water laws applicable to the project, explore the issues of water management and current operations and then offer some theories on how the San Juan-Chama water can be most effectively used.

## INTRODUCTION AND BACKGROUND

The San Juan-Chama Project was authorized by Congress in 1962 through PL 87-483, which amended the Colorado River Storage Act of 1956 (PL 84-485) to allow diversion of Colorado River Basin water into the Rio Grande Basin of New Mexico. The original planning projections for the San Juan-Chama Project contemplated an ultimate diversion of 235,000 acre-feet per year, with an initial phase development to accommodate an average annual diversion of up to 110,000 acre-feet. Only the initial phase was subsequently constructed by Reclamation. The project takes water from the Navajo, Little Navajo, and Blanco Rivers which are upper tributaries of the San Juan River, itself a tributary of the Colorado River, for use in the Rio Grande Basin, New Mexico. Primary purposes of the San Juan-Chama Project are to furnish a water supply, via trans-basin diversions, to the middle Rio Grande valley for municipal, domestic, and industrial uses. Project facilities are shown in Figure 1.

The primary storage reservoir for the Project is Heron Reservoir and is operated by Reclamation in compliance with applicable federal and state law, including the Rio Grande and Colorado compacts. Only imported San Juan-Chama Project water may be stored in Heron Reservoir; there are no provisions for storing native water. The maximum Project storage is 401,000 acre-feet. The annual project delivery requirement is 96,200 acre-feet. Project water is committed by contract to 16 different entities for a variety of irrigation, recreation, municipal, domestic and industrial purposes.

Two basic principles control the water release schedule from Heron Reservoir. The first is that groundwater pumping by contractors and those who lease contractors' water results in an annual depletion of the Rio Grande. These depletions are offset by releases of San Juan-Chama water from Heron Reservoir sufficient to ensure that no residual effect occurs to native waters of the Rio Grande. The New Mexico Interstate Stream Commission (ISC) computes these depletions and sets the volume and timing of the associated releases. Project waters are conveyed past Otowi for use by downstream contractors. The second principle is that water is often called for by contractors for release and storage in secondary facilities such as Abiquiu, Jemez, Cochiti, El Vado, Nambe Falls, and Elephant Butte Reservoirs. All contracts for Heron Reservoir water require water allocations be released from the reservoir by December 31 and that carryover storage in Heron is not permitted. The Middle Rio Grande Basin map is shown in Figure 2.

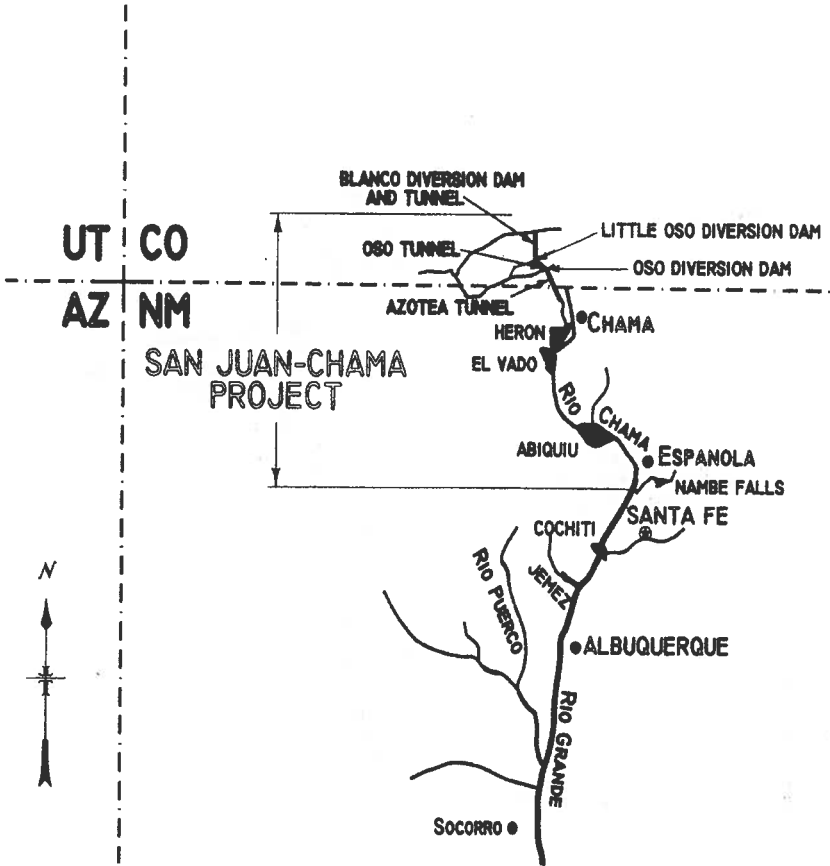


Figure 1. San Juan-Chama Project Map

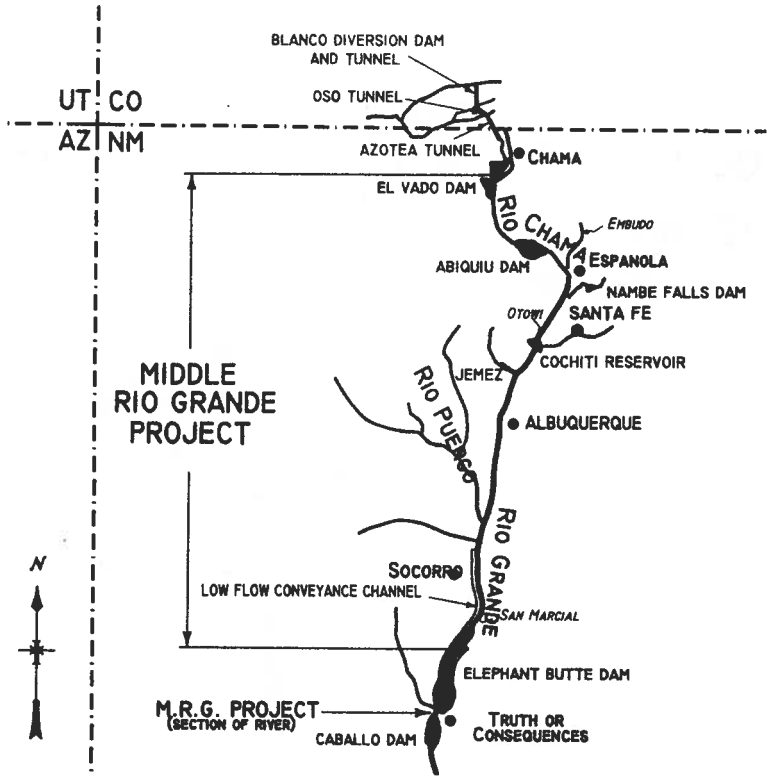


Figure 2. Map of Middle Rio Grande Basin



### RIO GRANDE SILVERY MINNOW

The Rio Grande silvery minnow was listed as endangered under the Endangered Species Act (ESA) in 1994. This listing elevated the awareness and concern of potential environmental effects of water and river management activities.

Drought conditions in 1996 resulted in significant challenges for those responsible for water management in the middle Rio Grande basin. Reclamation and the U.S. Army Corps of Engineers (Corps) closely coordinated all activities with other entities throughout the 1996 and 1997 irrigation seasons to minimize impacts to the silvery minnow. Actions taken during this period included leasing available water from the City of Albuquerque and other San Juan-Chama contractors, improvements to portions of the Middle Rio Grande Conservancy District's (MRGCD) water conveyance system, improvements in water measurement and operational efficiency, and increased biological monitoring.

To begin the process of addressing long term water needs within the middle Rio Grande valley, a team including the Fish and Wildlife Service, the Corps, Reclamation, ISC, and MRGCD prepared a draft "white paper" in November 1996. In response to this paper, representatives from environmental advocacy groups prepared a "green paper" containing additional suggestions. Both papers outlined possible water management strategies that could lead to long term solutions for protecting endangered species.

From 1996 to 1999, water needs for the silvery minnow were met through cooperation with the MRGCD and the supplemental water leases. The river was kept wet through Brown's Arroyo which is near Socorro. Through this program, Reclamation leased San Juan-Chama water from willing sellers. This water was released for use by MRGCD. In exchange, MRGCD bypassed an equivalent amount of native water which it is entitled to divert under its water rights. In 2000, a severe drought created water supply shortages on the Rio Grande.

Table 1. Supplemental Water Lease Program

Year	Amount of water released under lease program
1996	47,547 acre-feet (15.5 billion gallons)
1997	14,418 acre-feet (4.7 billion gallons)
1998	47,033 acre-feet (15.3 billion gallons)
1999	19,485 acre-feet (6.4 billion gallons)
<b>2000</b>	<b>159,922 acre-feet (52.1 billion gallons)</b>

By the year 2000, most of the Rio Grande silvery minnow were located in a small stretch of the river between San Acacia Diversion Dam and Elephant Butte Reservoir. This drought year also brought a request for a Preliminary Injunction by a coalition of environmental interest groups against Reclamation and the Corps requesting that we maintain continuous river flows to Elephant Butte Reservoir. The chronological history of the *Rio Grande Silvery Minnow, et al. v. Eluid L. Martinez, et al.* (CIV 99-1320 JP/KBM-ACE) and critical operational events is located at Table 2.

### **Year 2000 Water Operations**

In contrast to 1977 and 1996, the Upper Rio Grande Basin received much needed precipitation in early April increasing the snow pack to about 61 percent of average. Much of this snow pack melted off in late April and early May. The snow pack within the Upper Rio Grande Basin, as of the May forecast, was roughly 17 percent of average. In the Rio Chama Basin, there was an increasing trend in snow pack up until the last week of March. However, as seen in the Upper Rio Grande Basin, unusually warm spring temperatures caused a large part of the snow to melt off by the first week of May. Other basins contributing to spring runoff on the middle Rio Grande showed similar trends.

As expected with the sub-par snow pack, stream flow forecasts for the area were also well below average. Figure 3 illustrates the forecasted runoff for key locations in the Rio Grande Basin. Table 3 provides historical comparison of annual volume at selected USGS gages. These gages are depicted on the Map of the Middle Rio Grande Basin, Figure 2. The Low Flow Conveyance Channel (LFCC) is also identified on the map in Figure 2.

Table 2. *Rio Grande Silvery Minnow, et al. v. Eluid V. Martinez, et al.*  
Chronological History and Critical Operational Events

- **January 29, 1999** Plaintiffs file a Notice of Intent to Sue.
- **November 15, 1999** Environmental groups collectively filed suit against Reclamation and the Corps for NEPA and ESA violations.
- **January 21, 2000** Middle Rio Grande Conservancy District files motion to intervene.
- **April 10, 2000** Plaintiffs filed a Motion for Preliminary Injunction asking the Court to direct Reclamation and the Corps to maintain continuous river flows to Elephant Butte Reservoir.
- **June 12, 2000** The State of New Mexico files motion to intervene.
- **July 3, 2000** The City of Albuquerque files motion to intervene.
- **July 24, 2000** All Parties entered into court-ordered mediation before the Honorable Robert J. DeGiacomo, United States Magistrate.
- **August 2, 2000** Mediation concludes with an Agreed Order resolving the plaintiffs' Motion for Preliminary Injunction.
- **September 2000** Reclamation realized that the water provided under the Agreed Order would be insufficient to guarantee continuous flows through the end of the irrigation season.
- **September 13, 2000** Reclamation submitted a Biological Assessment of actions associated with the Agreed Order.
- **September 18, 2000** All Parties appeared again before the court for additional mediation and came to agreement on supplemental provisions.
- **October 5, 2000** The Supplement to the Agreed Order was signed.
- **October 16, 2000** MRGCD concludes the irrigation season.
- **October 17, 2000** MRGCD begins modified operations to deliver water to the Pueblos Prior and Paramount Lands until **November 15**.
- **October 26, 2000** Reclamation submitted a Supplemental Biological Assessment for the October 5 Supplement to the Agreed Order.

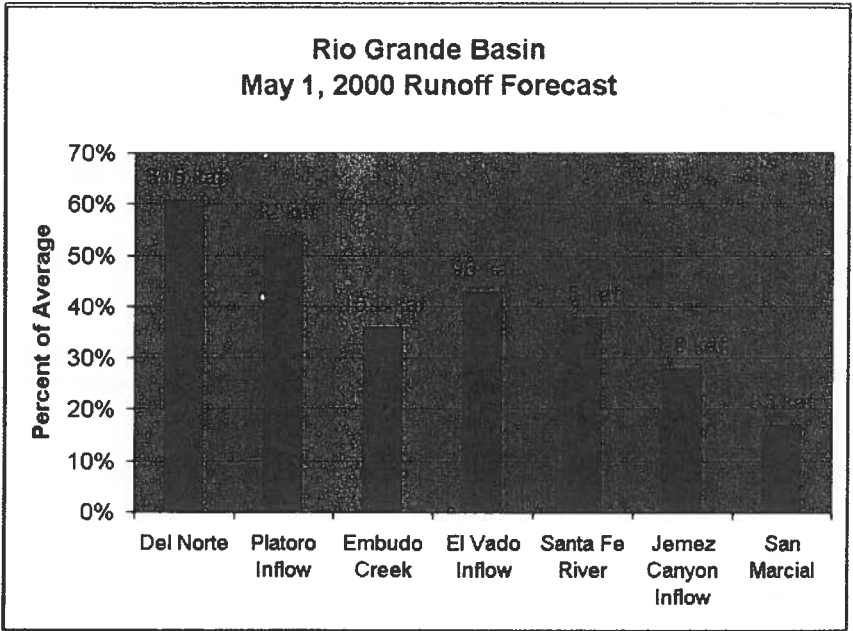


Figure 3. Graph of Forecasted Runoff

Table 3. Annual Volumes at Selected USGS Gages

USGS Gage	Average Annual Volume (ac - ft)	1977 Annual Vol (ac - ft) (% of avg)	1996 Annual Vol (ac - ft) (% of avg)	2000 Annual Vol (ac - ft) (% of avg)
Embudo	607,100	211,000 (35 %)	307,000 (51 %)	281,000 (46 %)
Otowi	1,144,000	434,000 (38 %)	671,000 (59 %)	753,000 (66 %)
San Marcial (LFCC+River)	593,000	224,000 (38 %)	278,000 (47 %)	441,000 (74 %)

Comparison of historical gage data from 1970 to 2000 shows that calendar year 2000 was very similar in total gage flow to the 1977, 1981, and 1996 dry years.

Reservoirs on the Rio Chama and Rio Grande started the year nearly full, and ended the year fairly empty, as shown on Table 4 and Figure 4.

Table 4. Comparison of End-of-Year Storage at Reservoirs on the Rio Chama and Rio Grande

Reservoirs	Allowable Storage acre-feet (af)	1999 End of Year (EOY) Content (af) (% of full)	10 Most Recent Year Avg EOY Content (af) (% of full)	2000 EOY Content (af) (% of full)
Heron	401,332	379,936 (95 %)	365,120 (91 %)	267,252 (67 %)
El Vado	186,252	139,480 (75 %)	99,346 (53 %)	23,964 (13 %)
Abiquiu /1	183,881	177,313 (96 %)	167,227 (91 %)	91,320 (50 %)
Cochiti	49,467	50,814 (100 %)	53,927 (100 %)	51,682 (100 %)
Jemez Canyon	24,425	18,375 (75 %)	21,715 (89 %)	4,548 (19 %)
Elephant Butte	2,040,010	1,708,173 (84 %)	1,650,000 (81 %)	1,284,000 (63 %)

/1 On October 18, 2000 MRGCD started moving 17,500 af of San Juan-Chama water to the City of Albuquerque storage pool in Abiquiu. This was at the request of Reclamation and approved by Albuquerque. The operation was needed in order to draw El Vado down to elevation 6810 feet allowing Reclamation to perform emergency maintenance on the outlet works trash track.

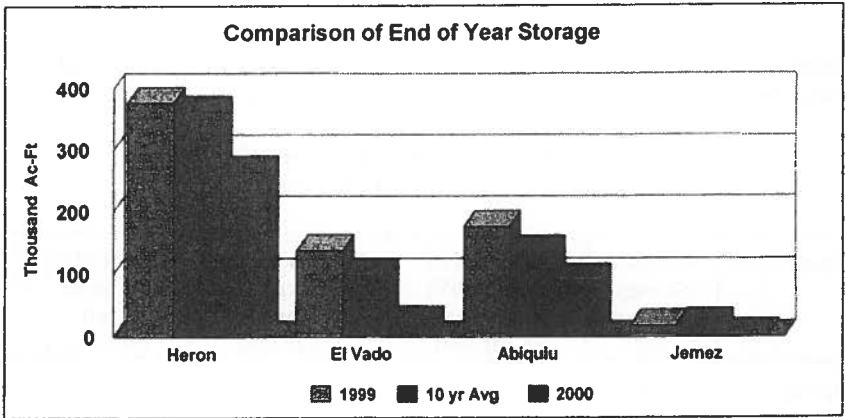


Figure 4. Comparison of End-of-Year Storage at Reservoirs on the Rio Chama and Rio Grande

An abnormally wet year in 1999 allowed Reclamation to carry over leased supplemental water which was not used. The 28,595 af of 1999 lease water was used by the end of April 2000.

Reclamation began acquiring additional San Juan-Chama water in March 2000. The first release of year 2000 lease water was an eight-day release from March 13 through March 20. The second release was April 3 through April 22. Supplemental water was then released on a continuous basis from May 6 through September 30. From October 1 through October 21, the City of Albuquerque moved 8,473 af of their San Juan-Chama water from Abiquiu Reservoir to Elephant Butte Reservoir. The river was kept wet after October 21 from MRGCD irrigation district return flows and runoff from rain events that occurred intermittently valley-wide.

During the last week of July, the flow below San Acacia Diversion Dam fell below minimum target levels. As a result, the river became intermittent for at least 7 miles in the reach between the south boundary of the Bosque del Apache National Wildlife Refuge and Fort Craig. Pumping from the LFCC was not at full capacity during this period but did contribute to continuous flowing conditions downstream of Ft. Craig.

The Agreed Order, which resulted from mediation on the silvery minnow lawsuit mentioned earlier, provided for an additional 85,900 af of water. This included 36,000 af for MRGCD to use for carriage and irrigation losses. A benefit to the silvery minnow of using this water for carriage was that it helped move

supplemental water through the system with significantly less transport losses. The releases for MRGCD's carriage and irrigation water began from Heron Reservoir on August 18, 2000 and ended September 14, 2000 with a total release of 20,000 af. Releases started from Jemez Reservoir on September 20 and lasted until the end of irrigation season on October 15. A total of 10,874 af was released which left 1,126 af of agreement water remaining in Jemez Reservoir. Reclamation acquired 49,900 af of supplemental water that included 20,900 af from MRGCD in Heron Reservoir and 29,000 af from the City of Albuquerque in Abiquiu Reservoir.

The Agreed Order water ran out on September 20, 2000. As per the subsequent supplement to the Agreed Order, the City of Albuquerque provided up to 45,000 af of San Juan-Chama water from Abiquiu Reservoir. About 7,127 af of this water was released from September 20 through September 30 and exchanged with native water. From October 1 through October 21, 8,473 af of water was released from Abiquiu Reservoir and moved to the City of Albuquerque's pool in Elephant Butte Reservoir. Of the 45,000 af provided by Albuquerque in the supplement to the Agreed Order, only 15,600 af was used. The releases were stopped early because adequate water was in the river from the end of irrigation season drain out and rainfall runoff.

Figure 5 graphically summarizes the supplemental water used in 2000 and compares it to supplemental water used in 1996, 1997, 1998 and 1999. The annual volumes are substantially different from 1996 to 1999 because in those years the river was managed for a recession to Brown Arroyo and was not kept wet all the way to Elephant Butte Reservoir. In 2000, supplemental water was used to manage for a continuous flowing river all the way to Elephant Butte which took a substantially higher volume of water.

Figure 6 shows the actual San Acacia flows compared to the minimum targeted flows. Minimum target flows were met except for the period between July 25-27.

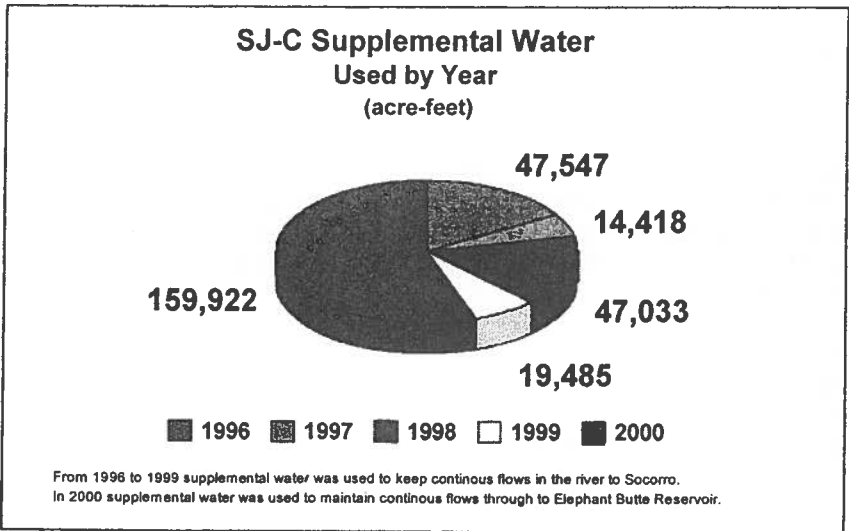


Figure 5. San Juan-Chama Supplemental Water Use

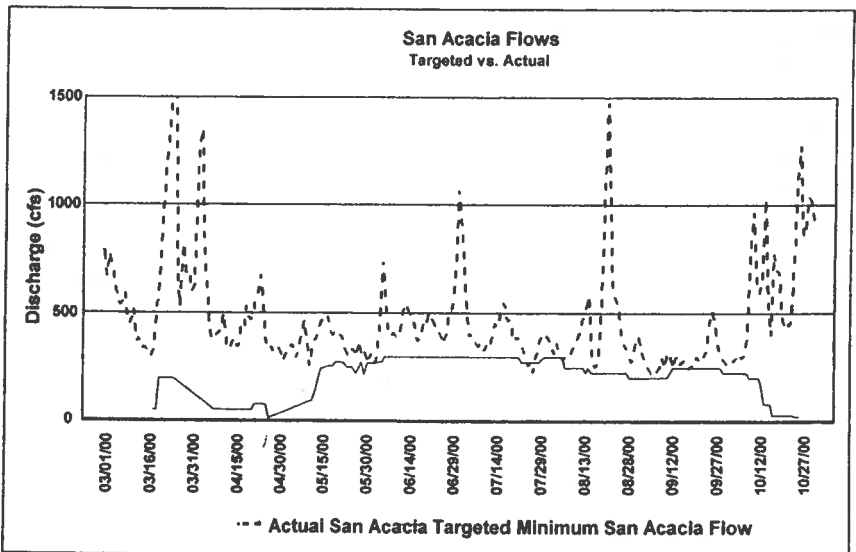


Figure 6. Targeted Versus Actual San Acacia Flows During 2000 Water Year



During the irrigation season from March 1 to October 31, 2000, there was adequate native flows in the river system to exchange with supplemental San Juan-Chama water. Native flows included Embudo gage data which reflects the native flow in the river above the confluence with the Rio Chama, the native water releases from Abiquiu Reservoir which reflect the amount of native flow in the Rio Chama, and an average daily City of Albuquerque wastewater return flow.

### **Low Flow Conveyance Channel Pumping**

Reclamation installed and operated 20 pumps between Socorro and Elephant Butte Reservoir during the 2000 irrigation season. These pumps moved water from the LFCC into the Rio Grande. The pumps were operated to assist in maintaining a minimum target flow of 50 cfs at San Marcial, allowing Reclamation to reduce supplemental water releases from upstream storage. The pumps also provided flexibility for filling in depressions in river flow that were observed moving downstream.

On July 25, Reclamation started operating pumps, one at the north boundary of Bosque del Apache and two downstream of Fort Craig. These pumps were operated as needed to maintain minimum flows, but their capacity was limited. Reclamation acquired more pumps throughout the summer, and brought them on-line as they arrived. In the Agreed Order, Reclamation committed to providing 75 to 100 cfs pumping capacity to move water from the LFCC to the Rio Grande below San Acacia Diversion Dam.

The pumps were completely shut off on October 23, 2000 because the volume of water in the river was adequate to maintain continuous flows due to District return flows and rain fall runoff.

### **2000 Summer Monsoon Season**

Typical weather patterns for New Mexico include a seasonal monsoon developing near the start of July and continuing through the summer. This year the typical monsoonal pattern never developed. Temperatures were unseasonably warm and rainfall was well below average. Rainfall did help out in early March when supplemental releases were stopped for 13 days starting on March 21, and again at the end of October where San Juan-Chama releases from Abiquiu Reservoir were stopped on October 22 through the end of October.

### **2000-2001 Winter Operations on the Rio Chama**

The City of Albuquerque's 2000 San Juan-Chama allocation in Heron Reservoir was waived from delivery by December 31, 2000 to provide 100 cfs flow on the Rio Chama between Heron and Abiquiu through March 31, 2001.

### LONG TERM SOLUTIONS

Numerous challenges will need to be overcome in order to formulate long term solutions to the Rio Grande problems. In 2001, the mediation under the silvery minnow case was terminated and we have returned to litigation. However, the stakeholders have recognized the need to collaboratively come together to work on solutions. A positive beginning occurred in 2001, with the State of New Mexico obtaining a special permit for storage of water for an ESA conservation pool. The Compact Commissioners agreed to under-delivery of New Mexico's obligations so that runoff water, in excess of existing middle valley water right demands, could be stored in upstream reservoirs and released in a manner more compatible with the needs of the silvery minnow. This creative short term idea lends some hope that long term solutions will be possible.

The stakeholder workgroup has identified a number of ideas to improve the conditions for the minnow. Some of the ideas focus on improved water management.

- The Middle Rio Grande Conservancy District has proposed a water banking program. This program would be difficult to implement because the water rights are based on vested rights rather than actual irrigated use. It will be difficult to distinguish between a "paper right" and real water for the bank. Also, the amount banked would need to be limited to the consumptive use savings from crop forbearance and not a diversion right because of potential adverse impacts from banking water which is needed and used by the basin in the form of return flow to the river and groundwater recharge.
- The current water management could be improved by optimizing storage in upper reservoirs during spring runoff and then timing releases to maximize the river conditions. The Rio Grande Compact Commissioners have agreed to New Mexico's proposed under delivery at Elephant Butte so that it can store water in upstream reservoirs. Because of Reclamation's supplemental water program, New Mexico has a credit of water in Elephant Butte which can be released for delivery to southern New Mexico and Texas.
- It may be impossible to keep the entire stretch of river wet at all times. River channel improvements and modification of habitat to assist recovery of silvery minnow in exchange for reduced flow requirements may be an acceptable alternative. Salt cedar removal and development of special areas for the minnow may be necessary.

- Groundwater pumping in some areas of the basin may be possible without harming the aquifer. If the pumping is strategically timed as part of a conjunctive use program, it may work to supply water to vital reaches of the river at critical times.
- It may be necessary to permanently install pumps in the Low Flow Conveyance Channel. The channel serves as a water collector in that part of the basin and it may be the fastest way to get water into the river if it suddenly drops. Any permanent installation would be met with resistance by people concerned about Compact deliveries. The LFCC was constructed to improve water deliveries to Elephant Butte Reservoir. There is concern over increased losses of water if the water is returned to the main river channel.
- A key component for silvery minnow survival may be the removal of San Acacia Diversion Dam. Most of the minnows are located below this dam and better habitat for the minnow exists above the dam. The dam was built by the Middle Rio Grande Conservancy District and rehabilitated by Reclamation and is considered part of the Middle Rio Grande Project. If substitute facilities for diverting and delivering water to that portion of the District can be designed and constructed, it may be possible to reach an agreement to remove the dam.

As the workgroup begins to meet and identify possible solutions, ideas will be discarded and new concepts proposed. The important factor will be the ability of the parties to work together and have enough trust in each other to move forward toward resolution. It is our belief that the San Juan-Chama water should not be viewed as a potential long term solution to this water management problem.



# **SQUEEZING BLOOD FROM A TURNIP, OR MAKING THE MOST OF EXISTING TRANSBASIN PROJECTS**

Philip C. Saletta<sup>1</sup>

Kevin Lusk<sup>2</sup>

## **ABSTRACT**

Colorado Springs Utilities derives about eighty percent of its water, about 77,000 acre feet per year, from four different transbasin diversion projects located in the Upper Colorado River Basin. These are the Blue River Project, the Homestake Project, the Twin Lakes project, and the Frying Pan-Arkansas Project. As the demand for water increases and the prospects for new large transbasin projects diminishes, it becomes vitally important to maximize the use and benefit from the existing projects. Colorado Springs Utilities has been and continues to be very proactive in developing new and innovative ways to make the most of our water system. In 1961, Colorado Springs started delivering reclaimed transbasin wastewater to large irrigation customers through our Nonpotable Wastewater Reuse System. Colorado Springs Utilities is currently in the process of developing a Nonpotable Master Plan to expand the use of reclaimed water. In the late 1970's Colorado Springs began our exchange program. The concept of the exchange program is to recapture the reusable return flows of transbasin water through water trades and effectively increase the yield of these systems. Currently, Colorado Springs Utilities is working with the Southeastern Colorado Water Conservancy District in developing a plan to re-operate the Frying Pan-Arkansas facilities to better manage existing storage space in the upper Arkansas River Basin. Colorado Springs Utilities through its Water Resource Plan will combine these valuable water resources with increased storage space to deliver additional water supply to the community of Colorado Springs that will meet the level of water demands projected for the year 2040.

## **INTRODUCTION**

Located at the foot of Pikes Peak on the Colorado front range (Figure 1.), the City of Colorado Springs, Colorado, was founded in 1871 as a resort community and as a center of commerce for the gold miners of Colorado's Mining Districts. The City is situated within the Arkansas river basin at the confluence of Fountain and Monument Creeks. These streams are historically ephemeral in nature, and realize much of their annual flow in a few days of spring runoff and during flood events from occasional heavy precipitation. Colorado Springs is not located near

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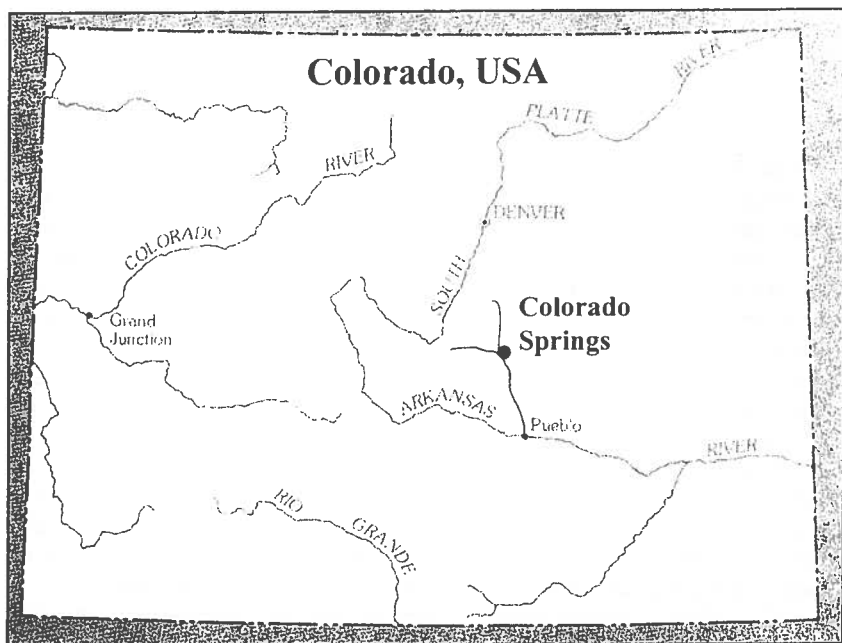


Figure 1. Colorado Springs Vicinity Map

a major river or body of water. The climate is characterized as semi-arid, with average annual precipitation of about 15 inches. Much of this amount is concentrated in a few large precipitation events each year. It was this lack of an adequate and reliable local water supply which led to the development of transbasin water projects. The City first looked to the far side of Pikes Peak for transbasin water to augment its local supplies, then, as demands grew, it reached further. Colorado Springs now takes water from four transbasin diversion projects located in the Upper Colorado River Basin over 200 miles away.

Colorado Springs Utilities (CSU) is a four service Utility that serves the community of Colorado Springs. CSU's Water Resources Department serves water to an approximate 204 square mile service area with a population of over 376,000 people. During the 2000 water year, CSU delivered 96,487 acre feet (86 MGD) to our customers (Table 1., Figure 2.). Of this, 77,440 acre feet (69 MGD) was derived from transbasin sources. This equates to about 80% of the annual supply. The average annual yield of Colorado Springs total water supplies, developed and undeveloped, is projected to be 220,900 acre feet (197 MGD), of which 181,200 acre feet (156 MGD) will be from transbasin sources.

Deliveries to Colorado Springs Municipal System

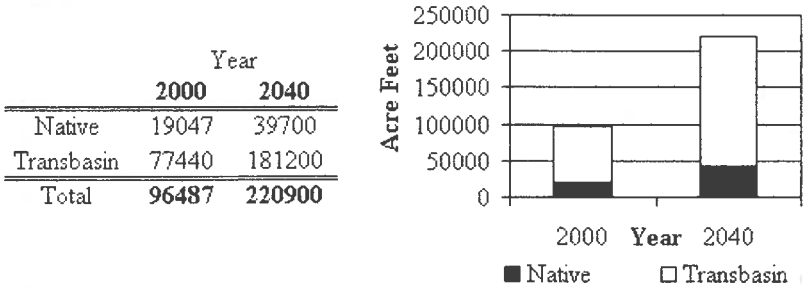


Table 1., Figure 2. Current and Future Water Supplies, in Acre Feet

**TRANSBASIN SYSTEMS**

Colorado Springs found it necessary early in our history to seek water from other water basins. Borrowing from the successes of earlier agricultural transbasin projects, Colorado Springs developed our own systems for municipal use. Below is a brief description of the 4 major transbasin diversions and other supplies used by Colorado Springs (Figure 3.).

**South Slope System**

In 1891, Colorado Springs began the development of the “Seven Lakes”, or South Slope System. This system, located on the south aspect of Pikes Peak, takes water from the Beaver Creek drainage into the Fountain Creek Drainage. This was first accomplished by ditches flowing by gravity across the divide between the drainages. Then, in 1904, St. Johns Tunnel was constructed to deliver the water across the divide. This transbasin water flows through five tunnels and has powered three hydroelectric plants at various times, two of which are still in operation. Another similar but separate system on the south side of Pikes Peak is the Rosemont System, originally built in the 1930’s to serve the needs of the Broadmoor Hotel and Resort. This system collects water from a different fork of Beaver Creek and brings it through a pipeline into the Fountain Creek basin. Colorado Springs purchased this system from the Broadmoor in the 1970’s. These systems can produce about 4,700 acre feet of water which would not have been available in the Fountain Creek drainage. However, since the basin of origin, the Beaver Creek basin, is ultimately tributary to the Arkansas River, this water is considered native in nature.

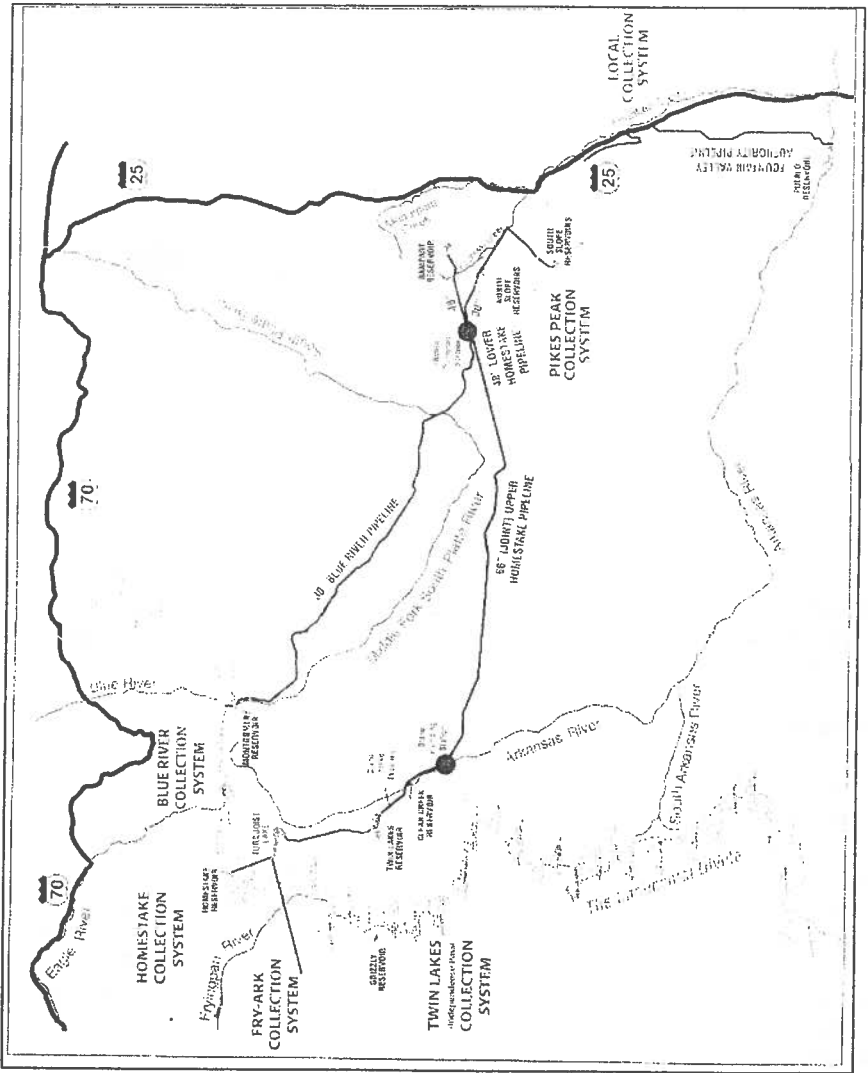


Figure 3. Water System and Transbasin Projects

**Blue River System**

In the early 1950's Colorado Springs completed the Blue River Project. This ingenious and sometimes contentious system was built in part to supply the needs of the proposed Air Force Academy, and only was possible after Presidential intervention and Congressional action. This system is located in the headwaters



of the Blue River, a tributary of the Colorado River, above the town of Breckenridge. The project collects water from numerous small streams and delivers it through pipelines and tunnels across the Continental Divide into Montgomery reservoir in the South Platte River Basin. From there a pipeline takes the water across another divide into the Arkansas Basin and to terminal storage on Pikes Peak. This system imports about 13,100 acre feet of Colorado River and Platte River water (Table 2., Figure 4.). The projected values for yield in 2040 shown in Table 1. are for an average year. Some of these values appear to be less than 2000 deliveries because the year 2000 was a high production year for some of the systems.

**Homestake System**

Colorado Springs and the City of Aurora, through a joint venture, opened the Homestake Project in 1967. This project collects water from the upper Eagle River, another tributary to the Colorado River, in a remote area which was subsequently designated as the Holy Cross Wilderness Area. The water is delivered to the Homestake Reservoir through a series of pipelines and tunnels, and from there it travels through a five and one half mile long tunnel beneath the Continental Divide to the Arkansas Basin. It is then stored in either Turquoise or Twin Lakes Reservoirs before it is pumped through the Otero Pump Station and Pipeline, a distance of over 80 miles, to terminal Storage above Colorado Springs. The developed supply from this system is 14,600 acre feet. There are an additional 10,100 acre feet of undeveloped water rights for this system. Colorado Springs and Aurora are continuing efforts to develop this water through the Eagle Park Conjunctive Use Project, which will utilize underground aquifer storage. This project is also part of a cooperative agreement to produce water for users on both sides of the Continental Divide.

	Year	
	2000	2040
Blue River	20674	13100
Homestake	18933	26300
Twin Lakes	15607	30500
Fry-Ark	543	12400
Exchange	8305	77300
Other	13378	21600
<b>Total</b>	<b>77440</b>	<b>181200</b>

Table 2. Breakdown of Transbasin Water Supplies, in Acre Feet

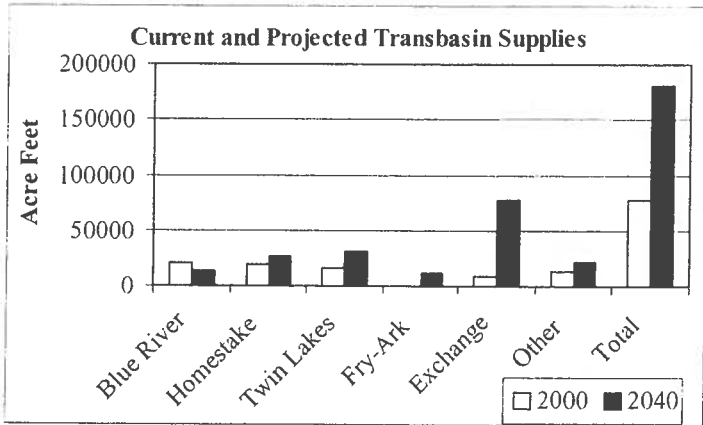


Figure 4. Breakdown of Transbasin Water Supplies

### Twin Lakes System

The Twin Lakes / Independence Pass System was originally constructed to supply agricultural interests in the Arkansas Valley. In 1972, Colorado Springs purchased a majority interest in this system which collects water from the Roaring Fork River in the Colorado Basin. The water is stored in Grizzly Reservoir, transported through the Twin Lakes Tunnel beneath the Continental Divide, and received into Twin Lakes for storage until it is pumped through The Otero Pump Station and Pipeline to Colorado Springs. This system can produce about 30,500 acre feet of transbasin water and an additional 6,700 acre feet of native water from its east slope water rights.

### Fryingpan Arkansas System

This Federal water project was built by the US Bureau of Reclamation to deliver transbasin water from the Frying Pan river in the Colorado basin to agricultural and municipal users in the Arkansas Basin. This water is brought through the Boustead Tunnel into Turquoise Reservoir, and from there it flows to Pueblo Reservoir. Colorado Springs takes delivery of this water through the Fountain Valley Conduit, a pipeline and pump system from Pueblo Reservoir up to Colorado Springs. Colorado Springs' share in this project yields 12,400 acre feet of transbasin water, and an additional 3,100 acre feet of native water from its east slope rights.

### Exchange and Other Reuseable Water

As is evident in Table 1. and Figure 4., Colorado Springs has other waters that we classify as transbasin, or more specifically reusable. This concept is discussed in

detail below. One such supply is exchange water, which is a second or subsequent use of water. Other sources include nontributary groundwater, fully augmented tributary groundwater, and consumptive use water transferred from agricultural uses. Although the water from these other sources are not strictly transbasin, it shares with the transbasin water the characteristic of being fully reusable, so their classification as transbasin relates more to use than origin.

### REUSABLE WATERS

One very important characteristic of transbasin water under Colorado Water Law is its reusable nature. Native water is allowed to be used only once before it must be released downstream for use by downstream water users. The entire system of prior appropriation is built upon and relies upon the return flows from native water use. However, since transbasin or imported water has never historically been relied upon to satisfy uses in the priority system, the return flows from such water can be recaptured and used again and again to extinction. This makes transbasin water intrinsically more valuable to users, because one acre foot of water imported from another basin can yield two to five, or even more acre feet of beneficial use. Therefore a discussion of transbasin water, in the context of use and efficiency, is more appropriately a discussion of reusable water.

To take advantage of this very attractive property, the user is required to maintain "dominion and control" over the water in order to have the legal right to reuse it. This usually consists of a tracking and accounting system to quantify the amount and some mechanism to recapture and reuse the water. Colorado Springs Utilities has been and continues to be very proactive in developing new and innovative ways to make the most of our reusable water. The Nonpotable Reuse System and our Exchange Program are the mechanisms we use to squeeze the blood from this turnip.

### NONPOTABLE REUSE SYSTEM

In 1961, Colorado Springs began delivering treated wastewater to parks, cemeteries, golf courses, and commercial properties for turf grass irrigation. This system is one of the oldest in the Western United States. It was constructed to fulfill the requirements of the Blue River Decree, which was the water right awarded to Colorado Springs for our Blue River Transbasin Diversion Project. The Decree requires Colorado Springs to completely reuse all of the return flows resulting from the first use of the transbasin water. Beyond this requirement, the use of reclaimed wastewater has been and will continue to be an efficient and environmentally sound water management tool.

This system currently serves approximately 2,500 acre feet of highly treated reclaimed water per year to approximately 30 accounts. The system takes secondary effluent from Colorado Springs' Las Vegas Waste Water Treatment Plant, treats it again in a tertiary sand filter plant, disinfects it, and pumps it

through a separate nonpotable distribution system to the customers. A Nonpotable Master Planning effort is currently under way. The goal of the Master Plan is to develop alternatives that will at least double the amount of nonpotable water used in Colorado Springs by the year 2040. Nonpotable Water Development is one of four components of future water supply as identified in Colorado Springs Utilities' Water Resources Plan.

### THE EXCHANGE PROGRAM

The concept of exchange has been in use in Colorado for well over 100 years. An exchange is a water trade, where water is taken from one source and replaced with water from another source. An typical exchange occurs when an appropriator takes water at his point of diversion out of priority, or when he is not legally entitled to the water, if the water is replaced in like amount and at a location that keeps all senior appropriators whole. For instance, a ditch company can continue diverting at their head gate when called out of priority if they release the same amount of water from a downstream reservoir. However, this can be done only if the calling right is satisfied by the release, and no water users in the intervening reach, or exchange reach, is injured. Likewise, a municipality can release a volume of water from a waste water treatment plant, and can take a like amount at an upstream diversion point. This system of water trades can be a very good water management tool to increase the efficiency and yield of a water system.

Colorado Springs Utilities started exchanging waste water effluent into various upstream reservoirs in the 1970's. Since then our exchange has increased and it is now a major source of supply for Colorado Springs. The key to the exchange is the reusable waters. As mentioned above, these are the only waters that can legally be recaptured by exchange and reused in our water system. Effluent from the Las Vegas Waster Water Treatment plant is discharged into Fountain Creek, which flows south to the Arkansas River. This effluent is comprised of several "colors" or types of water. The two major types are Native and Reusable. Colorado Springs has an extensive water measurement, tracking, and accounting program that is used to determine on a daily basis the volumes of native and reusable water used in the system and discharged from the wastewater treatment plant. The reusable water is used for exchange and augmentation of groundwater use.

The accounting and tracking of water use also allows Colorado Springs to claim non-sewered return flows. About 40% of the annual volume delivered to the city is used for outdoor purposes, and thus the return flows are not tributary to the waste water system. Through close monitoring of water use and daily accounting, Colorado Springs determines how much reusable water is used for turf irrigation. We calculate using climatic data and engineering analysis how much of the irrigation water applied returns to the groundwater system. Then, through groundwater modeling and a stream flow measurement program we determine the

lagged volume of reusable return flows accruing to the stream system. That volume can then be claimed and exchanged or otherwise reused.

The use and subsequent reuse of water from each of the above listed transbasin sources is separately tracked. Over ten different "colors" of water are tracked through the system in streams, pipes and reservoirs. This extensive tracking and accounting ensures that Colorado Springs maintains dominion and control over these waters, and provides for our continued use and reuse of these sources.

The 1980's saw the development of Colorado Springs' Exchange Program which formalized exchange as a strategy for acquiring a new supply of water for the City. Under that program, Colorado Springs acquired several Appropriative Rights of Exchange, which are in essence a priority system for exchanges, based on physical water availability in exchange reaches. These rights are for our Local Exchange and Arkansas River Exchange.

### **Local Exchange**

The local collection system on Pikes Peak and various local streams have diversions with varying priority dates which from time to time are not in priority. In times before the exchange, these rights would have to be turned out when called out of priority by a senior diverter. This would mean that the water actually diverted for use by the City was less than what was physically available in the stream. This required much effort by our system operators to turn diversions on and off, especially during times when the call on the river would change daily. With the local exchange, those waters are diverted whenever they are physically available, regardless of the call, and all out of priority diversions are replaced with reusable water discharged from the wastewater treatment plant. With the local exchange in operation, pipes keep flowing and reservoirs fill when normally the water would have to be bypassed. By allowing the use of as much locally available water as is physically possible, the efficiency and yield of the local collection system is greatly increased. It also reduces the amount of work required for operation of the system.

### **Arkansas River Exchange**

The Arkansas Exchange allows the exchange of water from Colorado Springs to various reservoirs or diversions on or tributary to the Arkansas River above the confluence with Fountain Creek. The major facilities used in this exchange include Pueblo Reservoir, Twin Lakes, Turquoise Reservoir, The Otero Pump Station, and the South Slope Reservoirs. Colorado Springs has storage space in Pueblo Reservoir through a contractual agreement with the Bureau of Reclamation on an "if and when" available basis. Space in Twin Lakes and Turquoise Reservoirs is owned outright by Colorado Springs. The Arkansas Exchange is dependent on the physical availability of flows in the exchange

reaches. At times when there is no exchange potential, meaning no physical flow to exchange against, or when there is no storage space available in the upstream reservoirs, the effluent can be run down stream from Fountain Creek to Lake Meredith on the Colorado Canal for storage by direct flow. The water stored in Lake Meredith can later be exchanged for water upstream when conditions are more favorable.

The ultimate goal of the exchange is to get water discharged to Fountain Creek moved up into the upper Arkansas Basin, where our primary delivery facilities are located. The water is there stored in Twin Lakes or Turquoise Reservoirs, for subsequent punping to Colorado Springs through the Otero Facilities. This exchange allows Colorado Springs to capture most of our reusable return flows for subsequent reuse in our potable water supply system.

### Contract Exchange

Contract, or "paper" exchanges are a very efficient variation of the exchange concept. These types of exchanges are accounting trades, where water deals are transacted over the phone and storage accounts in reservoirs are debited and credited, with no actual movement of water. These can be very attractive because they are done completely independent of the physical limitation of river flow, and often the parties can realize more yield due to the fact that there is no transit loss assessed to the water. A user with water stored in an upstream reservoir can do a contract exchange and get delivery of an equal amount of water from a down stream reservoir. He will realize a net gain on the transaction because there will be no loss of water resulting from running it down the river to his point of use. The other user will benefit from moving his water upstream. Colorado Springs utilities proactively uses contract exchanges whenever possible to gain more yield and efficiency in the administration of our water supplies.

The Exchange Program is a major supply of water for Colorado Springs and is only possible because of the reusable nature of transbasin water. The exchange program currently yields an average of 10,000 to 12,000 acre feet per year. In the future, this number is expected to increase to 77,300 acre feet per year. This amount and its growth are dependent on water use in the City, and its growth. The population of Colorado Springs is projected to approach 900,000 people by the middle of this century, and this growth will drive the supply for, and the need for these exchanges. The other essential elements to be able to supply the growing demand with these exchanges, as well as other water sources, are storage space and delivery capacity.

## RESERVOIR RE-OPERATIONS

Colorado Springs is working cooperatively with the Southeast Colorado Water Conservation District and other water users in the Arkansas basin to develop a

plan whereby storage space in the basin is used more efficiently. Currently storage space in federally built projects is tied to water developed for those projects. In other words, only project water can be stored in project reservoirs on a firm basis. Under re-operations, these reservoirs could be operated to allow for more efficient use of all waters, both project water and other water. This would allow entities to have guaranteed storage space and store any type of water in it. As the demands for storage space increase, and the likelihood of new storage projects being built diminishes, maximizing the use and efficiency of existing storage facilities becomes of paramount importance. Re-operations will allow Colorado Springs to store and move exchange water, as well as first use transbasin water and thus make better and more efficient use of the water imported from other basins.

Colorado Springs, the Southeast District, and other water users are working cooperatively to implement the Preferred Storage Options Plan. This Plan assessed the future needs of water users basin wide, and identified storage options to meet those needs. The Plan has identified reservoir re-operation and enlargement of Pueblo and Turquoise Reservoirs as the preferred alternatives. This will provide Colorado Springs with up to 45,000 acre feet of storage in Pueblo Reservoir and Turquoise Reservoir. This additional storage is needed to provide for our needs as identified in our long range planning effort, The Water Resource Plan.

### THE WATER RESOURCE PLAN

In 1996, Colorado Springs completed five years of planning which outlined our needs and supply alternatives until the year 2040. The plan projected the population served by Colorado Springs Utilities in 2040 to be about 900,000 people, and the corresponding water demand was projected to be 181,700 acre feet. This is an additional 102,600 acre feet over 1995 usage levels, the baseline for the Plan. The Water Resource Plan did not address acquiring any new water rights or sources of supply, but rather was focussed on delivery capacity and supply utilization. This Plan outlined ways for Colorado Springs to get the most out of our existing supplies, including transbasin supplies.

The Plan identified four components of supply to meet those demands (Figure 5.) The first component is Conservation. The plan recognized that Colorado Springs has already implemented the most effective conservation measure in that it has been fully metered since the 1940's, and has a very active conservation program. These existing measures in combination with future conservation efforts are projected to reduce future demand by 24.5%, or 25,100 acre feet. The second component of future supply is Nonpotable Development. The goal, as stated above is to double the use of nonpotable water, which will provide 2.5% of the future supply, or about 2500 acre feet. In Colorado Springs, there are three sources for nonpotable water, reclaimed wastewater, raw or untreated surface

water, and groundwater. The third component is Existing System Improvements. This is the optimization operation and expansion of existing facilities to realize

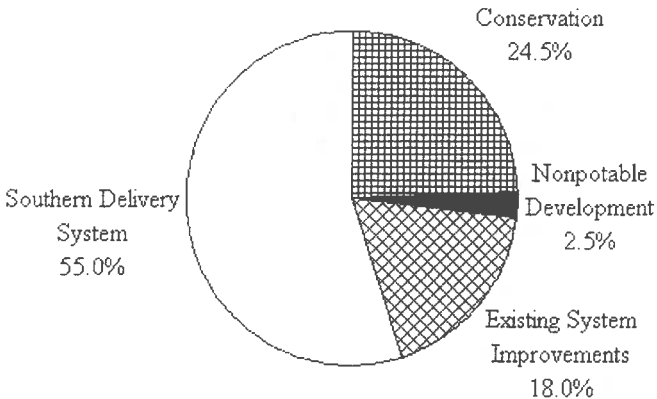


Figure 5. Future Supply Components of the Water Resource Plan

the greatest amount of yield possible. This includes expansion of the Otero Pump Station and Pipeline capacity, as well as capital projects to capture more water for potable use from our local collection system. This is projected to supply 18%, or about 18,500 acre feet of the additional need. The final component of the Plan is a major delivery system. The preferred alternative is the Southern delivery System. This is a pump and pipeline system extending from Pueblo Reservoir to terminal storage on the eastern edge of Colorado Springs. It is projected to deliver 55% of the future need, which equates to about 56,500 acre feet.

One alternative evaluated in the Plan which did not become the preferred alternative at this time was direct potable reuse of wastewater. The technology exists today to take the entire waste water effluent stream, treat it to drinking water standards, and introduce it back into the potable water system. This is the most efficient way to reuse the transbasin waters from the point of view of water loss and amount of infrastructure. It would require little if any storage on the Arkansas River, much shorter pipelines, and the water is moved much less, resulting in less transit loss. The Regulations for discharging wastewater are anticipated to continue to tighten, to where the difference in treatment for release to the environment and treatment for potable use will effectively merge. Public opinion of this idea was surprisingly favorable, with roughly 50% of the respondents being willing to drink highly treated wastewater. This percentage will likely increase over time as environmental awareness and education of water issues increases. The largest hurdle for this concept has been the cost of treatment technology. However, the costs for this technology are constantly dropping, and



the costs of other supply options are constantly increasing. Colorado Springs expects that the next major increment of supply, after implementation of the current Water Resources Plan, will be direct potable reuse.

### SUMMARY

Transbasin water is by far the largest source of water that we will use to supply the future demands of the City. With Colorado Springs limited local supply of water, the transbasin water becomes the lifeblood of this community. Capturing the transbasin water locally and reusing it for nonpotable irrigation is one way to maximize the beneficial use of transbasin water. The Exchange Program tracks transbasin return flows to the Arkansas River and provides a mechanism to capture them for subsequent use and reuse, effectively multiplying the beneficial use of the water. Since delivery of the transbasin water is to the Arkansas River, and since the Exchange Program is predominantly operated on the Arkansas River, it is critical for Colorado Springs to work cooperatively with other water users on the Arkansas to make the best use of existing facilities through re-operation and facility enlargement. But that is not enough. There is still the need for infrastructure to deliver this water from the Arkansas River to Colorado Springs. The Water Resource Plan addressed the infrastructure needs and synthesized the diverse water sources into a cohesive water supply and water management system.

As Colorado Springs looks to the future, it is certain that the Water Resource Plan and its components will be revised as prevailing conditions in the industry, society, and the community change. Colorado Springs Utilities is committed to facing the changes and challenges of the future with the same foresight and proactive ingenuity that previous generation of planners and engineers used to build this water system. However, amid all the changes to come, what will remain constant is Colorado Springs reliance on transbasin water supplies.

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## ON TAP: AN INTERACTIVE WEB SITE TO FACILITATE WATER TRANSFER IN CALIFORNIA

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### ABSTRACT

The combination of federal reclamation law and state water code creates a complex regulatory environment governing the transfer of water within the State of California. In addition to regulations directly pertaining to the transfer of water, other regulations often come into play when transfers would utilize federal or state water conveyance facilities. During development of the CALFED Bay-Delta Program's Water Transfer Program, it became apparent that these water transfer approval processes take substantial time and effort to complete. As a result, these approval processes are perceived as inefficient by transfer proponents, although they are needed to ensure protection of environmental, other legal water users, and third-party interests.

Given the fact that many water market transactions are proposed to resolve immediate or near-term water supply shortages, approval delays can be frustrating and costly for transferring parties and the approving agency. The CALFED Bay-Delta Program has developed an online, information system that will assist water transfer proponents to understand approval requirements, undertake better planning to secure needed permits, and prepare more complete applications, expediting agency review and timely permit issuance. In addition, this online resource also provides historic transfer information that can be accessed by the interested public.

This paper describes the features of the "On Tap" web site, plans for additional features, and some details of its development. On Tap provides water transfer proponents with a complete picture of jurisdictional authorities, application requirements, and links to pertinent information. Ultimately, On Tap may provide a means for the direct submittal of applications to agencies with authority over water transfers with the intent of eventually obtaining online approvals. Such a feature would contribute to decreasing the time needed for approval and increasing the utility of this water management tool throughout the State.

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## INTRODUCTION

The CALFED Bay-Delta Program is an open, collaborative, state-federal-stakeholder effort seeking to develop a comprehensive long-term plan to restore ecosystem health and improve water management for beneficial uses of California's Bay-Delta system. Water market transfers can play an important role in achieving that goal. As such, CALFED has begun to implement several actions to help improve the framework upon which the water market operates throughout California. One of these actions is the development of an interactive web site for water market information.

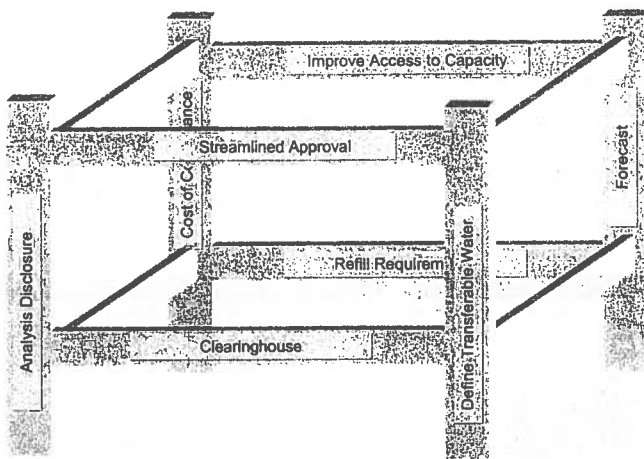
## NEED FOR WEB SITE

As part of efforts to develop solutions to perceived water market inefficiencies, CALFED identified a range of current water market limitations. However, several of the water market's limitations are not distinct items that operate independently of one another but are closely related. Thus, developing discrete solutions did not seem appropriate in all instances. CALFED chose to focus on an integrated solution to help resolve related issues.

This integration worked especially well for developing recommendations to address resource protection-related issues such as minimizing third-party socioeconomic impacts or environmental and beneficial uses. Other recommendations, especially those addressing technical or regulatory issues, such as defining the need for carriage water or methods to streamline the water transfer approval process, required a more individually tailored solution because of their unique qualities.

However, all of the CALFED recommendations recognize that these issues must be considered in a manner that is integrally linked in an effort to improve the existing structure of the California water market (see Figure 1).

CALFED concluded that one way to display this linkage would be through an interactive web site. Such a web site could help reduce confusion of the State's water market processes and help disseminate information such that all parties would collectively have access to the same information.



**Figure 1.** All recommended actions, policies and processes are interconnected into a structure designed to improve the existing water market.

## ON TAP – CALIFORNIA WATER MARKET INFORMATION

This On Tap web site serves as a direct interface between the oversight agencies – responsible for approving most transactions – and proponents wanting to conduct a market transaction or users requesting information. The web site facilitates the sharing of water transfer data, research, and assessment methodology. The web site is administered and managed jointly by the California Department of Water Resources (DWR), the U.S. Bureau of Reclamation (USBR), and the California State Water Resources Control Board (SWRCB).



The On Tap web site has two primary functions:

- An on-line Transaction Guide that provides proponents with information regarding appropriate approval authority and other details such as environmental compliance requirements and relevant application fees.
- A searchable Water Transfer Database of all historically approved transfers (populated with data historically collected by the agencies but previously difficult to obtain by the public).

In addition to these primary features, the site includes links to each agency web sites and other useful information. Figure 2 illustrates the On Tap homepage. The On Tap development team has made this site available using the following URL: <http://ontap.ca.gov>. This allows the site to be hosted through the State of California's Internet provider system and is an easy address to advertise and to remember.

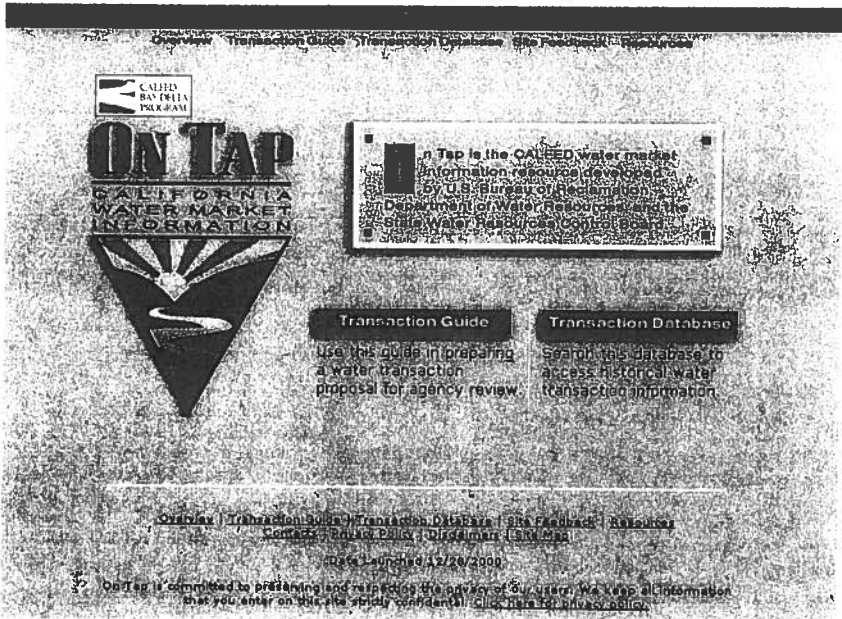


Figure 2. Homepage for California water market information web site.

### **Transaction Guide**

The Transaction Guide (Guide) is a primary component of the web site. It guides proponents through a series of questions, returning relevant information about application requirements specific to their proposed transaction. The intent of the guide is to ensure that a proponent understands all pertinent details for a proposed transfer prior to submitting a request for review to DWR, USBR, or SWRCB. Case-specific feedback will be provided based on information from the applicant regarding, but not limited to the:

- Transaction participants (seller, buyer, intermediary)
- Underlying water right
- Method proposed to make the water available to transfer
- Destination of the water proposed for transfer and,

- Duration of the transfer

Detailed text of the questions and answers posed in the guide are included in *Attachment A*. Figure 3 provides a view of the Guide's login page. The Guide is designed to allow a user to create a profile and save their "sessions", or use the Guide anonymously. The anonymous login will not allow a user to save the session.

Overview | **Transaction Guide** | Transaction Database | Site Feedback | Resources

## Transaction Guide

This guide is not an application; it is a guide to assist you in preparing a more complete water transaction application package. It can also be used to test water transaction scenarios you may be considering. In order to complete this guide and get useful results, you need to provide some basic information. You must provide the proposed water source, and either the conveyance path or destination.

**Login**

E-mail:

Password:

[New User](#)

[Anonymous Login](#)

If you login as an anonymous user, On Tap will be unable to retain any information you enter into the Transaction Guide. You will be unable to revisit or change the scenario you have entered once you leave the Transaction Guide.

Overview | [Transaction Guide](#) | [Transaction Database](#) | [Site Feedback](#) | [Resources](#)  
[Contacts](#) | [Privacy Policy](#) | [Disclaimers](#) | [Site Map](#)

Figure 3. Login page for Transaction Guide – allows a user to save a “session”

The Guide responds to the user-supplied answers with clear and understandable information on policies and procedures governing the review and approval of proposed water transfers. The agencies prepared these responses to reflect their individual policies and procedures. When possible, the three agencies developed consensus language that formed common responses. Ultimately, it is intended that the use of On Tap will promote more standardization of their policies and procedures, further simplifying the various agency approval processes.

Questions posed in the Guide are primarily driven by the array of responses that any one of the agencies may give in a particular situation. For instance, if a proposed transfer involves water currently delivered in accordance with a federal Central Valley Project (CVP) water service contract and is going to another CVP


contractor, then only the USBR needs to be involved. Consequently, the responses provided direct the proponent to consult and coordinate with the respective USBR office that maintains authority over the water service contract. However, if the same water were to be transferred to a water user that does not have a federal water service contract, then both the SWRCB and USBR would need to review and approve the proposal. In this case, the responses would direct the proponent to also consult with the SWRCB.

The Guide provides responses directed toward the following categories:

- Agency with water rights jurisdiction
- Agency with conveyance jurisdiction
- Environmental compliance requirements
- Agency(ies) Application Fees and/or Use Charges
- Applicable Transfer Charges (USBR Contractors only)
- Carriage Water Requirements
- Socio-Economic Impact Assessment Requirements
- Notification Requirements
- Quantification Document Requirements
- Reservoir Refill Requirements
- Storage/Conveyance Information
- Water Quality Standards

Figure 4 illustrates the Transaction Guide response page. The responses may be composed of several pages as determined by the number and type of responses generated.





**ON TAP**  
CALIFORNIA  
WATER TRANSFER

[Your Session List](#) | [View Your Profile](#) | [Name This Session](#) | [LOG OUT](#)

## Transaction Guide Responses

[Jump to Responses](#)

**CALFED makes every effort to provide accurate data according to the resources available to us. While CALFED believes the information to be reliable, human or mechanical error remains a possibility. Therefore, CALFED does not guarantee the accuracy, completeness, timeliness, or correct sequencing of the information. CALFED shall not be held responsible for any errors or omissions, or for the use or results obtained from the use of this information. CALFED has made a reasonable effort to ensure that all information is accurate at the time of release. We would appreciate any errors, omissions, outdated materials, or other identified problems being brought to our attention. No guarantee is made, either express or implied.**

You have completed the transaction guide. The following is a summary of your answers, followed by On Tap's recommendations on how to proceed with your transaction proposal.

[Jump to Responses](#)

Session Name: Scenario 1

Answers Summary	
<b>Source:</b>	• Glenn Colusa Irrigation District
<b>Water Right:</b>	• Contracted federal project water (CVP)
<b>Duration:</b>	• Temporary (<1 year)
<b>Existing Use:</b>	• Agricultural
<b>Method:</b>	• Following
<b>Destination:</b>	• San Luis Water District (DMC)
<b>Intended Use:</b>	• Agricultural

Figure 4. Initial page of responses returned by the Transaction Guide. The length of this page will vary depending on the responses triggered. Note the Answer Summary that reiterates how the user answered various questions.

The Guide is only as accurate as is allowed by the user's answers. A user answering questions in unrealistic ways will result in less useful responses. In the end, the applicant is provided with responses that are tailored to their unique transfer proposal. This will help the proponent know who will review the transfer, what requirements must be satisfied, and what criteria the review agency will use when reviewing the proposal.

### Transaction Database

This portion of the web site is designed to allow the public to access available data on specific water transfers directly over the Internet. Initially, only historically approved transactions are included. The database is populated with historic transfer data stemming as far back as 1945, when limited data was collected, to and including the most recent completed transfers. Upon agency approval, all newly completed transfers will also be entered into the database. The target audience for the database includes consultants, researchers and public

policy advocates, and others who will view the historic information for a wide variety of purposes.

The database allows users to query the data using a “search screen”. The search screen has initial search fields based on the source, destination and dates; or the user can take advantage of advanced search fields. To make the users’ experience as easy as possible, the search fields only allow the user to select from pre-defined data in a variety of field categories. Figure 5 illustrates the search screen.

Overview Transaction Database Site Feedback Homepage

## Transaction Database

This database contains available historic water transaction information from 1945 to 2000. Select your search criteria using the fields below.

Source:

Alameda County Water District  
Alhambra Pacific Joint Venture  
Alta Irrigation District  
American Canyon Co. Water District  
American River Division-CVP (MUD & ID)

Destination:

Alameda County Water District  
Alhambra Pacific Joint Venture  
Alta Irrigation District  
American Canyon Co. Water District  
American River Division-CVP (MUD & ID)

Date Range: From:  To:

[Help](#)

### Advanced Search Fields

Use the following fields to refine your search parameters

Duration:

Long-term option  
Permanent Sale

Figure 5. Transaction Database search screen. Several advanced fields for refining the search are available to the user.

Advanced search fields include: duration of transfer, type of transaction, water right authority, water right, conveyance authority, jurisdiction, method to transfer water, environmental compliance, and various date types. If the user is interested in a select set of specific information, using the advanced fields can greatly refine their search.

Many of the 60-plus fields do not contain any data for each of the 850 current transfers in the database. This is because agencies did not previously collect this information. However, as part of the development of this centralized database, the agencies all agreed that the additional pertinent and relevant data would be collected on all future transactions (not all 60 fields would be used by any one transaction, but the fields are needed to represent the complexity of the data that can be collected).

Once a user selects their criteria, the web site provides a results page with data matching their selections. From the "results" page (see Figure 6), the user can obtain detailed information for a particular transaction by "clicking" the transaction. This triggers a "detailed results" page with all available information listed.

**Transaction Database Results**

(Note: A "--" indicates that data was unavailable for this field.)

11 records from your criteria. [Advanced Search](#)

**Source:** All Sources

**Destination:** Westlands Water District

**Date Range:** 1988 to 1990

Approx. Year	Source	Dest.	Duration	Trans. Type	Qty. Delivered
1989	Dudlav Ridge Water District	Westlands Water District	--	--	900 acre-feet
1989	Kern County Water Agency	Westlands Water District	--	--	45,000 acre-feet

Figure 6. Results of a search using the Transaction Database to view historic transactions.

### **Future Web Site Development Phases**

The On Tap web site is structured to grow as agencies refine their policies and procedures and users help define what information they want made available. In addition to on-going refinements to the Transaction Guide, several new features are envisioned or are under development to add value to the web site. These include:

- **Pending Transaction** - A section within the Transaction Database will be added that identifies proposed transactions pending approval by DWR,

USBR, or SWRCB. This is intended to help third-party interests to determine the status of pending water transfer that are being actively considered .

- Public Forum – This proposed new feature of the web site, would provide a forum for those who use the functions of the site and the oversight agencies. Various methods will be explored to make this a dynamic tools that allows dialog and feedback on pertinent issues.
- Export feature – A web-application will be added to the existing historic transaction database to allow users to export search results to a file, such as Excel, that can be readily used.
- Agency Database Administrator – A web-application will be built to allow the three agencies to easily enter new data into the historic transaction database. Currently, data has to be entered manually into the database software by the host of the site.

## DEVELOPMENT

Development of this interactive web site required a strong commitment from the involved agencies and a team capable of developing this type of technology. To ensure that the web site took advantage of the latest in Internet technology, CALFED agencies employed contractors experienced with both web site development and interactive databases, as well as a technical understanding of the California water transfer market. Jel Productions of Sacramento California was the lead web application developer for the team. In addition to the agencies' and CALFED representatives, the team also included Modcom, Davids Engineering, CH2M Hill and Jarvis A&E.

The On Tap web site was developed using a combination of ColdFusion programming language, Javascript and HTML. Much of the web site functions by accessing data contained in several databases. These were built using Microsoft SQL Server 7.0 (Structured Query Logic) software. For instance, all of the question and response text is contained in a database. The ColdFusion software converts this information to what the user views on the site. Using this technique, the text can easily be updated or modified, without needing to modify the site itself. Thus, the site allows the agencies to easily add or subtract detailed responses, depending on their policies.

One of the biggest challenges to complete the first phase of the site was obtaining approval from the agencies of all the site's content. This required legal review by each agency regarding privacy policies, disclaimers, response text and other content. In addition, since the responses in the Transaction Guide are relevant to particular transaction scenarios, the agencies needed to assist in creating the

complex relationships between how questions were answered and what response(s) were appropriate. Substantial effort was spent testing a wide variety of possible transfer scenarios to ensure that the Transaction Guide would respond correctly. This effort provided the agencies with assurance that the responses were correct and gave them confidence needed to launch the web site. The web site was officially launched on December 28, 2000.

### **CONCLUSION**

In an effort to improve the flow of California water market information, the On Tap web site was launched on December 28, 2000, to serve a wide variety of users. After initial launching of the web site, work will continue to develop and refine additional site features, further improving the site's usability and value. Thus, the web site will play an integral role in meeting CALFED's commitments to improving the California water market.

**ATTACHMENT A – TRANSACTION GUIDE  
QUESTION AND ANSWER TEXT**

Question 1 - Choose the participant that represents the source of the water (seller/provider.) You must know the source of the water, and you must know either the destination or the conveyance path, in order to complete this guide.

- |   |                                 |
|---|---------------------------------|
| 1. <i>(User chooses from a list of over 600 water suppliers and other participants)</i> | 2. Destination entered manually |
|---|---------------------------------|

Question 2 - Is the source (seller/provider) a public or private water supplier or an individual served by a water supplier?

- |  |            |
|--|------------|
| 1. Water supplier                        | 3. Neither |
| 2. Individual served by a water supplier |            |

Question 3 - What is the source's contract? (*Guide answers this based on Question 1*)

- |            |                                     |
|------------|-------------------------------------|
| 1. Federal | 4. Member unit of KCWA              |
| 2. State   | 5. Member Agency of MWD of So. Cal. |
| 3. Neither |                                     |

Question 4 - What is the source's system type? (*Guide answers this based on Question 1*)

- |                           |                        |
|---------------------------|------------------------|
| 1. Central Valley Project | 6. Lower Colorado      |
| 2. Klamath Project        | 7. State Water Project |
| 3. Orland Project         | 8. None                |
| 4. Solano Project         | 9. New Hogan Project   |
| 5. Cachuma                |                        |

Question 5 - What is the source's contract type? (*Guide answers this based on Question 1*)

- |  |                 |
|--|-----------------|
| 1. Project water service or long term water supply contract (including interim contract) | 2. Settlement   |
|  | 3. Exchange     |
|  | 4. 215 Contract |

Question 6 - What is the source's area office? (*Guide answers this based on Question 1*)

- |                    |  |
|--------------------|--|
| 1. Willows -- NCAO | 5. Klamath                                 |
| 2. Folsom -- CCAO  | 6. Boulder Canyon Operations Office - BCCO |
| 3. Tracy -- SCCAO  | 7. SWPAO                                   |
| 4. Fresno -- SCCAO |  |

Question 7 - Choose the participant that represents the destination of the water (buyer/recipient.)

- |   |                                 |
|---|---------------------------------|
| 1. <i>(User chooses from a list of over 600 water suppliers and other participants)</i> | 2. Destination entered manually |
|   | 3. Do not know                  |

Question 8 - Is the destination (buyer/recipient) a water supplier or an individual served by a water supplier?

- |  |            |
|--|------------|
| 1. Water supplier                        | 3. Neither |
| 2. Individual served by a water supplier |            |

Question 9 - What is the destination's contract? (*Guide answers this based on Question 7*)

1. Federal
2. State
3. Neither
4. Member Unit of KCWA
5. Member agency of MWD of So. Cal.

Question 10 - What is the destination's system type? (*Guide answers this based on Question 7*)

1. Central Valley Project
2. Klamath Project
3. Orland Project
4. Solano Project
5. Cachuma
6. Lower Colorado
7. State Water Project
8. None
9. New Hogan Project

Question 11 - What is the destination's contract type? (*Guide answers this based on Question 7*)

1. Standard
2. Settlement
3. Exchange
4. 215 Contract

Question 12 - What is the destination's area office? (*Guide answers this based on Question 7*)

1. Willows -- NCAO
2. Folsom -- CCAO
3. Tracy -- SCCAO
4. Fresno -- SCCAO
5. Klamath
6. Boulder Canyon Operations Office - BCCO
7. SWPAO

Question 13 - What water right(s) or contract(s) is associated with the source water? (More than one answer may be selected)

1. Riparian water right
2. Pre-1914 appropriative water right
3. Post-1914 appropriative water right
4. Adjudicated surface water right
5. Contracted federal project water (CVP)
6. Contracted federal project water (non-CVP)
7. Contracted state project water (SWP)
8. Groundwater right
9. Adjudicated groundwater
10. Stored groundwater

Question 14 - What conveyance path(s) is required to move your water from the source (where the water is coming from) to the destination?

- |   |   |
|---|---|
| 1. Natural Water Body (i.e. river or stream)      | 15. Kern Facilities                           |
| 2. California Aqueduct (including San Luis Canal) | 16. Colorado River Aqueduct                   |
| 3. North Bay Aqueduct                             | 17. All American Canal                        |
| 4. South Bay Aqueduct                             | 18. Coachella Canal                           |
| 5. Coastal Aqueduct                               | 19. Folsom South Canal                        |
| 6. Delta Mendota Canal                            | 20. Contra Costa Canal                        |
| 8. Tehama Colusa Canal                            | 21. Corning Canal                             |
| 9. Madera Canal                                   | 22. Spring Creek Power Conduit                |
| 10. Friant-Kern Canal                             | 23. Putah South Canal                         |
| 11. Cross Valley Canal                            | 24. Wintu Pumping Plant (Bella Vista Conduit) |
| 12. Mokelumne Aqueduct                            | 25. Tracy Pumping Plant                       |
| 13. Hetch Hetchy Aqueduct                         | 26. Mule Town Conduit                         |
| 14. Metropolitan Water District Facilities        | 27. Mendota Pool                              |
|   | 28. San Luis Canal (federal portion)          |
|   | 29. Do not know                               |

Question 15 - What is the intended duration of the transaction?

2. Temporary (
3. Long-term (>1 year)
5. Permanent Sale

Question 16 - What California Water Code Section will you use to govern your transaction?

1. 382 - 387 -- Transfer of Surplus Water or Water Right
2. 1211 -- Transfer of Treated Wastewater Discharge
3. 1707 -- Change for Purposes of Environmental Enhancement
5. 1435 - 1442 -- Temporary Transfer to Meet an Urgent Need
6. 1725 - 1732 -- Temporary Water Transfer
7. 1735 - 1737 -- Long-Term Water Transfer
9. 1020 - 1030 -- Water Lease
10. Not Applicable (i.e., for contractor to contractor)
11. 1220 -- Pumping of Sacramento and Delta Basin Groundwater
12. 1706 -- Long-Term Transfer of Pre-1914 Right
13. 1740 -- Transfer of Rights Determined Under Court Decree
14. Not applicable - This is a pre-1914 water right

Question 17 - What is the existing use of the source water? (More than one answer may be selected)

- |                             |   |
|-----------------------------|---|
| 1. Agricultural             | 4. Environmental enhancement and recreation |
| 2. Municipal and industrial |   |

Question 18 - What is the source's water rate type?

- |  |                                   |
|--|-----------------------------------|
| 1. Agricultural -- CVP preferential rate | 2. Agriculture -- CVP normal rate |
|  | 3. Municipal and industrial       |



Question 19 - Will you transfer water by:

1. Discharging return flow or groundwater into a canal or stream
2. Reducing your diversion of a source so it can be used elsewhere (or a reservoir-based operation)

Question 22 - What method(s) will be used to make the water available for this transaction? (More than one answer may be selected)

- |   |  |
|---|--|
| 1. Release of stored water                                      | 7. Conservation of "losses" from irrigated agriculture |
| 2. Bypass of water intended for storage                         | 8. Conservation of "losses" from urban uses            |
| 3. Re-operation of reservoir                                    | 9. Redirect State Water Project (SWP) entitlement      |
| 4. Fallowing  | 11. Use of groundwater in lieu of surface water        |
| 5. Crop modification (reduction of evapotranspiration [E.T.])   | 12. Direct transfer of groundwater                     |
| 6. Other consumptive use reduction (crop stressing, replanting) |  |

Question 23 - Is the location of the intended use in the same watershed as the storage facility? (This inquiry is needed to determine applicability of reservoir refill criteria.)

1. Yes
2. No
3. Do not know

Question 24 - Does the conveyance path require movement of water across the Sacramento/San Joaquin Delta? (This inquiry is needed to determine applicability of carriage water requirements.)

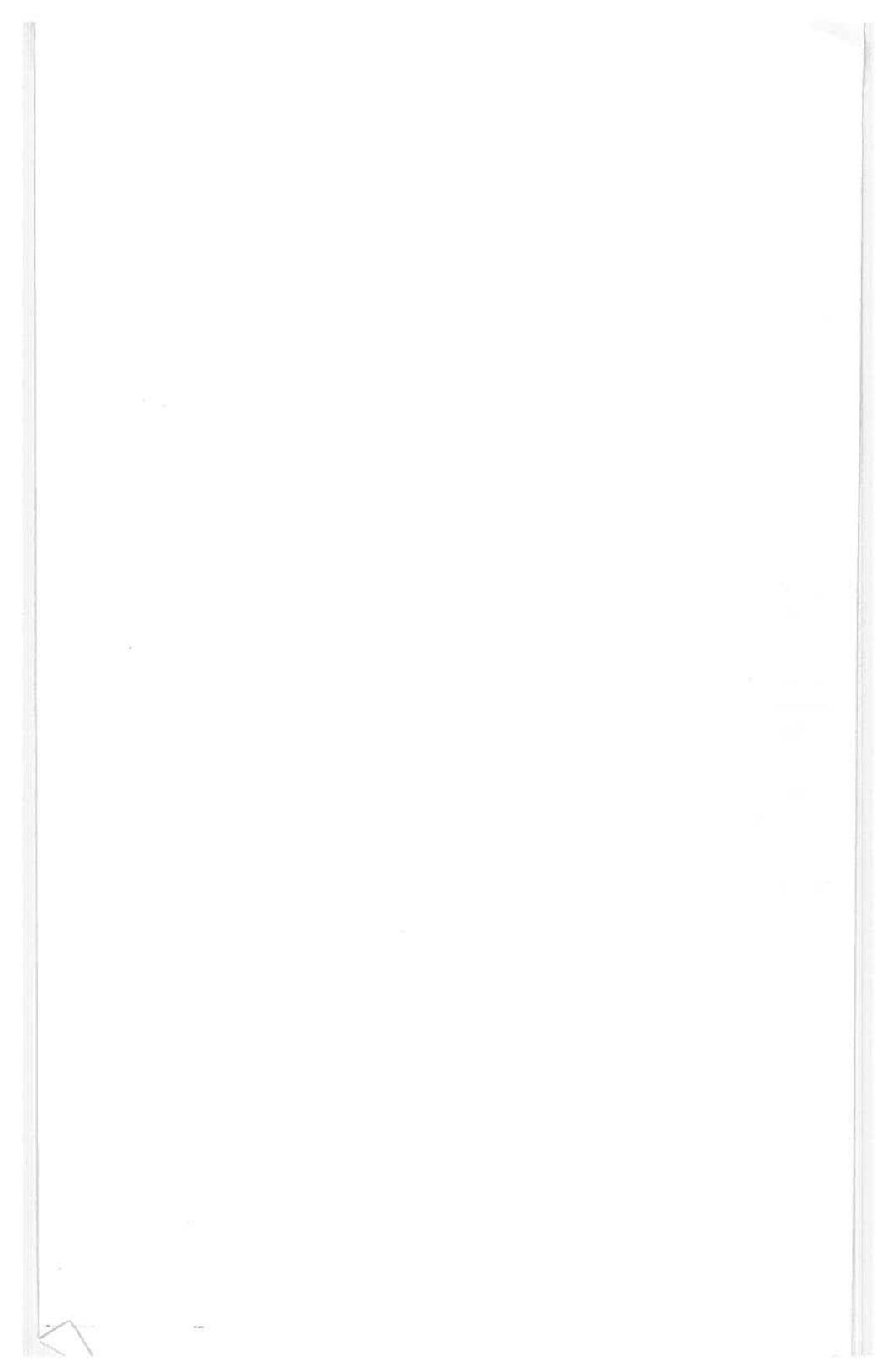
1. Yes
2. No
3. Do not know

Question 25 - How is the current water right designated?

1. It is a direct diversion right
2. It is a right to store water
3. It is both

Question 26 - What is the intended use of the destination water? (More than one answer may be selected)

1. Agricultural
2. Municipal and industrial
4. Environmental enhancement and recreation
7. Do not know



## MITIGATION OF TRANS-MOUNTAIN DIVERSIONS? RE-OPERATION!

David A. Kanzer<sup>1</sup>

David H. Merritt<sup>2</sup>

### ABSTRACT

The fact that trans-basin diversions are 100 percent consumptive to the basin of origin makes their impacts substantially more significant than in-basin diversions. These impacts are felt the greatest by downstream in-basin interests and can have serious environmental, social, economic, political, and diplomatic consequences. The loss of return flows not only reduces the availability of dilution flows, it can adversely impact the natural hydrograph components that can be required under federal endangered species recovery programs. In this time of escalating environmental regulation and scrutiny, especially under Sections 7 and 9 of the Endangered Species Act (ESA), in-basin interests are increasingly insisting that these burdens must be equitably shared with transmountain diverters.

In recent years the Colorado River Water Conservation District (CRWCD) has actively participated in the Upper Colorado River Endangered Fish Recovery Program (Recovery Program). This program is designed to strike a balance between water development and environmental concerns by developing and implementing Programmatic Biological Opinions (PBOs), which provide basin-specific ESA protection to water users in exchange for specific mitigation actions.

Although the CRWCD believes that in-basin efforts can provide mitigation benefits, additional, effective, and more efficient mitigation can be achieved through re-operation of trans-mountain diversion projects. Recent studies have shown that significant benefits can be achieved without affecting the acceptable, legal yield of these projects. In addition other management innovations such as water re-use, recycling, which are required under certain decrees, such as the Blue River Decree in Colorado, and delivery system improvements, can be effective tools in demand-side management. These techniques have the additional benefit of reducing the mitigation burdens for all diverters, in and out of basin, and minimize the environmental impacts associated with increased water development, thereby promoting the equitable sharing of the burden of mitigation.

This paper illustrates these points using a case study of the operations of the Colorado-Big Thompson (C-BT) Project in the headwaters of the Colorado River Basin in Colorado and demonstrates how some new transbasin diversion

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management proposals and ideas can reduce the significant diversion impacts to the basin of origin and share the burdens of environmental mitigation.

## INTRODUCTION AND PROBLEM DEFINITION

Until recently in Colorado, the ability of decreed water users to divert water from natural streams was practically an inalienable right, guaranteed by the Colorado state constitution; the prior appropriation doctrine and water court ruled supreme. But since four species of fish in the Colorado River Basin were listed under the Endangered Species Act, all this has changed dramatically. Now even the constitutionally guaranteed ability to divert and use water can be impacted by permit requirements, and the economics of water use now can include costly environmental mitigation requirements.

These new costs and regulatory burdens have begun to impact the ability of water users to continue in their historical practices and paradigms. The new paradigm shift has been dubbed the "Pie of Pain," whereby water users are subjected to a slice of 'pain' in the form of new costs or operational constraints. This is an apt image, as long as all water users get served an equal-sized piece of 'pie.' However, many in-basin users have begun to feel that they are getting force fed more than their share whilst transmountain diverters excuse themselves from the table and continue drinking freely through the old paradigm of "compensatory storage". But in these days of environmental mitigation, the cry of "I gave at the office" because "I already built and paid for my compensatory storage" rings hollow to the ears of in-basin water interests. This is because these compensatory storage pools were only designed and built for two specific reasons: 1) to replace out of priority depletions in the face of river administration under the prior appropriation doctrine, and 2) to compensate the basin-of-origin for transmountain depletions by providing a wet water benefit. Compensatory storage cannot be used for new environmental mitigation requirements.

These new environmental mitigation requirements have been spawned in recent years through the Recovery Program. The Recovery Program is made up of a broad array of interests including water and power users, environmental concerns, various agencies of the States of Colorado, Utah, and Wyoming, and members of the federal family: the US Bureau of Reclamation (USBR), and the US Fish and Wildlife Service (USFWS), among others. It is designed to strike a balance between water development and environmental concerns by striving to develop and implement basin-specific Programmatic Biological Opinions (PBO) such that both historical water uses and an increment of future water development is allowed to continue while recovery of four listed endangered fish species occurs. This is done by the creation and implementation of mitigation initiatives called Reasonable and Prudent Measures or RPMs. These measures are designed to offset depletion impacts and thereby prevent "jeopardy," as defined by the USFWS to the continued existence of the endangered species. These RPMs

generally target system improvements to create "flow" by reducing head gate diversions or by rearranging flows to improve overall environmental conditions through emulation of the natural hydrograph. They can include diversion efficiency improvements, flow enhancement activities (timing, augmentation), and other water management measures. In addition, the RPMs can include some biological measures such as habitat improvements and non-native species control.

The CRWCD is a political sub-division of the state of Colorado that represents water users within the Colorado River Basin. It encompasses all or parts of 15 counties in northwestern Colorado (see Figure 1 for an illustration of its boundaries) and was set up in 1937 by state statute to balance the water supplies of the west slope as against the growing transmountain demands of the east slope.

Since the inception of the Recovery Program, the CRWCD has actively participated in the program and its many activities, and as such, the CRWCD has endeavored to see that all water users are treated equitably under the program. An excellent example of these efforts is the recently signed PBO for the Upper Colorado River, commonly called the "15 Mile Reach PBO", (USFWS, Dec, 1999). This programmatic biological opinion relies on several RPMs, which call for specific re-operations, studies, and other flow-related activities. The net result of these RPMs is a near wholesale change in how some western slope reservoir supplies get used. To the consternation of the CRWCD, these RPMs appear to rely solely on western slope supplies and test only the re-operation potential of western slope facilities.

This approach had repeatedly resulted in small "hits" to in-basin water users' interests. There has been dedication (and thereby loss of potential yield) of storage volume in many western slope reservoirs (Wolford Mountain and Ruedi), for "fish pools." This is water that the USFWS has obtained from the west slope through contract and/or permit requirements, and which it can release at their discretion for flow support for the endangered species in the identified critical reach from Palisade, Colorado, to the mouth of the Gunnison River, called the "15 Mile Reach". The location of this section of river is illustrated in Figure 1 and has been identified by the USFWS as being crucial to the recovery of the endangered fishes. To date, however, the only commitment of water for the endangered fish by transmountain diverters is an interim, 10-year agreement to provide 5412 acre-feet from Williams Fork Reservoir, a west slope source owned by the Denver Water Board, for late season augmentation.

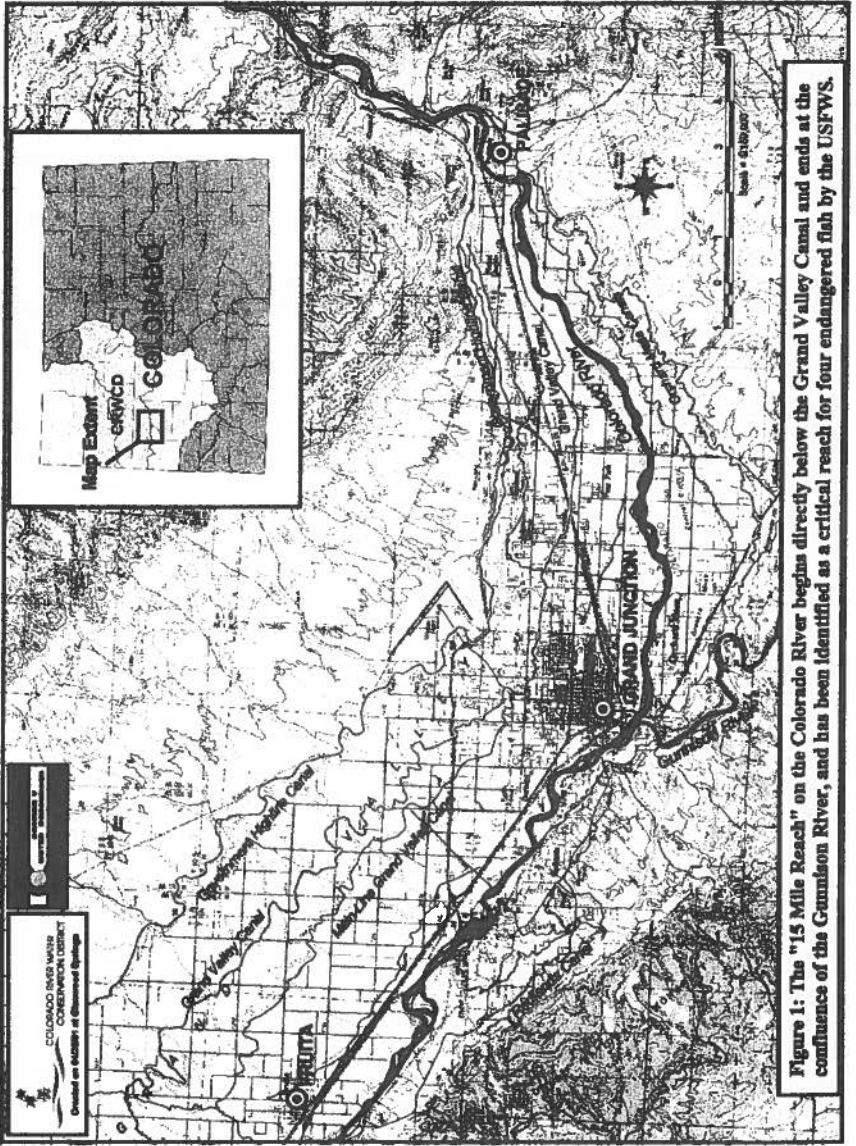
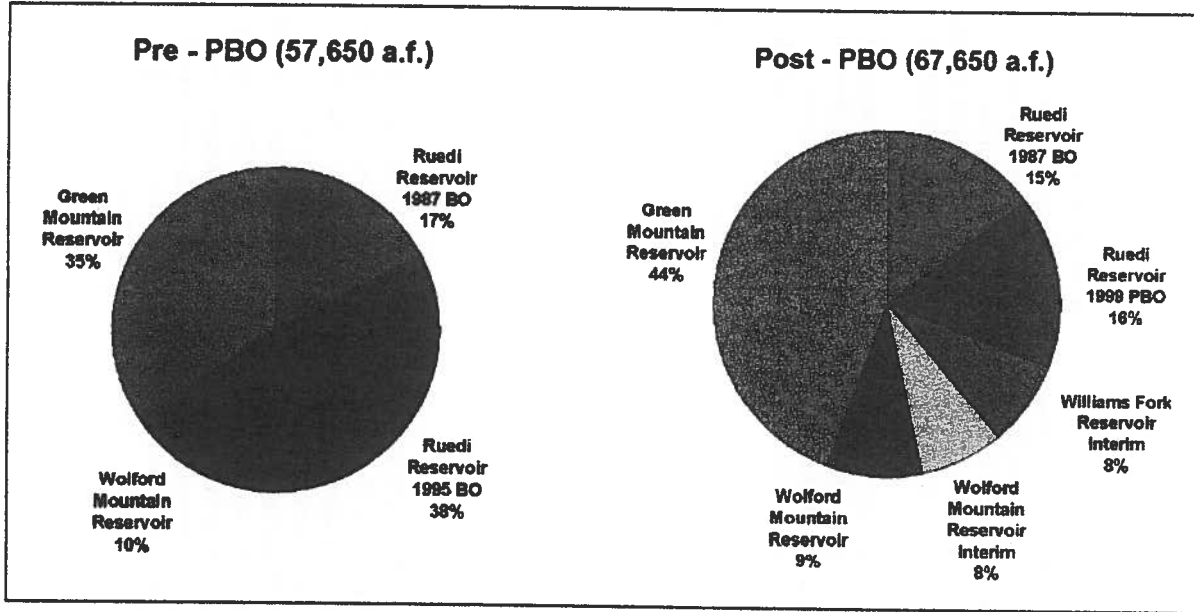


Figure 1: The "15 Mile Reach" on the Colorado River begins directly below the Grand Valley Canal and ends at the confluence of the Gannison River, and has been identified as a critical reach for four endangered fish by the USFWS.

These new reservoir commitments or “fish pools” can be used to illustrate the “Pie of Pain” concept quite well. Figure 2 shows how the PBO has dramatically changed the distribution of dedicated Colorado River reservoir supplies and how all of the endangered fish mitigation waters come from west slope facilities. Each fish pool is represented by a proportional pie slice or the proportion of “pain” felt by each reservoir facility. It is very important to note that except for a very small slice in Williams Fork Reservoir, all other waters come from west slope facilities, including those built as compensatory storage for transmountain diverters. The largest transmountain diverter, the Colorado-Big Thompson Project (C-BT) has no commitment to contribute reservoir water for the endangered fish.

In addition to the obligation of reservoir water for the benefit of the endangered fish, there have been considerable expenditures of time and money on efficiency improvements for the agricultural projects in the Grand Valley, near Grand Junction, Colorado, for the benefit of the endangered fish. These efforts include seeking new water management schemes that could be implemented to reduce headgate diversions, aimed to make more direct flow and stored water available in the critical reach. Even disparate headwater storage facility operations have been coordinated under the Coordinated Reservoir Operations Study (CROS) to bypass otherwise in-priority, storable water, during the critical spring runoff period, to reduce impacts to the peak flows desired by the Recovery Program for the benefit of the endangered fish. Some believe that this spring peak augmentation effort and/or diversion impact reduction effort may even eventually include the construction of new storage facilities to store “surplus” flows (those surplus to desired optimal flows), which occur off peak, for the purpose of additional spring peak augmentation.

Although the coordinated efforts of CROS (currently including Williams Fork, Wolford Mountain, Dillon, Green Mountain, and Ruedi Reservoirs in the Upper Colorado River Basin and depicted in Figure 3) have been deemed to have been successful in the past several years, recent data has shown that even the combination of all these efforts has not been sufficient to meet published USFWS spring peak flow recommendations for the endangered fish in the 15 Mile Reach. Thus, the Colorado mainstem system is currently being further investigated (as required under the PBO) for additional opportunities to enhance the spring peak in the 15 Mile Reach. This investigation is looking for opportunities to expand CROS to include more facilities to contribute an additional volume of 20,000 acre-feet during the time of the spring peak. Specifically, the PBO calls for: *“...the Coordinated Management of Colorado Water Division Number 5 Facilities. This initiative is intended to assess water management facilities and operations that can be coordinated to benefit fish habitat in spring and late summer. This analysis will include, but not be limited to examining options similar to what is proposed for operation of Ruedi Reservoir where water is made available to the fish until needed by water interests. The intent of the initiative is for project sponsors to secure a firm water supply for project purposes, and to*



**Figure 2:** The 15 Mile Reach PBO has resulted in the re-operation of various Colorado River reservoirs (all located on the western slope of Colorado) and has resulted in the obligation of reservoir water for the benefit of the four downstream endangered fishes. This distribution of fish water obligations to mitigate the depletion of all water users illustrates the “pie of pain”. The volume of water dedicated in each reservoir represents the proportion of “pain” felt by each facility.

It can be seen that the main burden has shifted away from Ruedi Reservoir to Green Mountain and Wolford Reservoirs. It is also important to note that the entire “pie of pain” is being “consumed” by only west slope facilities and that the largest transmountain diverter, the C-BT, does not participate .





utilize flexibility that may currently exist to provide water for enhancement of the spring peak. Other options being evaluated include storing or withholding release of available flows in excess of the Service's winter flow recommendations for release during the spring peak, and examining the feasibility and benefits of an off channel storage facility somewhere below the Shoshone Power Plant. The amount of water available, benefits, physical and legal constraints, and recommended options will be determined through the analysis and presented to the Recovery Program. The intent is to provide additional water up to approximately 20,000 acre-feet/year, without diminishing project yield or causing project sponsors to incur significant costs, for meeting fish flow needs either short-term or under certain hydrologic conditions (above what is currently targeted for coordinated reservoir operations). Following the analysis, agreements and/or operating protocols will be developed, as needed. The analysis should be completed by September 2000 and agreement on implementation reached by March 2001. An example of the benefits of this proposal is that if an additional 20,000 acre-feet is released in a given year, it would augment spring peak flows by approximately 1,000 cfs for 10 days in the 15-Mile Reach." This study has been dubbed the "Coordinated Facilities Operations Study" or CFOPS.

Even casual reading of this passage illustrates the need for additional mitigation water. So as the environmental mitigation heat increases upon water users on the west slope, the heat to counteract the perceived inequities and find other participants to "share the 'Pie of Pain,' " has likewise increased from a simmer to a boil.

In the face of this pressure-cooker, the CRWCD Board of Directors adopted a policy (original adoption: 10/27/97; revised and re-adopted: 1/19/99), which strongly encourages equity among all water users, and thereby formalizes the equitable sharing of the "pie of pain". In part, it states: *Now therefore be it resolved that the River District supports the Recovery Program and its purpose of recovering the endangered fish species. In order to insure that the implementation of the Recovery Program is consistent with State law and Colorado's entitlement under the Colorado River Compact and Upper Colorado River Basin Compact, and for the River District to continue its support for the Recovery Program, the following actions must be accomplished:*

a. [not relevant - deleted].

**b. The Recovery Program must ensure that the burden of implementation, operation, and compliance will be equitably distributed upon all water users, including transmountain diverters, without regard to the geographic locations of the legal beneficial uses of the diverted water, within the State. The components of this equitable distribution must include:**

*(i) The level of regulatory certainty provided by the Recovery Program to the Western Slope compensatory storage components of transmountain diversion projects must be equivalent to the regulatory certainty provided to the transmountain diversions from the Colorado River Basin; and*

*(ii) Any Federal or State commitment West Slope water resources (eg. Ruedi Reservoir water delivery to the 15-Mile Reach) must require that compensation or substitute water for the benefit of Western slope users be provided by all East Slope parties benefiting from the Recovery Program.*

The full text of the CRWCD policy on the Recovery Program can be obtained and read on the internet at the CRWCD website: <http://www.crwcd.gov/RIP4.html>.

To meet these objectives of ensuring equity among water users, the CRWCD contracted an independent consulting firm<sup>1</sup> to investigate how the largest of Colorado's transmountain diverters and therefore largest river depletor, the C-BT, could be reoperated to shoulder its portion of the environmental mitigation burden; provide some much-needed relief to the in-basin interests, and thereby contribute to the success of the Recovery Program.

### PROBLEM SOLUTION

The search for the solution to the equity question led the Board of the CRWCD to scrutinize on-going C-BT operations for potential opportunities for depletion impact reduction and/or environmental mitigation, especially during the identified critical flow periods. The primary question the consultant was tasked with was: "*how can the C-BT participate in CFOPS and can its depletion impacts to the 15 Mile Reach and endangered fish be mitigated through re-operations without the loss of acceptable system yield?*" Up to this point, the test of re-operation potential had been limited to West Slope facilities.

The analysis of the C-BT project operations was focused on their supplemental water supply, which is diverted from the headwaters of the Colorado River through the west portal of the Alva B. Adams Tunnel at Grand Lake. This is shown on the map in Figure 4. The final consultant report was completed in October, 2000 and describes the results of a custom spreadsheet model analysis of the operation of the C-BT Project during water years 1983-98. Specifically, the analysis was concerned with:

- 1) the extent to which in-priority, native, east-slope, Big Thompson River water was diverted and integrated into the project water supply,

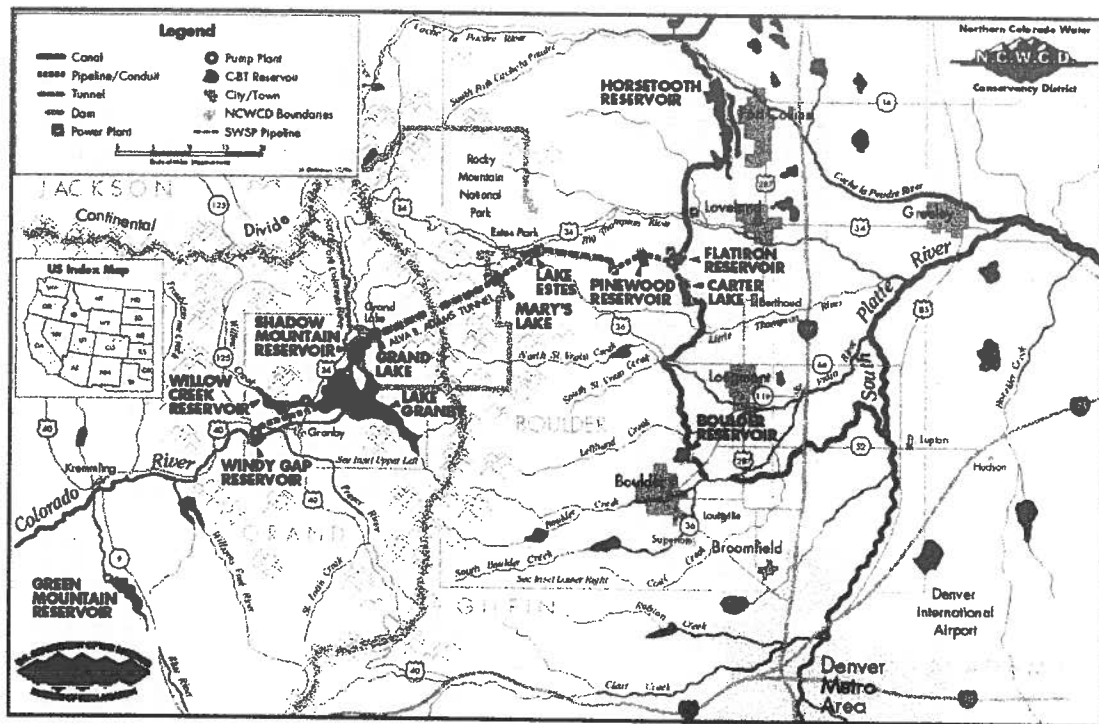


Figure 4: Schematic of the Colorado - Big Thompson Project (CBT), showing the significant transmountain diversion and distribution facilities. The project was built by the U.S. Bureau of Reclamation as a supplemental water supply for the Northern Colorado Water Conservancy District and is operated jointly by these agencies. Source: NCWCD

- 2) the extent to which non-charge, or non-contracted, water has been delivered from the Colorado River to the several streams in the Northern Colorado Water Conservancy District (NCWCD) service area and diverted and used by the water users, and
- 3) the effects of these two aspects of the C-BT operation on the flow of the Colorado River in the "15-Mile Reach".

Initially, data regarding the physical specifications, historical operations, and diversion records of the C-BT Project were collected, studied and understood. (As shown in Figure 4, the project is made up of an extremely complex system of dams, power plants, diversion structures, and delivery canals. It was built in the 1940s by the USBR as a supplemental water supply for the NCWCD and is cooperatively run by these two agencies.) A three-part spreadsheet model was then developed and applied to the historical operations data. The first part of the spreadsheet was used to estimate the water that was available from the Big Thompson River under the C-BT Project native, in-basin, water rights. This was also used to evaluate the diversion of the non-charge, or non-contracted, water released to the Big Thompson River from the Adams Tunnel. The second spreadsheet was used to simulate the Adams Tunnel diversions and the operation of the east slope project features under three different operational scenarios: Runs A, B, and C. Run A was designed to simulate the historical conditions. It used historical diversions of Big Thompson River water, historical deliveries of both charge and non-charge water to the water users, and average historical storage contents for storage targets. Run B simulated increased utilization of the native, in-basin, Big Thompson River water available under the C-BT Project decrees, historical deliveries of both charge and non-charge water to the water users, and different storage targets designed to reserve storage capacity in the east slope reservoirs so that the Big Thompson River water could be diverted at optimum rates and made part of the project water supply. Run C simulated increased utilization of the Big Thompson River water, deliveries of only charge, or contracted, water to the NCWCD water users, and the same storage targets as Run B.

The third spreadsheet simulated the re-operation of Granby Reservoir and calculated the resulting spills from Granby Reservoir, new flows in the 15-Mile Reach of the Colorado River, and the potential for additional enhancement of spring peak flows as required by the 15 Mile Reach PBO.

The principal conclusions from the consultant analysis can be summarized in the following paragraphs:

1. The C-BT Project did not make full use of its decreed Big Thompson River water source during 1983-98. In fact, the analysis indicated that on an annual average basis, an additional 21,862 acre-feet of Big Thompson

River water could have been diverted and/or stored during this period. Most of this water, an average of 18,331 acre-feet, was available during the peak runoff months of May and June. It was found that an average of not more than 6,710 acre-feet of native Big Thompson River water was diverted annually. This indicates that **less than one-third of the legally available, native, east slope supplies available in priority, was actually diverted annually.**

2. The full utilization of the Big Thompson River source water would have significantly reduced the Adams Tunnel diversions that were necessary to supply the historical project demands. The analysis indicated that the Adams Tunnel diversions could have been reduced by an average of approximately 15,200 acre-feet annually. Results show that reduced Adams Tunnel diversions would have increased the spills from Granby Reservoir by an average of approximately 13,000 acre-feet annually and **would have reduced target peak flow shortages in the 15-Mile Reach by an average of more than approximately 3,600 acre-feet annually.**
3. The analysis showed that Carter Lake and Horsetooth Reservoir, the main east slope storage facilities in the C-BT project, can be operated so that **virtually all of the in-priority Big Thompson River water can be diverted and made part of the project water supply without reducing the historical yield to the C-BT shareholders.**
4. The C-BT Project delivered an annual average 37,800 acre-feet of non-charge water during 1983-98. During this period these non-charge deliveries occurred in 9 of the 16 years or 56% of the time (1983-87 and 1995-98) and amounted to about 18 percent of the total deliveries. **The non-charge deliveries exceeded 100,000 acre-feet in 1986 and 1987 and approached 100,000 acre-feet in 1997.** Prior to 1983, non-charge deliveries occurred in only 1962 and 1971.
5. The C-BT delivered an average of 8,730 acre-feet of non-charge, or non-contracted, water to the Big Thompson River each year during the study period. Of this volume the study indicated that an average of 3,423 acre-feet of this water was not diverted by Big Thompson River water users. **Thus, an average of 39.3 percent of the total non charge, non-contracted water went undiverted and unused on the Big Thompson River.** It is important to note that this analysis considered only water uses on the Big Thompson River. The fact that no formal, administrative senior water rights calls were documented on the South Platte River on the days when this non-charge, (uncontracted) water was being delivered indicates that it may not have been fully diverted or used in Colorado. Preliminary inspection of the flow records for the Cache La Poudre River and the South Platte River downstream from the mouth of the Big

Thompson River tends to confirm this. Although, flow records from the latter part of the study period suggest that a larger percentage of the non-charge water may have been diverted and used by water users on the South Platte River in Colorado, the flow records, especially from the 1980's, may not be adequate to determine this completely.

6. Reductions in the non-charge deliveries during 1983-98 would have reduced the Adams Tunnel diversions and hence the flow shortages in the targeted 15-Mile Reach. In fact, the analysis indicated that the **elimination of the non-charge, non-contracted, deliveries would have reduced the target flow shortages by an average of approximately 13,300 acre-feet annually when combined with increased utilization of the C-BT Project's Big Thompson River water supply.**
7. Diversion of the available Big Thompson River water and reduced or precluded deliveries of non-charge deliveries would have enhanced the spring peak flows in the 15-Mile Reach significantly and would have accomplished or largely accomplished the CFOPS goals in this regard. **The analysis indicated that diversions of the available Big Thompson River water would have increased the spring peak flows in the 15 Mile Reach by an average of 18,498 acre-feet in the middle-range flow years, which would have nearly met the CFOPS goal for spring peak flow enhancement of an average 20,000 acre-feet annually. Increased diversions of the available Big Thompson River water and the total elimination of the historical non-charge deliveries would have increased the spring peak flows by an average of 74,409 acre-feet annually.**

## CONCLUSIONS

Reoperations have been a major component of the many and varied RPMs identified by the USFWS in the development of the 15 Mile Reach PBO. Many west slope water users entities have participated and have felt the "pain" associated with these Recovery program activities. In the minds of most of these west slope entities, especially the CRWCD, the distribution of this "pain" or the "pie of pain" has not been equitably distributed. The water storage facilities that were built as basin-of-origin compensation and earmarked for the users in the Colorado River Basin have provided most of the environmental mitigation, rather than being saved for the users for which they were built, whereas, the most significant Colorado River depleter, the C-BT, has no direct environmental mitigation commitment.

To address this inequity, a CRWCD-sponsored study has shown that re-operating transmountain diversion projects can have a profound mitigating effect on the endangered fishes in the critical 15 Mile Reach. Specifically, it was found that:

1. It is clear that the C-BT Project did not make full use of its Big Thompson River water source during 1983-98. A large volume of native, in-priority east slope, water was available and could have been diverted to meet the needs of the NCWCD without reducing the historical yield to the C-BT beneficiaries and thus could have helped: a) minimize the impacts to the endangered fish, b) reduced target flow shortages in the 15 Mile Reach, and c) reduce and/or balance the mitigation burden on the west slope water users.
2. The non-charge (non-contracted deliveries) program comprises a significant portion of the C-BT water deliveries (occurred over 50% of the study period) and can amount to about a fifth of the C-BT total deliveries. In wet years it can exceed 100,000 acre-feet, and in recent years the frequency of non-charge, non-contracted, deliveries have been increasing. Flow records from the study period suggest that only approximately 40 percent of this water was diverted, on the Big Thompson River, for use by NCWCD users. Later, more complete flow records from the late 1990's, however, suggest that this percentage of water use may be higher.

Overall, the re-operations study initiated by the CRWCD has revealed several significant areas of concern which indicate a considerable potential for lessening the mitigation burdens on west slope water users through no loss of yield to the C-BT. In addition, the study suggests that further re-operation investigations of the C-BT system are warranted: 1) the practices of carrying over C-BT quota water (from the west slope) one year to the next, and 2) recent operations and accounting of Windy Gap Reservoir water in the C-BT system.

Future studies will examine these two operational issues. For example, when C-BT quota water is carried over from one year to the next in individual contractee accounts, (outside of the general NCWCD water supplies) which has occurred since the early 1980s, the following year's available C-BT water supply can be adversely impacted, and could potentially create a larger draw on the west slope supplies. This can occur when users' carry over storage of west slope water in east slope storage space limits the ability to divert and store, native, in-basin supplies. If the carry over program was limited or eliminated, saved water from the previous water year would revert to "project water" and hence, could result in a smaller draw from west slope supplies. Future analysis of the removal of the practice of individual carry-over accounts may illustrate a potential additional benefit to west slope water users.



In addition, future investigations of recent operations and accounting of Windy Gap Reservoir (owned and operated by the municipal sub-district of the NCWCD) water within the C-BT system is warranted. At present, the commingled operations of Windy Gap and the C-BT system appear to reduce the prospect of a spill from Granby Reservoir and appear to make additional capacity available in the Adams and Olympus Tunnels for the non-charge, non-contracted water, program and for Windy Gap deliveries. The net effect of these operations appear to cause a greater draw on west slope supplies and can thereby increase mitigation burden, or the "slice of pain" that west slope users are once again forced to consume.

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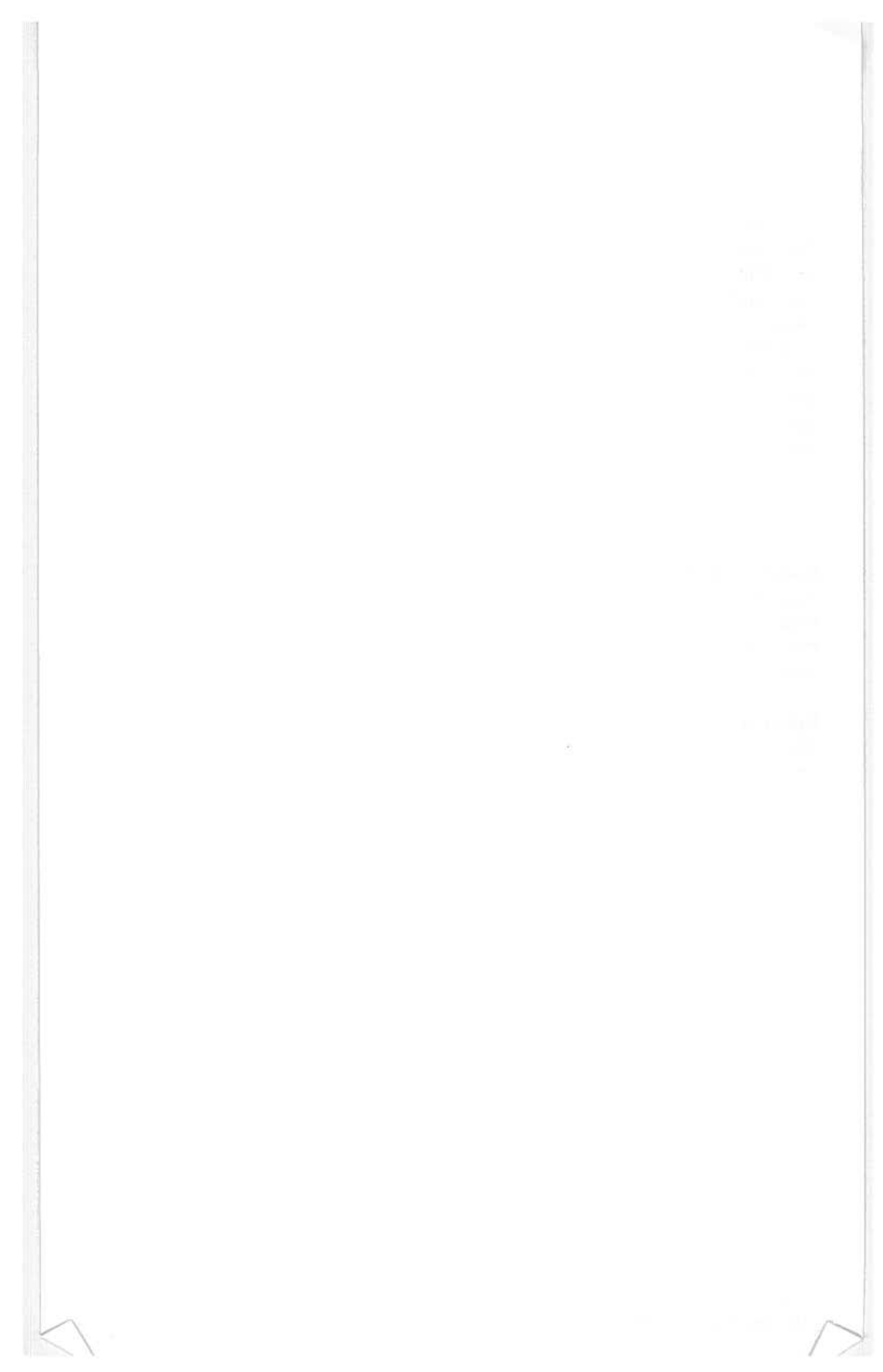
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### ENDNOTES

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<sup>1</sup> The firm of Helton and Williamsen, PC was selected to perform this task.



## DAM SMART TRANSBASIN WATER TRANSFERS

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R. Joseph Bergquist, P.E.<sup>2</sup>

### ABSTRACT

The settlement and economic development of the Western United States was largely the result of successful development of the region's water resources. Transbasin water transfers linked to construction of large water storage dams were an important component of this development. Changes in regulatory requirements, federal funding and environmental interests during the last 30 years have significantly increased the cost and time needed to permit and construct a transbasin water diversion and the associated large storage projects. A successful new diversion project must balance public sentiment, in terms of structuring a win-win (cooperation for mutual benefit) strategy for both basin stakeholders. If this is done, you can still permit and build a project, which can be termed a "dam smart transbasin water transfer".

Probably one of the greatest concentrations of transbasin water transfers in the world is along the Front Range of Colorado. There are about 19 tunnels/ditch collection systems that bring water from the western slope of the Colorado River Basin to the Front Range stretching from Fort Collins to Pueblo, Colorado. The reason for this is that about 80 percent of Colorado's water resources are on the western slope, but about 80 percent of the State's population reside along the Front Range. In fact, the Front Range area receives only about 14 inches of rain, making it a high plains desert. Additionally, most of the water supply occurs in a three-month window associated with spring snowmelt. The highly variable precipitation levels in Colorado require that water be stored in times of plenty for use in times of drought. Past and present physical and legal wars over water rights highlight the importance of water in Colorado. With today's regulatory, environmental and societal needs, there is a strong call to strike a balance between water development, conservation and environmental needs.

The authors have been and are currently active on providing engineering services on existing and potential transbasin diversions in the Western United States. This paper will provide an overview of the required partnership that has to be structured between the stakeholders in the basin of origin and the receiving basin. Examples of transbasin diversion projects, include: the unsuccessful Union Park Project in Colorado, the Imperial Irrigation Transbasin Diversion Project, and the

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proposed Wind River, Wyoming, Indian Water Right transfers to high demand areas are discussed in the following sections.

## INTRODUCTION

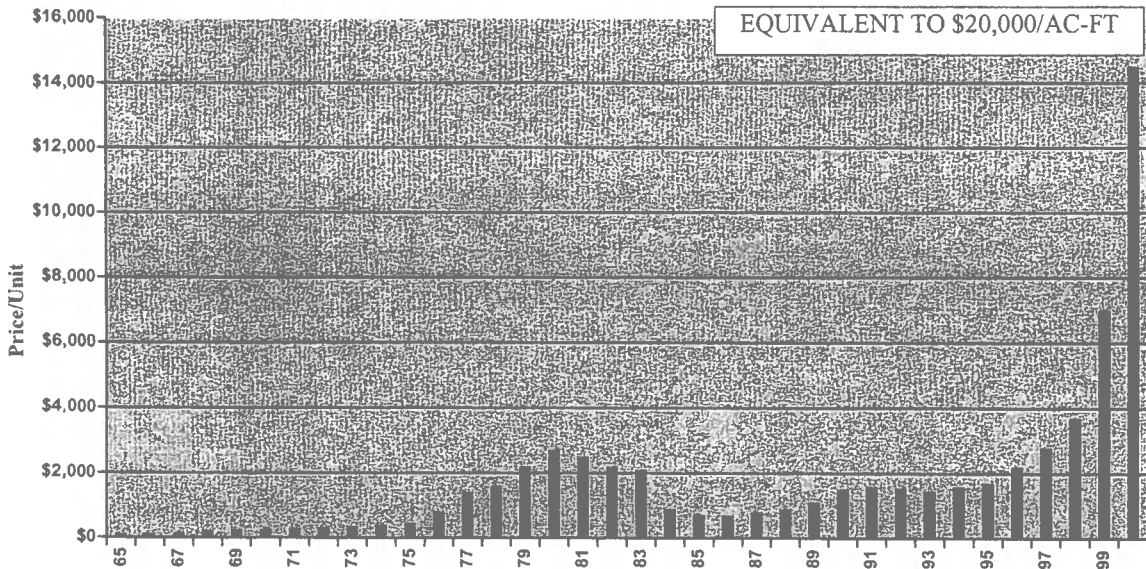
It is clear that in the west the supply of water has been essentially the same for thousands of years. However, the level of competing uses for a finite supply has increased dramatically over the past 50 years. These uses today span the range from environmental instream flow, recreational, agricultural to municipal and industrial consumptive water demands.

Future transbasin diversions are required in order to deliver water resources from areas that may have available water to areas of water supply shortage. The professionals charged with providing a safe and reliable water supply to the area of growing need cannot change their primary mission of assuring a reliable water supply. To think otherwise is like asking a piranha to become a vegetarian. However, before the transbasin project can be politically supported in the permitting process in the western United States, the basin of need has to demonstrate a clear strategy that best management practices (BMP) for water conservation have been fully implemented.

Along the Front Range of Colorado, the water resources available to the growing population are in great demand. This demand has driven up prices for existing water supplies that are reasonably marketable without extensive permitting issues, such as those provided by the transbasin Colorado-Big Thompson (CBT) project that delivers water to the Front Range, and eastward for supplemental irrigation uses, from the Colorado River Basin on the western slope. CBT water costs that municipal entities are willing to pay have increased dramatically over the past five years (see Figure 1) reaching a peak of about \$20,000/acre-foot (af) last year.

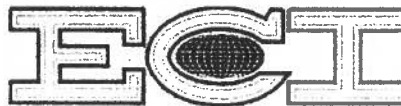
One of the most valuable components to municipalities in their water supply system in today's highly regulated environment is storage. Storage is important to municipal water providers both from an operations standpoint as water demands and the available water supply varies from day to day, and for carryover (year to year) to provide firm yield water during drought periods. This is one of the main reasons why the CBT water supply, which is essentially firm yield water has experienced such dramatic price appreciation in recent years.

Given these high costs for new firm yield acquisition of water, it is clear that additional efforts will be focused on transbasin project development. One such project that has been unsuccessful is the Union Park Project that proposed to divert water from the Upper Gunnison Basin in Western Colorado to the Front Range. This project, the first that we explore, is analyzed as to why the Colorado Water Courts did not award a suitable volume of water for transbasin diversion making the proposal uneconomical.



Note: One unit yields about 0.7 acre-feet/year  
 Information obtained from recent NCWCD transactions

Figure 1: Colorado—Big Thompson Water—  
 Schedule of Representative Market Prices



The second project that we explore is in Southern California where great expenditures and public acceptance for BMP for water reuse is setting the national trend. Thus, with maximum conservation and reuse of highly treated wastewater for irrigation of open space, the political/regulatory framework was reasonably satisfied to move ahead with a large conservation program in the Imperial Valley, about 100 miles east of San Diego, consisting mainly of lining canals to reduce seepage losses. This salvaged water could then be exported to San Diego at competitive municipal water prices that would adequately compensate the basin of origin in addition to paying for the improvements. The details of this transbasin diversion are discussed in the following pages.

The last project to be explored is the proposed water leasing strategy that the Wind River Tribes in Wyoming are contemplating. The Tribes were awarded a large block of water by the U.S. Supreme Court. They are interested in the potential for exporting this water to California, the Colorado Front Range or other users. This potential project is explored in the final case study.

Thus, one needs to be mindful of the fact that with rapidly escalating cost of reliable or firm yield water, it is clear that additional transbasin diversion in the western United States will be developed.

### **THE NEW PERMITTING PARADIGM**

In today's regulatory environment, there is an ever-increasing necessity to strike a balance between needed transbasin diversion and associated water storage projects together with environmental mitigation and enhancement strategies. When this balance is ultimately negotiated by the stakeholders, a successful project usually develops.

The siting and permitting processes used in the past for large projects are now ineffective. Challenges and costs of siting, permitting and constructing new transbasin water supply systems continue to become increasingly restrictive. Most major project development efforts are plagued with long delays, escalating permitting expenses, and extreme risk of failure and frustration of the municipal administrators and their professionals charged with meeting their fiduciary responsibility of providing adequate resources for meeting future water supply reliability objectives. Typical transbasin diversion projects take 10 to 20 years to obtain the required permits and at the conclusion of this exhaustive and costly process, often are denied.

At the outset of a project, planning studies may include realistic water demand projections, economic evaluations, water rights modeling, and preliminary cultural resources and environmental studies. When early findings confirm that the project is needed, is feasible, and has a sponsor who is both willing and able to provide the political public leadership and finance the project, the next step in the

project development cycle is typically permitting. The traditional approach consists of completion of engineering studies followed by project announcement and defense of the project and the preparation of an Environmental Impact Statement (EIS). Unfortunately, defending a project in today's regulatory environment without consideration of viable alternatives usually means defending the project to its death.

More successes can be achieved by utilizing cooperative concepts to develop win-win projects that can be developed. Prior to entering the EIS process, a better approach to avoid a long and costly permitting battle, is to complete reconnaissance-level evaluations and preliminary screening of practicable alternatives. This approach should incorporate the requirements of Section 1502.14 of the Council on Environmental Quality Regulations for the Implementation of the National Environmental Policy Act (NEPA) and Section 404(b) of the Clean Water Act. These regulations require an evaluation of reasonable and practicable alternatives that would be required in the EIS anyway. Furthermore, in many cases, a third party regulatory function becomes involved in the project who is not as familiar with the technical issues as the project development team. This results in wasted time and dollars that are consumed studying impacts associated with alternatives that do not meet the sponsor's purpose and need, or are impractical or not permissible. This innovative, yet simple, alternative screening process can be used prior to entering the formal permitting process for the project. The result is a more efficient, focused and ultimately a successful EIS process leading to permit acquisition and project construction. This process was used in San Diego recently and resulted in permitting the highest roller compacted concrete dam in the United States at 308 feet without one lawsuit.

### **BRIEF HISTORY OF THE COLORADO RIVER COMPACT**

Because the following case studies all involve the Colorado River, a brief overview of the compact is provided. The Colorado River's length is about 1,400 miles, starting near Estes Park, Colorado and ending at the Gulf of California, as shown on Figure 2. The total drainage basin, about 242,000 square miles, drains portions of Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona and California. It is interesting to note that the drainage basin in the State of Colorado contributes about 70 percent of the virgin flow to the river. The Colorado River supplies more than 30 million people and irrigates some 2 million acres of land in the seven basin states, as well as northwest Mexico. The 1922 Colorado River Compact equitably apportioned the flow of the river between the tributary states. Unfortunately, the period of record that was available to allocate the quantity of water between the states overestimated the long term average volume of water available for allocation. Thus, from the very outset, the seeds for future conflict were sown.

COLORADO RIVER BASIN

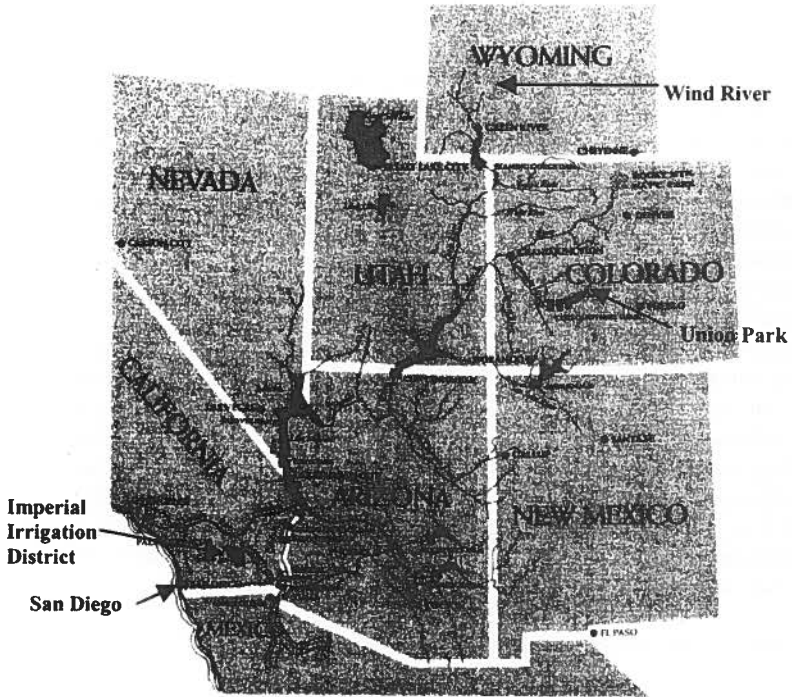


Figure 2: The Colorado River System





## PROPOSED UNION PARK RESERVOIR TRANSMOUNTAIN DIVERSION SAGA

The proposed Union Park Project is a 325,000 af storage and conveyance system from the Upper Gunnison River Basin to the Front Range of Colorado, see Figure 2. The project proponents obtained a conditional decree from the Colorado Water Courts of 325,000 af in 1984. Subsequently, the project was expanded to a storage capacity of 900,000 af and the applicants' request for a conditional decree was rejected. The threat of such a large diversion from the upper Gunnison, that is largely dependent on streamflows to support its agricultural and recreational economic base, greatly alarmed the local residents. Many of the more vocal project opponents either hold senior water rights or contemplated future water uses in the basin.

The proposal created a major uproar in the Gunnison Basin and the Colorado Water Courts concluded that there was insufficient unappropriated water available in the Basin for the proposed diversion. The Project proponents argued unsuccessfully that the upper basin contained sufficient water to effect the transbasin diversion across the Continental Divide for ultimate use along the Front Range. What the Project proponents argued unsuccessfully was the fact that all of the downstream federal projects (Aspinal Unit) and their associated decrees used water to full beneficial use through hydropower generation, fish and wildlife and recreation purposes. The Colorado Water Courts found that the United States has an absolute decree for the federal projects water right and these rights have been put to beneficial use. The storage/hydropower right is in excess of 1.2 million af adjudicated in the Colorado Water Court which effectively precludes any future major transbasin water diversion from the Upper Gunnison. The only exception would be to purchase water from the federal projects for transbasin diversion. However, it is probable that any proposal of this type would be defeated by strong local opposition.

The Project proponents claimed that the Upper Gunnison River Basin has a large undeveloped high-quality water resource available for diversion to the Front Range. Such diversion would also facilitate development of the water apportioned to Colorado by the Colorado River Compact. In fact, the Colorado Water Court found that when the federal purpose (mainly hydroelectric power generation on the Gunnison River) is factored into the analyses, only about 20,000 af are available for the transbasin Project development. This volume of water is too small for an economic project. The Project proponents also argued that Congress did not want existing federal reservoirs with State water rights decrees to restrict the development of future projects that would facilitate Colorado River Compact Water Use in Colorado. However, the Courts found that the federal projects on the Gunnison store water in order for Colorado to meet its down basin compact obligations during dry periods.

### IMPERIAL IRRIGATION TRANSBASIN DIVERSION PROJECT

It is a simple fact of life that when the demand for water increases and new facilities are not constructed, an imbalance soon develops that leads to serious shortages, especially during drought periods. The electric power situation in California can be used as a reasonable analogy to water needs since it is a classic example of no new construction of powerplants at a time of escalating demands. The simple truth is that the west is growing more rapidly than anyone reasonably predicted 10 years ago, yet we are not building major new water supply projects. Furthermore, Southern California is in desperate need of additional water to serve its enormously successful economic growth engine.

The San Diego County Water Authority (SDCWA) has the responsibility for supplying water to nearly three million people and associated industries and agricultural enterprises in San Diego County, see Figure 2. Like much of Southern California, San Diego County has a dry climate with average annual rainfall of only about 12 inches per year. Due to the lack of abundant local supplies, up to 90 percent of the region's existing water supply is provided by purchasing imported water through the Metropolitan Water District of Southern California (Metropolitan).

SDCWA is one of the largest urban water suppliers in the state of California, providing the imported water supply to meet the needs of San Diego's \$103 billion economy and to sustain the quality of life of the nearly three million people who live and work in San Diego County. Currently, SDCWA is completely dependent upon Metropolitan for the water supply it imports to serve its customers. This imported water supply constitutes an average of 75 percent to 90 percent of the San Diego region's annual average water supply requirements. SDCWA is Metropolitan's largest water purchaser. SDCWA's annual water purchases from metropolitan have grown from about 40,000 af in 1948 to more than 600,000 af in 2000.

The SDCWA has reached two agreements that will make available to the San Diego region a new supply of up to 200,000 af of water annually well into the 21<sup>st</sup> century. This water will increase the reliability of SDCWA's current and future supplies, thus helping to sustain the San Diego region's economy, job base and quality of life.

The first agreement is the Water Conservation and Transfer Agreement between SDCWA and the Imperial Irrigation District (IID) signed April 29, 1998. This agreement provides for the implementation of voluntary, extraordinary conservation measures by Imperial Valley farmers. The conserved water will then be made available to SDCWA. A contingency of the agreement was that the SDCWA would secure a way to convey the transfer water to the San Diego region. This may be accomplished through a Water Exchange Agreement

between SDCWA and Metropolitan. Metropolitan will take delivery of the transfer water via its Colorado River Aqueduct. In exchange, Metropolitan will deliver to SCDWA a like quantity and quality of water. Currently there are also other potential delivery options being explored. It should be noted that Metropolitan has in place a similar program to salvage 106,000 af.

In the Contract's first year, the cost of water will be approximately \$233 per af. The price will be indexed to Metropolitan's rate at a discount. The discount is 25 percent the first year, declining to a long-term value of 5 percent by year 17. The agreement allows for a "price determination" process to adjust the price to market values 10 years after the start of deliveries. During dry years, when water availability is low, the conserved water will be transferred under IID's Colorado River rights, which are among the most senior in the Lower Colorado River Basin. Without the protection of these rights, SDCWA could suffer delivery cutbacks. In recognition for the value of such reliability, the contract requires SDCWA to pay a premium on transfer water under defined regional shortage circumstances.

A California law passed in September 1998 provides \$235 million in state funding that advances the canal lining and storage projects; this satisfies the state funding contingency of the Exchange Agreement.

Without the Colorado River water made available through SDCWA's agreements with IID and Metropolitan, additional demand would be placed on water supplies from Northern California and the State Water Project (SWP). The SWP draws water from the environmentally sensitive Sacramento/San Joaquin Bay-Delta estuary in northern California. Southern California's wise use of the Colorado River supply reduces pressure on the Delta.

Any transbasin diversion is not completed until the water is flowing. Even then many arguments can develop as to the long-term operation. In that context, the planned IID to San Diego Project is still in sensitive negotiations since the IID Board recently suspended discussions since the \$200 million the State was to provide for lining the canals has recently been spent on buying electrical power by the State. These monies now have to be replenished.

### **WYOMING TRIBAL WATER SALES POTENTIAL**

Near the end of 1999 members of the Wind River Reservation's Joint Business Council took the first step towards a win-win situation for the Tribes (Northern Arapaho and Shoshone) and the State of Wyoming by approaching the Governor for water study funding. The study they requested was to assess ways of utilizing the water in the Wind River basin for the benefit of the Tribes without harming the junior water right users, see Figure 2. The Wind River is on the east side of the Continental Divide and is part of the Missouri River Basin. This was the first

step in their water development process the Tribes took after being awarded the senior water rights on historic lands of approximately 290,000 af per year and to future irrigated lands of approximately 200,000 af/yr.

The request was positively received and resulted in three studies being funded under the Wyoming Water Development Commission's (WWDC) annual water development program. The three studies included a transbasin export investigation, a storage site review, and an irrigation system feasibility design. The Tribes Water Resource Control Board worked with the WWDC to develop scopes of work and select engineering consultants to perform the work. The consultants started work in June of 2000 and will be completed by November 2001.

Members from the Tribes Water Board, WWDC and the State Engineer's Office sit on the steering committee and hold quarterly progress meetings. Different individuals from these agencies and the Tribal Water Engineer's are using the consultant's findings to hold public involvement meetings. All efforts are being used to keep stakeholders informed and involved. Conflicting goals are being raised and addressed.

The objectives of the transbasin export study are to:

- Determine quantifiable water demands outside the basin and predict that demand's growth into the future.
- Develop and cost on prefeasibility level water conveyance systems [diversions, pumps, pipelines, tunnels, and power] to move the water out of the basin and into the North Platte basin or the Upper Colorado River watershed.
- Analyze and define the firm water yield available to a potential export alternatives.
- Define the potential of the receiving entities' willingness to defray the cost of developing the supply system.
- Establish the environmental concerns and permit requirements.
- Help build the relationships required to develop a successful transbasin diversion and storage project.

Progress in phase one of the study has been made on all objectives. A future municipality water demand of about 40,000 af/yr has been quantified in the North Platte basin. This demand is above the environmental water demand of over 80,000 af/yr in the Platte River below Grand Island, Nebraska. Larger demands

exist in Northern Colorado and California areas. Water yield studies indicate with storage these demands can be satisfied on annual bases. Three conveyance routes have been studied and capital costs estimated. The tunnel routes to the Green River basin are the lowest in cost, but highest in environmental and compact agreement conflicts. Of the two main pipeline routes to the North Platte the one to the Sweetwater River is the more economical and less environmentally sensitive.

### CONCLUSIONS

Based on the authors' experience, the profile of a successful smart transbasin water project consists of several factors including:

- A clear quantifiable demand.
- The political/financial ability to pay for the infrastructure.
- The water short entity has to have the vision, financial and political skill to develop broad-based community support for the project in both basins.
- A clear win/win strategy for both the basin of origin and the end user.
- Good stewardship and building a balanced trust relationship between both areas.
- The ability to obtain the necessary permits, including appropriate funding of mitigation strategies, particularly for threatened and endangered species.

Risk control is another important consideration. If you get involved in a transbasin water project, you must make early decisions as to the "off ramps" for project development, otherwise, you may end up throwing good money after bad. Most of the western water wars like the Union Park Proposal end without a project along with embarrassed professionals and politicians who must answer for large, often wasted expenditures.

The process of permitting and constructing transbasin diversions and their associated storage facilities has become lengthy, unpredictable and expensive. The successful water manager must respond to the social pressures and be more sensitive to environmental issues. The key for new water projects is to strike a balance between water needs and environmental needs, thus leading to preservation of our quality of life in concert with environmental values. The practice of transbasin diversion and associated dam engineering needs to continue to adjust to the emergence of new technical concepts with innovative and responsive permitting and design strategies.

Transbasin diversion projects fall under NEPA compliance, the proactive approach suggested here to evaluate and discard poorer alternatives prior to

entering a complex EIS process demonstrates that large water supply projects can be developed in today's complex regulatory environment. A key to the success of this approach is that the sponsor uses the environmental regulations to their advantage. Many similar projects fail because alternatives were not adequately analyzed. This approach eliminates this argument and helps focus the EIS on the real environmental issues associated with only projects that would meet the owner's needs.

In conclusion, the whole area of water project development must get more creative – not controversial. We must have a stronger win-win philosophy among all stakeholders in terms of what we are trying to do in the water business. We also need to make sure that our water projects are successful and demonstrate characteristics of the five F words – farmers, families, fish, fowl and, most importantly, finances. Finally, it is critical that we negotiate our water partnerships/transfers during non-stress times. Much of the West has been lucky in that we have not had a really serious drought since the early 1950s.

## WATER MANAGEMENT IN THE NORTHERN COLORADO WATER CONSERVANCY DISTRICT

Darell D. Zimbelman <sup>1</sup>

Brian R. Werner <sup>2</sup>

### ABSTRACT

The Northern Colorado Water Conservancy District (District) has established a set of policies and procedures and, in cooperation with the U.S. Bureau of Reclamation (Reclamation), has constructed a water storage and distribution system to effectively and efficiently transfer water on an annual rental basis, or on a permanent basis, to meet changing demands or climatological conditions. The District operates and maintains the Colorado-Big Thompson (C-BT) Project, which captures runoff from the headwaters of the Colorado River on the West Slope of the Colorado Rocky Mountains. The water is then transferred to storage reservoirs on the East Slope of the mountains for subsequent delivery to District allottees. The District delivers an annual average of 224,000 acre feet of water to supplement the runoff of six, East Slope drainages; namely the Cache la Poudre River, the Big Thompson River, the Little Thompson River, the St. Vrain River, Left Hand Creek, and Boulder Creek. From 1990 through 1999, 30 percent of the deliveries were for municipal and industrial uses, with the remainder used for agricultural purposes.

The District's policies and procedures allow water to be transferred from one allottee to another on an annual rental basis, without regard to type of use or location, simply by filling out a postcard and mailing it to the District. This process allows water to be reallocated to areas and uses that best fit demand patterns. This powerful management system tool transfers water on an annual basis to the individual or entity with the "greatest" demand. Water can also be transferred permanently. While permanent transfers take more time to process, they allow water to be transferred to meet the overall changing demands of the area, usually from agriculture to municipal uses. C-BT transfers can occur without being encumbered by the sometimes lengthy and costly legal process required of other water supplies in Colorado. The Colorado water rights system is a judicial process that requires a diverter to submit a water right transfer to the water court, along with necessary legal and engineering reports, demonstrating that senior water rights holders will not be adversely impacted by the transfer. Since this legal

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process is open to objection, it can be protested, resulting in a substantial delays and increasing transfer costs. It may also result in less water being transferred.

## INTRODUCTION

Farming on the high plains of northeastern Colorado began in the mid to late nineteenth century when a few disillusioned miners, who had come to the region in pursuit of gold and silver, began to raise food and fiber for local mining communities and the U.S. Cavalry. At the same time, the railroads began their movement westward. When annual precipitation (which averages less than 15 inches) proved inadequate, farmers began to construct diversion structures, canals, and storage reservoirs for irrigation. These irrigation systems captured the spring runoff from local streams and diverted it to farms and reservoirs to provide water in the hot summer months when many of the natural streams dried up.

As the agricultural economy in Colorado grew, farmers put additional lands under cultivation. When a severe drought hit the region in the 1930s, agricultural leaders realized they needed a supplemental water supply to stabilize and augment the native stream runoff. Irrigators hired former state engineer Royce J. Tipton to study the possibility of diverting water from the wetter, western slope of the Rocky Mountains to supplement stream flows on the eastern slope. In fact, by the 1930s several irrigation and reservoir companies had already developed transbasin diversions, including the Grand River Ditch, the Laramie-Poudre Tunnel, and the Michigan Ditch. During the 1930s, local agricultural leaders in northeastern Colorado organized themselves as the Northern Colorado Water Users Association (NCWUA) to actively promote the construction of a transbasin water project to stabilize and supplement local water supplies. After searching for the proper federal partner, the NCWUA settled on Reclamation. When Reclamation agreed to undertake the project, it required a local entity with the ability and authority to repay a portion of the project costs. To meet this requirement, the state legislature passed the Water Conservancy Act in 1937. The Northern Colorado Water Conservancy District was formed later that year under the Water Conservancy Act (Colorado Revised Statutes) to locally sponsor and contract with the federal government—U.S. Bureau of Reclamation, Department of the Interior—for the operation, maintenance and repayment of the C-BT Project. The District was the first conservancy district organized under the Water Conservancy Act.

Constructed between 1938 and 1957, the C-BT Project transports water from the Colorado River Basin beneath Rocky Mountain National Park to the Big Thompson River on the East Slope of the Rocky Mountains. The West Slope of the Rocky Mountains receives more precipitation, primarily in the form of winter snowpack, than does the East Slope due to prevailing west winds and moisture from the Pacific Ocean.



The water storage components of the C-BT Project consist of Green Mountain Reservoir, Willow Creek Reservoir, Lake Granby, Shadow Mountain Reservoir and Grand Lake on the West Slope; and Horsetooth Reservoir, Carter Lake, and Boulder Reservoir on the East Slope. Green Mountain Reservoir was constructed in accordance with a requirement in the Water Conservancy Act that requires the District to offset any impact the C-BT Project would have on Colorado River water users and their associated water rights. Water is delivered from the three, East Slope reservoirs during a six-month period (April 1 - October 30) to supplement the flows of the local East Slope streams, including the Cache la Poudre River, the Big Thompson River, Little Thompson River, St. Vrain River, Left Hand Creek and Boulder Creek. On a year-round basis, municipal and industrial water deliveries are made through a series of pipelines and outlets connected directly to the three reservoirs. Figure 1 displays the collection and distribution facilities of the C-BT Project. Green Mountain Reservoir is located on the Blue River and does not appear in Figure 1.

### **WATER ALLOTMENT POLICIES AND PROCEDURES**

The C-BT Project was originally constructed to store and deliver an annual average of 310,000 acre feet of water, resulting in the creation of 310,000 acre-foot "units." All 310,000 units were allotted to individual water users and municipalities located within the District's service area, which consists of portions of seven front range counties (Larimer, Boulder, Weld, Morgan, Washington, Logan, and Sedgwick). All seven counties are located in the South Platte River Basin below the Denver metropolitan area. C-BT units are allocated through an allotment contract, which is a "contractual right of use." The Water Conservancy Act divides these allotment contracts into the following three classes:

Class B (municipal)

Class C (industrial)

Class D (irrigation)

The District has a contractual obligation to deliver an amount of water to each unit, which is 1/310,000th of the total amount of water declared available for delivery by the District's Board of Directors each April. This annual amount is expressed as a "quota," which represents the percentage of an acre foot of water that will be available for delivery for each acre-foot unit. For example, an 80 percent quota means that each allottee has available eight tenths of an acre foot for each unit allotted. The quota has ranged from a maximum of 100 percent to a low of 50 percent, with the average for the first 43 years of operations of the project being about 72 percent.

The Board of Directors considers a broad range of issues and data before declaring the quota, including:

- a. The water currently in storage in the C-BT system and the amount of runoff forecasted to enter the system during the remainder of the runoff season;
- b. The water currently in storage in East Slope reservoirs and the amount of runoff forecasted to be available for diversion from East Slope streams;
- c. The forecast for temperatures and precipitation in the irrigated "agricultural" area of the District;
- d. The forecasted amount of carryover water that will be in storage, both in the C-BT Project and in East Slope reservoirs, at the end of the current water year;
- e. The status of the crops already planted and the need for irrigation water to ensure adequate moisture for germination; and
- f. The general economics of irrigated agricultural products.

Once the quota has been set, each allottee's account is credited with the proper volume of water and the allottee is free to request delivery at any time between April 1 and October 31. Municipal and Industrial users that can take delivery of water directly from a reservoir or a pipeline are allowed to take delivery of water from November 1 through March 31; however, they are limited to an amount that does not exceed their water availability if the District's Board of Directors declares a 50 percent quota in April.

Account balances are maintained by the District to ensure that delivered amounts do not exceed entitlement.

Control of the allotment contracts rests with the Board of Directors. District staff is responsible for administering the contracts in accordance with the rules, policies, and procedures established by the Board.

Class D allotments are for agricultural purposes. The units associated with Class D allotments must be attached to a parcel of land to which the water can be delivered. The Board of Directors has established a policy that specifies the parcel of land to which the units are to be attached must have been previously irrigated. To discourage speculation, District staff physically inspects each parcel and determines the amount of water that can reasonably be used on that parcel based on soil type, land slopes, cropping patterns, present water supply, etc. The difference between the water provided by non-C-BT supplies and the total amount that can reasonably be used establishes the limit on the number of units that can be attached to an individual parcel. For municipal and industrial purposes, the Board of Directors allows the entity responsible for providing the water to accumulate twice its demonstrated need in a given year. This accumulation is established based on existing demand patterns plus an allowance for planned or platted developments. The difference between demand and the yield from non-

C-BT water supplies represents the demonstrated need. That need in acre feet multiplied by two establishes the limit for C-BT units. This policy ensures that municipal and industrial uses are satisfied even when the Board sets a low, 50 percent quota. This policy recognizes that municipal demands are less able to deal with shortages than are agricultural water users. The District also provides an option whereby allottees can voluntarily accept a fixed quota of 70 percent. The quota for these allottees is fixed at 70 percent for a 10-year period. Allowances are made to reduce the quota below 70 percent in extreme drought periods.

### TRANSFERS

District policies and procedures allow water to be transferred between allottee accounts. On an annual basis, allottees that have more water than needed can "rent" water to allottees that need additional water. An informal network exists among allottees through which names of allottees that have water to rent, or names of allottees that need water to rent, can be found. If two allottees agree on a rental price, the renter of the water is required to submit a postcard form to the District. The District then debits the account of the renter by the amount transferred and credits the account of the rentee by the same amount. The District does not share financially in the transaction, nor does the District charge an administrative fee for making the transfer. Of the 224,000 acre feet of water delivered on an annual average basis, between two-thirds and three-fourths of that water can be transferred on an annual rental basis. The District does not monitor or control the volume of water transferred to any individual account during the water year.

Any water delivered from the C-BT Project or any water transferred for subsequent delivery must be put to beneficial use within District boundaries (see Figure 2). Neither the District nor the State of Colorado account for the changes in return flows or groundwater recharge patterns resulting from the transfer of C-BT Project water. Even though under Colorado's water rights system the water from transbasin diversions can be used and reused, the transbasin water provided by the C-BT Project is restricted by contract between Reclamation and the District to a single use with the return flows accruing to downstream water users.

The allotment contracts can also be transferred permanently. In a willing buyer/willing seller arrangement, allottees wishing to buy or sell units agree on a price. An allotment change application is then submitted to the District along with a small administrative fee. District staff then review the application to ensure compliance with established policies and procedures and does the necessary record checks to verify ownership and legal descriptions (in the case of Class D allotments). Once the information on the application has been verified and the compliance verified, the change application is submitted for approval to the Board of Directors. Following Board approval, the application is submitted to

Reclamation for concurrence. After Reclamation concurrence is granted, the requested change is implemented and the permanent transfer is completed.

### WATER MANAGEMENT BENEFITS

These allotment contracts and the associated administrative procedures are a very powerful and viable water management policy. This policy allows water, on a yearly basis, to be efficiently and effectively transferred from an entity or individual to another. The policy encourages more efficient use of water supplies by allowing transfers from relatively wet areas to relatively dry areas in any given year provided the beneficial use of the C-BT Project water occurs within the boundaries of the District. This management policy also allows the Board of Directors to set the quota based on district-wide conditions, and allows the water to be transferred from a watershed where the runoff that year is above "normal" to a watershed that is below "normal." This situation happened in 1987 when the Boulder Creek Basin in the south had above-normal runoff, but the Cache la Poudre Basin in the north was well below normal. In that year, allottees in the Boulder Creek Basin transferred large amounts of water to the Cache la Poudre Basin allottees.

The Board's policy of permitting municipal water suppliers to acquire twice as many units as acre-foot demands results in municipalities having the water they need in dry years regardless of the quota. In any year when the quota is above 50 percent, the municipalities generally have more water than they need. This additional water is usually leased to agricultural users.

This policy is an economical option for irrigated agriculture because the municipalities have to pay the annual fixed cost for carrying the water in their portfolio, but irrigators can use it in most years. By renting water on an annual basis, irrigators are able to adjust their available water supplies to more closely meet individual demands, while taking into account cropping patterns, weather, etc. In 1999, municipal and industrial allotments were 54 percent, while actual deliveries for municipal and industrial use was 48 percent, with the difference being available for lease to agriculture. In contrast, during 1998 the municipal and industrial use was only 30 percent of the available supply while their ownership of units was greater than 50 percent.

As municipal areas within the District boundaries have grown and expanded, much of the water supplies to support this growth came from agricultural users. In 1957, municipal and industrial allotments owned 15 percent of all C-BT units; in 1999 this amount/total had grown to 54 percent. This is a viable transfer because much of the land annexed by municipalities had been agricultural lands; thus, it made sense for the water previously used by agriculture on that land to transfer to the entity responsible for treated water supplies on that developed land. The

46 percent of the units remaining in agricultural ownership are being held in "trust" by the agricultural community and may be available at a future date for municipal uses. Eventually, the majority of C-BT Project water ownership may well rest in municipalities, with the annual rental and return flows being available to maintain a viable agribusiness community downstream of the municipal water treatment facilities.

### **CONCLUSION**

The C-BT Project provides the citizens of northeastern Colorado with a reliable, supplemental and economical water supply. The project water supplies are reliable, while at the same time flexible, in terms of delivery to areas with greater demands in any given year.

Figure 1 Colorado-Big Thompson Project Facilities

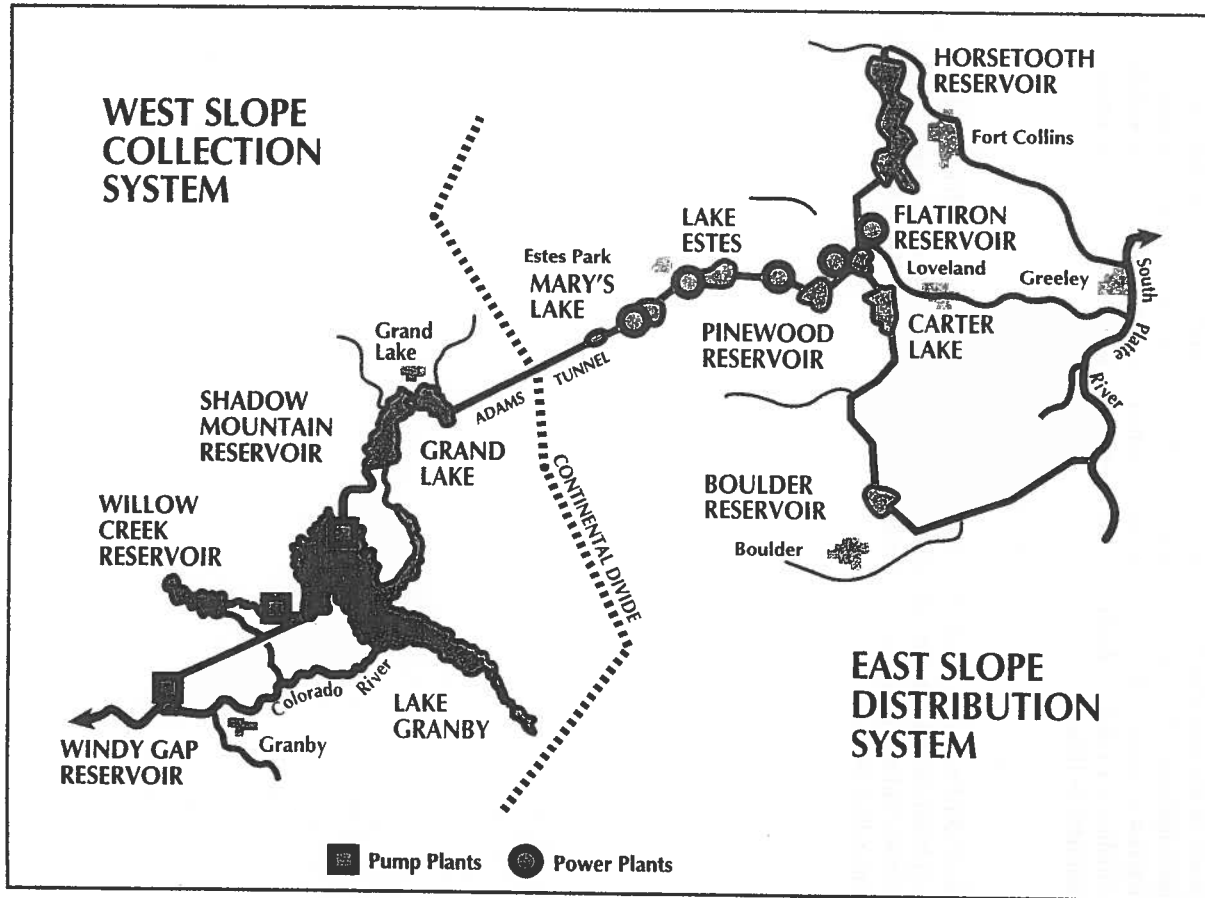
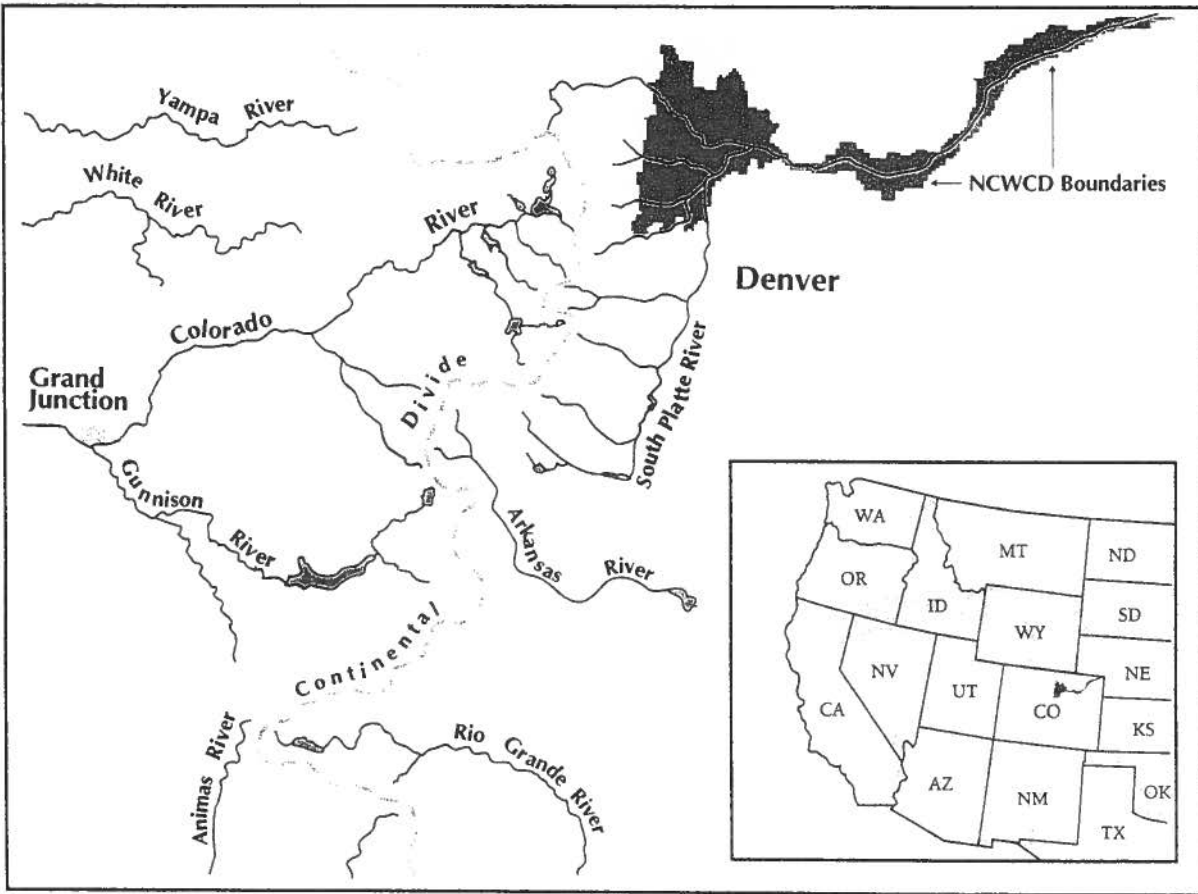
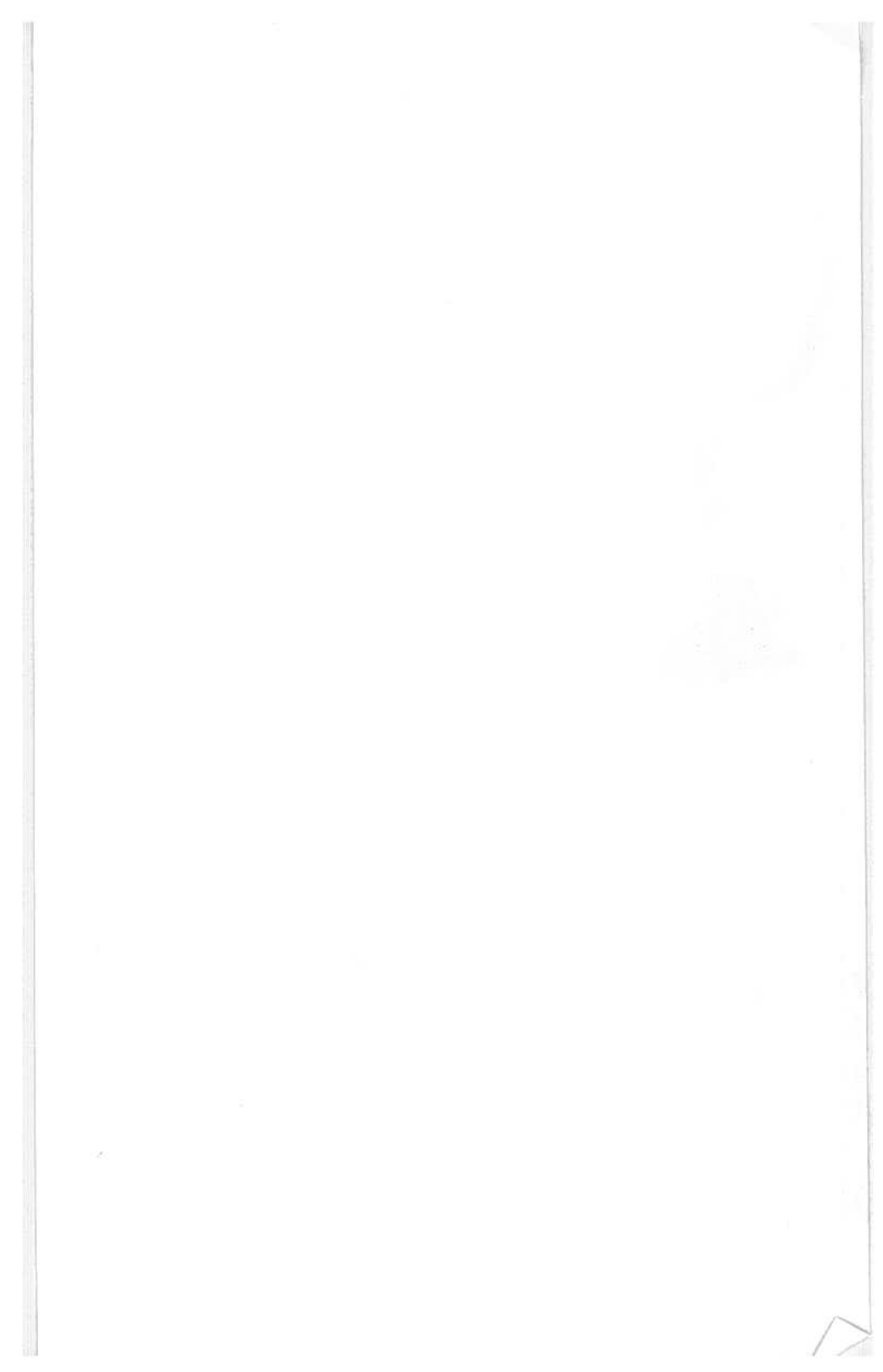


Figure 2 Colorado Index Map







**FACTORS CRITICAL TO THE FORMULATION AND  
EXECUTION OF THE  
LAJA DIGUILLIN TRANSBASIN DIVERSION PROJECT**

John E. Priest<sup>1</sup>

Oswaldo R Dunner<sup>2</sup>

**ABSTRACT**

It too often is the case that transbasin water transfer projects, worldwide, could be beneficial to an entire region and are well engineered and yet will never be constructed. This paper reviews social, political, financial, economic, and environmental factors that were dealt with in an effective manner by strong project advocates to realize the construction of the Laja Diguillin Irrigation Project.

The Project is located in Region VIII of southern Chile. It stretches across nearly 100 kilometers of stream-dissected terrain to the south of the City of Chillan. The newly built primary transmission canal was designed to convey 1400 cusecs (40 cumecs) of diverted river flow from the Laja River, across six intermediate streams, to discharge some 28 miles (45 kilometers) distant into a pool created by a rubber dam on the Diguillin River. From this pool at the town of Bulnes the water is to be further diverted, along with flow of the Diguillin River, into a system of large primary irrigation canals.

This transbasin diversion project was designed to provide economic uplift to the farmers of the region who had not participated in the near countrywide economic boom of the 1990s. Thus the Chilean Government chose to plan, design, and build the project while still maintaining the principle that the private sector should own, operate, and maintain irrigation projects.

Additionally, the Directorate of Irrigation of the Ministry of Public Works was empowered, after some 50 years without designing a major irrigation project, to carry out with government financing the Laja Diguillin Project. The coalescence of factors that the Ministry recognized and made effective accommodations for may be grouped into four categories. They were: 1) advocacy, which was strongly provided by Directorate personnel; 2) social, characterized by the challenge to integrate newly enfranchised irrigators with existing water users and their organizations; 3) government, which as a dynamic emergent democracy with an established bureaucracy of skilled technocrats and economists was flexible and able to adopt new or innovative approaches; and 4) competing interests for water and land, embodied in three groups who actively opposed the project for environmental and commercial reasons.

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## INTRODUCTION

The Laja Diguillin Irrigation Project was the only major transbasin irrigation project to be designed and constructed by the government of Chile during the last half of the 20<sup>th</sup> century. Several factors were responsible for the long period between projects. Foremost was the fact that irrigation systems traditionally have been constructed and operated by private interests. Of equal importance, perhaps, has been the turbulent political process coupled with high inflation and a lack of financing for the realization of social goals through intervention by the national government. The emergence during the 1990s of a dynamic economy that accompanied the peaceful transition from dictatorship to an elected government, alleviated prior constraints that had precluded government support to increase the irrigated area of Chile.

The province of Nuble, Region VIII is one of 13 regions of Chile. It embraces an area approximately 90 miles (150 kilometers) north to south across the breadth of Chile and is some 240 miles (400 kilometers) to the south of Santiago. Rainfed winter wheat is grown across the uplands of the region while summer crops are watered by gravity flow from temporary diversions along the streams. Irrigation water supply often is inadequate late during summer (December until the March harvest). Many smaller landholders have little or no irrigation water.

Chile witnessed rapid growth of the economy during the 1980s and 1990s. However, much of the agricultural areas of Region VIII, including the Sectors of Yungay, Pemuco, El Carmen, San Ignacio, and Bulnes, did not share in the growing prosperity. Thus, the federal government decided that it was essential to provide the means for irrigators to firm up water supply during the dry season, to extend irrigation to heretofore un-irrigated but commandable acreage, and to provide irrigation to landowners along the proposed main canal alignment who were growing only rain fed crops. In all more than 3000 landowners were to be benefited.

Thus, the Laja Diguillin Project was formulated to achieve social and economic goals along a 100-kilometer corridor of Region VIII. This uplift of an economically depressed area was to be achieved while recognizing and addressing factors favoring the project and countervailing factors that negatively influenced project formulation and realization.

Social – Organizations of water users (Juntas de Vigilancia) already existed and operated chartered private systems based on natural stream flows and water rights inherited from the Spanish. The Ministry worked with these organizations as the nucleus for the future operation, maintenance, and management of the new system of linked basins that was to serve a greatly increased number of irrigators.

Political/Economic – The popularly elected government of the 1990s was in transition from a dictatorship that had established a bureaucracy of economists and technocrats who administered a policy of user-pays accountability. Yet a social conscience existed which recognized that there were economically disenfranchised elements in society who needed some form of assistance by government. Among those needing assistance were many of the farmers of Region VIII.

Competing Interests for Land and Water – Three groups actively opposed project development. A group at the university in Concepcion undertook, in the name of environmental and recreational interests, to halt the commercial and industrial exploitation of the flows of the Biobio River of which the Laja River is a tributary. Second, the irrigators along the Laja River wished to continue their overuse of water. Third, forestry companies wished to buy the lands of the future irrigators to establish and expand plantations of fast growing timber for marketing as newsprint to Japan and elsewhere.

Advocacy – Technical personnel of the Directorate of Irrigation were dedicated to bringing into being a transbasin water transfer project that made positives of traditional water rights and methods of water control in this economically depressed region.

## DESCRIPTION OF THE PROJECT

### Geography of Rivers

The configuration of the project owes much to the geography of the region. Figure 1 shows Chile to be 2400 miles (4000 kilometers) long beginning at Arica in the north and extending to Punta Arenas in the south. Its width varies in the region of the project between 60 and 90 miles (100 and 150 kilometers). To the west the country is bounded by the Pacific Ocean and the eastern border generally follows the watershed boundary defined by the Andes Mountains in the north and central parts of the country and by the volcanoes in the south. Due to the short distance from the mountains to the ocean, the terrain slopes steeply to the west and major rivers flow westerly in parallel. The rivers are close together in temperate, humid regions such as that of the project. Morphology of the major rivers, including the Diguillin River is determined by the production of boulders in the upper reaches with cobbled and shingled beds being common in mid to lower channel reaches.

### Climate and Agriculture

Summers, December through March, are hot and relatively dry; and winters, June through September, are mildly cold and wet with snow accumulating on the Andes Mountains and locally on the Nevado de Chillan and the Chillan Volcano at the head of the Diguillin River. Snowmelt runoff occurs during the spring and



Fig. 1. Region VIII of Chile

continues into early summer. This runoff and summer rainfall diminishes over time with river flows reaching their minimums during March and April when often the flow of the lower Diguillin River has been diverted in its entirety.

Flow of the Laja River differs from that of the Diguillin River. Laguna de La Laja is a huge lake formed by activity of the Antuco Volcano. Flows seep through the natural dike at the head of the river. Flow also is diverted from the lake for the production of hydroelectric power. Thus, dry weather flows of the Laja River in its upper reaches are nearly equal to those of the wet season. Therefore, the possibility for transbasin diversion to the Diguillin River basin, during the dry season in particular, had been considered.

Winter wheat is grown across the uplands and in some of the lowlands that do not have access to irrigation water. Irrigation water is used for crops such as sugar beets and asparagus and for livestock watering.

### **Land Use In the Project Area**

Some 25,000 acres (10,000 hectares) of land, primarily along the right (north) bank of the Diguillin River, was being irrigated regularly before project construction, Figure 2. The project was designed to serve 160,000 acres (63,000 hectares). About 15 percent of the project area is to be served from the Main (Transportation) Canal. These lands had minimal pre-project irrigation water that was diverted from the small streams crossing the Main Canal between the Cholguan River and the Diguillin River. Some 100,000 acres (40,000 hectares) were to be served from the Bulnes Weir diversion with the remaining hectareage to be served from diversions along the Diguillin River upstream.

Even with completion of the project the lands dedicated to dry land farming will be extensive. However, during project layout, forestry companies were buying lands across the region for incorporation into their plantations. Commercial forest plantations existed along the alignment of the main transfer canal between the Laja River at Tucapel and the Cholguan River crossing. Also, plantations were being expanded through the purchase of farmland in blocks along and beyond the right bank of the Diguillin River.

### **Economic Conditions**

The national economy of Chile had been stabilized and rationalized during the regime of General Pinochet. The banking system had received important government support and had been effectively rechartered, able economists had taken important positions throughout the government, social security and medicare had been privatized and this in turn contributed to the government's ability to mandate inviolable budgets that matched revenues. Regulations and laws were revised to be friendly to "non-hot" capital inflow to the country.

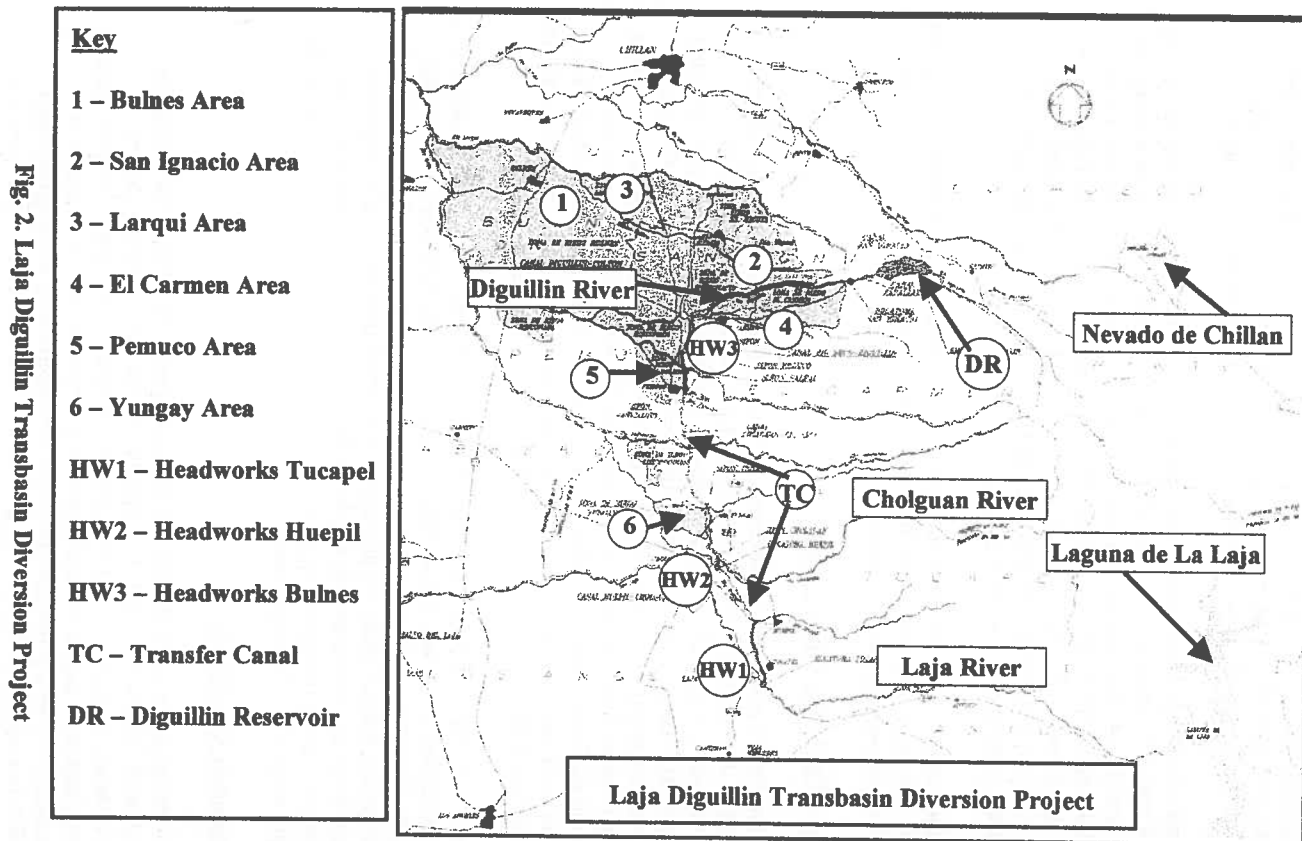


Fig. 2. Laja Diguillin Transbasin Diversion Project

Inflation was minimal and the export of farm and forestry products increased dramatically due to quality control measures and marketing across the world. During the mid 1990s Chile based its budget and governmental expenditures on royalties and returns on copper exports with a price well under one US dollar per pound. The price rose to \$1.25 per pound and revenue increases were considerable.

Prosperity was evident and the inflow of investment capital for mining in particular was massive. Mine development was supported by capital inflows from Canada, the United States, Australia, and South Africa. These funds and the aggressive private sector export drive stimulated wide ranging economic activity and well-being. There remained serious unemployment in areas and strata of the populace that were politically and economically isolated. One such pocket of underemployment and unemployment was the farming areas of region VIII.

#### **Pre-Project System of Ownership, Irrigation Water Use, and Management**

Run-of-the-river diversions, during the low flow season, were made from the Diguillin River and other streams through the pushing up of river gravels into dikes that extended part way across the channel. The diverted water was passed along canals that had large losses and irrigation applications were greater than necessary when water was available. However, the system was not as inefficient as it appeared. Throughout the region wasted water and subsurface drainage returns to creeks of the area, and the creeks in turn are used as canals or conveyance channels for users downstream. The system works well because the area is humid, temperate, and suffers little from the effects of salinity. It is a one-crop irrigation regimen and winter rains naturally provide any needed flushing or leaching.

Irrigators had organized as "Juntas de Vigilancia". Juntas are chartered groups of private water developers who have come together for development, operation, maintenance, management of irrigation systems. Juntas along the right (north) bank of the Diguillin River were well organized and effective. They were very important to the Directorate of Irrigation for assuring that designs would mesh efficiently with the existing systems, and even earlier they were key to the program of the marketing of additional project water. It was a requirement of the government that at least 55 percent of the water users with new or enhanced supplies be signed up for purchase of rights to the additional water before design could begin. During project preparation a new private organizational structure was formulated and negotiations were carried out with the water users to assure that the project could be fully turned over to them within 3 to 5 years. Also the sale of water rights continued.

### **Recreation**

The region supports winter and summer recreational activities and provides esthetic backdrops for residents and visitors. The Chillan volcano, at the head of the Diguillin River, is the site of a spa and hostelry with thermal springs and on the slopes of the nearby Nevado de Chillan is a ski lodge and ski runs. The Biobio River, to which the Laja River is tributary, supports white water rafting, fly fishing, and other water sports. Its water also is diverted for industrial use and there are discharges of wastes to the river before it empties into the Pacific Ocean at the city of Concepcion. Salto del Laja is a waterfall located several kilometers downstream from the Tucapel project diversion works on the Laja River. The falls are the site of a popular hotel where newlyweds choose to honeymoon.

### **PROPOSED TRANSFER OF WATER ACROSS NINE STREAMS**

Personnel of the Directorate were very resourceful during project conceptualization. The fundamental project concept is to transfer excess waters of the Laguna de La Laja and the Laja River system to the Diguillin River. In addition the transfer canal will capture, for irrigation, any flows in excess of prior water rights of the intermediate streams between the Laja and Diguillin rivers. Works have been constructed to capture flows of the Huepil, Cholguan, and Danicalqui rivers. In return, approximately 10,000 acres (4,000 hectares) along the main canal alignment will be provided water directly from the main (transfer) canal.

The consultant also was required to design the primary and secondary canals to permit continuation of the longstanding practice of utilizing creeks of the area for both drainage and for supply of irrigation water. This served to reduce construction costs and to improve the efficiency of water use through reuse one or more times along the creeks.

### **Works for Water Transfer**

A 1958 agreement between the Directorate of Irrigation and ENDESA, a power company, was drawn to govern the regulation and use of water from Laguna de La Laja. The Laguna is a lake formed on the upper reaches of the Laja River by a natural dam or dike created by the Antuco Volcano. In its natural state the Laja River passed downstream largely by seepage through the natural dike. An outlet tunnel was built a half century ago to release water to the Polcura River. There are three hydro-electric plants along the Polcura River that generate energy before the diverted water is returned to the Laja River several miles upstream from the Tucapel diversion. It was under this agreement that the diversion to the Diguillin River was to be for a maximum flow of 2,300 cusecs (65 cumecs). As noted later,



to satisfy environmental, recreational, and Laja riparians, the design capacity of the main canal was reduced to 1,400 cusecs (40 cumecs) and design and construction of a dam on the upper Diguillin River was committed.

The main canal (transfer canal) conveyance channels extend some 38 miles or 50 canal-kilometers and 12 river-kilometers from the headworks at Tucapel on the Laja River to the cross-channel weir on the Diguillin River near Bulnes. En route the main canal conveys flows some eight kilometers across country and discharges to the Huepil River, then it flows about 12 kilometers down the Huepil River channel to a cross-channel diversion structure of the project. The canal then traverses a 900-meter wide neck of land before passing beneath the Cholguan River through a double-barrel siphon each with a diameter of 4-meters. The diversions to the main canal at the Huepil River are non-appropriated flows of that river plus the transferred flows. Beyond the siphon the main canal continues about 11 kilometers to the Yungay service area where there are four small low-level offtakes. The intake for capture of non-appropriated flows of the Cholguan River is at the head of this canal reach. Fifteen kilometers of main canal traverse the Yungay to Pemuco sector. The canal passes along this reach through five twin barrel siphons under intermediate streams and there is a radial-gated offtake to serve the Pimuco area. There is an intake structure at the Danicalqui River to capture non-appropriated flows of that stream. The last main canal reach, which ends with discharges into the pool behind the Bulnes weir, is about 15 kilometers long. There are in this reach offtakes to serve three irrigated areas and there are three more twin barrel siphons under local streams.

The primary canal that offtakes from the Bulnes pool carries diverted flow of the Diguillin River and the transfers from the Laja River to the Bulnes irrigation area and through a siphon to the service area along the right bank of the Larqui River. Upstream near the site of Zapallar, limited flows of the Diguillin River are diverted to the San Ignacio and El Carmen areas. These flows that are adequate during normal streamflow years, will be fully firmed up for dry years only once a storage reservoir of some 85,000,000 MCM has been built on the Diguillin River near the town of Recinto. This dam was being investigated and designed outside the Laja Diguillin Project although some of the allocated monies were being reserved for construction of the dam.

### **FACTORS THAT INFLUENCED PROJECT REALIZATION**

Conditions that compelled the government to formulate and proceed with the Laja Diguillin Project, which had evolved within the Directorate of Irrigation over the preceding 20 years, included newly available financing, nationwide prosperity that had not improved conditions for the farmers of the project area, and a long standing commitment based on a 1958 power company (ENDESA) agreement with the Directorate. Conversely, constraints to the project moving forward to realization included active recreation and environmental interests and the forestry

industry that wanted to incorporate most of the project lands into their plantations within the region.

The breadth of constraints and conditions faced in Chile were similar to those faced elsewhere when a transbasin water transfer project is proposed. However, the relative importance of each and their relative effect of one on the other were unique to Chile during the decade of the 1990s. It was the coalescence of these factors and the actions of the government in addressing constraints effectively and in a timely manner that made possible the realization of the project during a single decade. The following is a summarization of recognized constraints and conditions favorable and unfavorable to project formulation, construction, startup and handover to private interests.

### **Financing**

The Government of Chile negotiated at the diplomatic level a loan with the Government of Japan (OECF, the Overseas Economic Cooperation Fund) adequate to finance a substantial portion of the Laja Diguillin Project and several large sewerage projects. Concurrently a loan from the Interamerican Development Bank (IDB) was negotiated for a substantial part of the engineering, project formulation, and construction of the project.

By the mid-1990s there were increases of export earnings from agricultural produce and metals mining that increased substantially government revenues. These additional revenues along with the large capital inflows that earlier had been made possible by favorable government regulations regarding repatriation of earnings, made possible a multi-year delay in the drawing of the OECF funding that carried substantial servicing fees and interest.

It was this available financing that inspired the Ministry to put the Laja Diguillin Project on an accelerated schedule.

### **Balanced Budget of National Government**

By the time budgeting for the project was undertaken, the effects of sweeping budgetary reforms initiated by the Pinochet regime had enabled the government to operate with a balanced budget. The fact of an assured flow of revenues, the available loan, along with a government budget in balance allowed the ministries to operate with confidence to implement priority projects and programs. Balanced budgets were not only assured because of the greatly increased revenues but because government entitlement programs were taken completely off budget.

Social Security and Medical Insurance for all workers had been privatized. The social and medical insurance funds of workers who had entered the work force after a given date were transferred to one of several private companies as chosen

by the worker. The funds for retirement were being invested across the economy by the selected companies, and with the buoyant economy of the 1990s they grew substantially in addition to the employer contribution. The medical funds were paid to medical insurance companies who provided comprehensive coverage. Important to the government was the capacity to accurately provide in the budget for those who already were retired or who faced only a few years of work before retirement.

The government maintained a balanced budget by annually allocating a given budget to each ministry without the burden of unpredictable runaway entitlement programs. In turn, a given ministry was able to carry out programs that used only the budgeted amount. Thus, even though there were foreign loans available for the Laja Diguillin Project, the Ministry of Public Works could not obligate those monies in addition to the budget. Any use of loan monies served to reduce monies available from the budget.

### **Active Environmental Interests Outside the Ministry**

Beyond the environmental analyses and reports required to satisfy contractual requirements of the financing agencies, the Directorate was sensitive to environmental concerns of recreationists, water users, biologists, and commercial interests.

Recreation in the basin of the Biobio River is well developed. The river is scenic in that it and its tributaries rise in the snowcapped Andes Mountains, pass through forested areas, and it exits to the Pacific Ocean after passing through an area of villages and small cities. Water based activities include white water rafting, fly-fishing, and boating. Land based activities include skiing, trekking, horseback excursions, mountain climbing, and camping. Hotels, resorts, and restaurants are located near thermal springs and along the river near some waterfalls. In sum the Biobio River is a beautiful stream that the Ministry did not wish to degrade. Therefore, the Directorate was sensitive to the interests of individuals and groups who expressed concerns about the impact of withdrawals of water from the Laja River an important tributary to the lower Biobio River.

A group at the university at Concepcion had for some time been vocal about the withdrawals of water from the river for industrial purposes and the discharges of the same industries back to the river. After the Laja Diguillin Project was officially publicized, Directorate and Consultant personnel held a workshop and visited individuals to explain the project and to receive feedback concerning what modifications could be made to better address public concerns regarding degradation of the Laja and Biobio rivers.

It was as a result of these meetings, coupled with meetings with other irrigators along the Laja River, and with hotel interests at the Laja waterfall that the original

plan to divert 2,300 cusecs (65 cumecs) was reduced to 1,400 cusecs (40 cumecs) and a dam and reservoir was to be built on the upper Diguillin River.

### Socio-Economic Conditions

The farmers of the region were able to grow a crop of winter wheat or pasture due to fairly dependable winter and spring rains. Successful summer cropping depended very much on run of the river diversions of irrigation water. Most years, river flows were too low in late summer to mature crops except on a quite restricted acreage. Irrigation systems thus extended to only part of the irrigable lands and even many of those systems could not be maintained. In fact many small landholders were selling lands to forestry companies. Even with the project, irrigators will be able to mature only one crop per year due to the cold winters.

### History of Water Use

Pre-project, along the Diguillin River development for irrigation was as it had been from the time of settlement by the Europeans. Diversion canals had been extended upstream ever farther as each canal was developed for irrigating areas more distant from the river. Consequently, upstream from the Bulnes crossing of the project, there were several parallel feeder canals that lay along the right bank of the Diguillin River. Each canal diverted water successively farther upstream. During low flow periods the irrigators would push up gravel ridges that partially blocked and increased the level of river flow.

The irrigators developed Juntas de Vigilancia, that is groups of irrigators, for the operation, maintenance, management, and financing of sizeable diversion canals and their systems. These juntas were private landowners who were chartered by the government. They functioned effectively to resolve and police water disputes in addition to managing the infrastructure.

It was these same irrigators who made sure that each irrigator got his share whether it was by direct diversion or by reuse of creek flows. Through reuse the irrigators were able to achieve very high levels of beneficial use of diverted waters. This system has been preserved, where possible in service areas of the project.

Water development along the Laja River has proceeded differently from that along the Diguillin River. Laguna de La Laja is a natural lake in the mountainous headwaters area. Its storage capacity is large in relation to the annual flow, and it was natural that early hydropower facilities would be built near the outlet of the lake. The power houses built there were so important to national supply that the level of Laguna de La Laja became an important factor in determining the rate charged for electricity throughout the power company (ENDESA) system.

Because of the importance of power to the pattern of water releases, it became necessary that an agreement be reached between the power company and other water users, in particular irrigators. It was this agreement reached in 1958 that recognized and quantified the need for transfers of water to the Diguillin River Basin. The cross-river structure at Tucapel, which is the starting point for the Laja Diguillin Project, initially was built with a diversion structure on the left bank to serve irrigators along the Laja River. Provision was made for a future diversion on the right bank to support diversions to the Diguillin River. That facility was built as one of the first structures of the Laja Diguillin Project.

### **GOVERNMENTAL ORGANIZATION FOR PROJECT IMPLEMENTATION**

Irrigation traditionally has been the province of the private sector. However, the Directorate of Irrigation has carried out a nationwide program of administration of the waters of the nation through the chartering of water user organizations and the allocation of rights. Also the Directorate has a tradition of planning and building major structures in concert with major hydropower developments and when necessary for transbasin diversions and long distance transport of water. Thus, the Ministry was able to implement the necessary programs to:

- Market water rights by signing up new water users and allocating additional water to existing water users, all on an equitable basis.
- Account for prior water rights that were downstream from the project along several of the intermediate streams between the Laja and Diguillin Rivers.
- Work with existing water user groups to structure a multi-layered organization to own and administer the project. It was intended that after three to five years of project operation, the government would hand over to this organization the financing and administration of all project works including reservoirs, river structures, and main, primary, secondary, and tertiary level canals.
- Carry out a public information program to educate residents of the region to the benefits of the project.
- Organize and conduct meetings with individuals and groups who questioned the need for the project and those who feared that the project would impact their interests negatively.
- Engage a Consultant to carry out investigations, make special studies, review the planning, design the structures and control system, and prepare contract documents.

#### **The Marketing of Water**

Before a consultant was engaged, the Directorate had signed agreements with more than 55 percent of the water users. During the design period, it was

important that the remaining water users commit in blocks to justify the finalization of canal alignments and sizes. Among issues that required resolution was how to award rights to those without financial resources.

### **Meetings and Workshops**

Meetings, workshops, and negotiations that were carried out were:

- An informational meeting that was conducted with a group of professors, students, water users, and citizens at the university at Concepcion. The social objectives and design of the project were presented along with an in depth discussion of the hydraulics and hydrology of the project and the impacts on the streams of the region. It also was explained that the Ministry had reduced the diversion capacity of the main canal from 2,300 to 1,400 cusecs (65 to 40 cumecs) and that a reservoir on the upper Diguillin River had been incorporated into the project to compensate directly on the Diguillin River for that reduced water transfer. This meeting was important in that the activities of project detractors greatly diminished thereafter.
- Meetings between the Juntas and Consultant and Ministry personnel were conducted on a political level in the regional capital of Chillan; in the offices of the Juntas for exchange of technical information; at Santiago to review designs, their efficacy and fit to the terrain and operating practices of the irrigators; and in the field to proof the contract documents. Besides, workshops were held to review the proposed Ministry plan to charter the future operating water user organizations. The Ministry proposal was to transform the Juntas into a multi-layered OM&M Organization which would deal with matters at the farm and tertiary canal level, at the secondary and primary canal levels, and with the main canal, cross river structures and eventually the Diguillin reservoir. Besides the organization ultimately was expected to operate a SCADA system to control diversions at rivers and flows along the main canal and in major primary canals.
- Meetings, negotiations, and legal dealings with forestry companies were contentious and drawn out. The forestry companies attempted to stop the project because they wished to buy up the lands and plant fast growing plantations to supply the world newsprint market. Since forestry company plantations lay astride the main canal alignment, the forestry companies insisted that their personnel accompany survey and foundation investigation crews and that the Ministry insure their personnel for very large amounts against the possibility that forest fires would be started. Eventually, the matter was resolved and the work was accomplished for the design phase.

In all sectors of the project, forestry companies bought lands that had been earmarked for water deliveries. During the last stages of design some 25,000 acres (10,000 hectares) of additional land was incorporated into the project around the San Ignacio and El Carmen sectors to compensate for lands lost to purchases of the foresters. At Yungay the area was moved to still open lands.

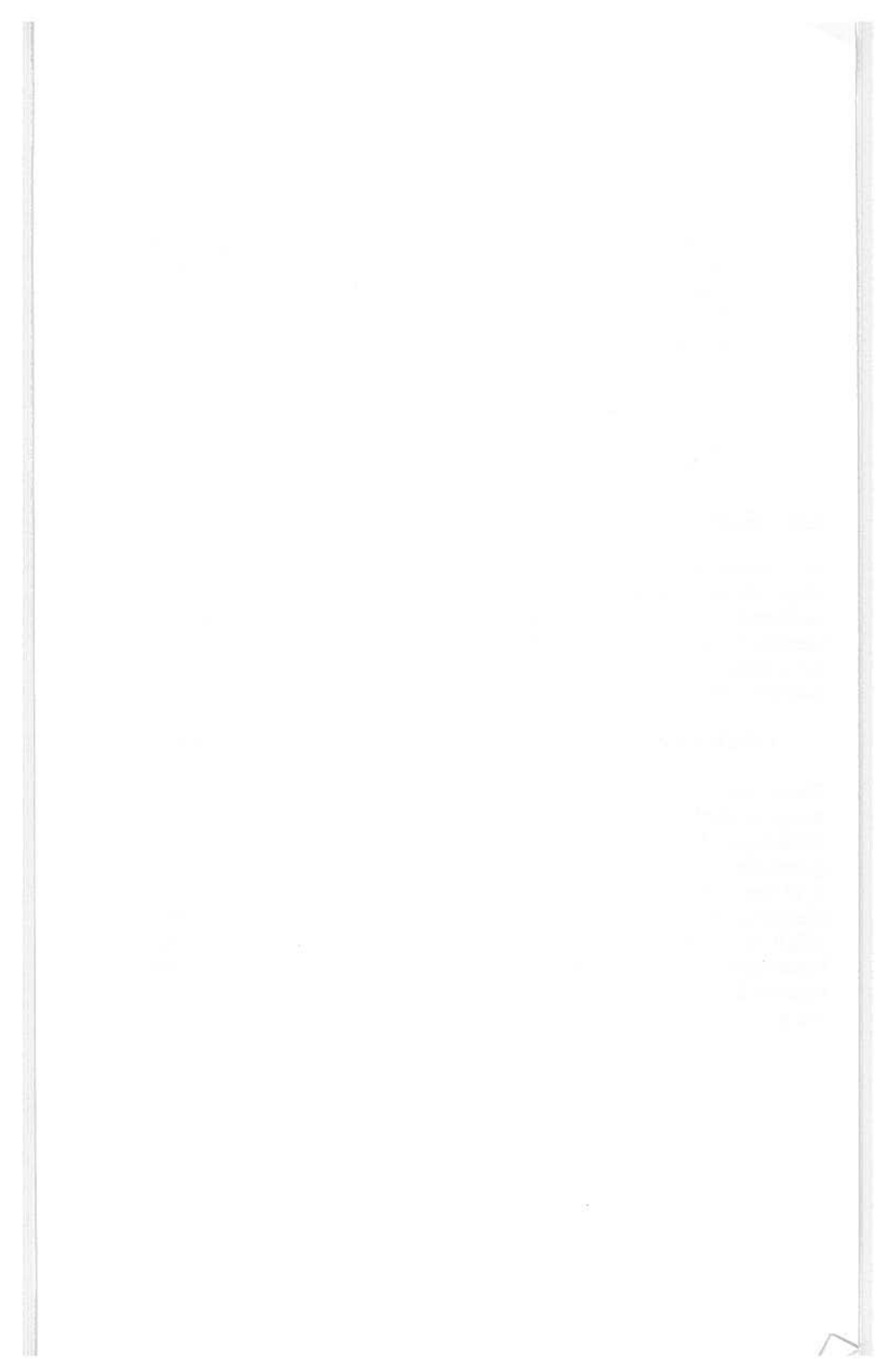
Eventually with patience and persistence the Ministry overcame obstacles created by the forestry companies and the project went ahead.

### **Environment**

An environmental report was prepared for the assessment of impacts of the project along the Diguillin River and for the Diguillin Reservoir. Besides environmental information was conveyed for the entire project to the financing agencies in meetings and in accordance with the requirements of the loan agreements with the Inter-American Development Bank and the Overseas Economic Fund.

### **SUMMARIZATION OF WHY THE PROJECT WAS REALIZED**

The project was realized in a period when the national economy was robust and the government felt compelled to achieve social and economic equity in remaining pockets of those not benefiting or who were disenfranchised. The government was fresh and not saddled with debilitating tradition and procedures. A 15-year dictatorship had only recently peacefully yielded through national elections to formation of an elected Congress and Presidency. The Directorate of Irrigation enjoyed dynamic leadership who had the skill to negotiate with future beneficiaries of the project and to deal rationally and effectively with those who opposed the project. Financing was fully available and the regional government and population wanted the project.





## TRANSBASIN DIVERSIONS – A VIEW FROM THE BASIN OF ORIGIN

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John H. McClow<sup>2</sup>

### ABSTRACT

The Gunnison River is the State of Colorado's largest tributary to the Colorado River System. Some also envision the Gunnison River as a potential tributary to the Platte River, once the necessary arrangements can be made to reverse a portion of its westward flow. Growing municipal demand on the Front Range of Colorado is driving the desire to transfer increasing amounts of water across the Continental Divide, from west slope basins to the east. This paper provides a perspective on transbasin water transfers from the point of view of the basin of origin. We will discuss how an out-of-basin transfer would affect existing water uses, the environment, economy, and quality of life in the Gunnison Basin. The paper will also discuss the water management alternatives that are available to Colorado's Front Range in lieu of transbasin water transfers. These include efficient use of existing supplies, integrating existing water supply and delivery systems, and continued evaluation of options such as short-term leasing of agricultural supplies, and coordinated management of existing groundwater resources.

### INTRODUCTION

On November 20, 2000, the Colorado Supreme Court issued a ruling affirming dismissal of an application for water rights to construct a storage project in the headwaters of the Upper Gunnison River Basin known as the Union Park Reservoir Project. The Court's ruling should mark the end of a protracted legal battle concerning the availability of water for a project that would have diverted an average of 110,000 acre-feet per year out of the East and Taylor River drainages for delivery to potential users East of the Continental Divide. Although the Supreme Court affirmed the water court's ruling that insufficient water is available to develop the Union Park Project, Front Range thirst for water originating in the Upper Gunnison Basin continues to grow unabated.

This paper was developed in anticipation of continuing pressure to utilize Upper Gunnison Basin water resources to meet perceived needs outside of the Basin. The information presented is intended to document the impacts on the Basin of a headwaters project similar to Union Park Reservoir, with emphasis on the Taylor and Gunnison River systems. Any export of water would be a fully consumptive loss and would have a detrimental impact on the Basin. However, a diversion

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from the headwaters is most damaging because flows throughout the affected river system are reduced prior to any use within the Basin and because removal of high quality water high in the system has significant impact on downstream water quality. The Upper Gunnison Basin is dependent upon its water resources for its recreation industry, environmental protection, crop irrigation, municipal and industrial uses. Tourism and recreation is the primary source of revenue in the Basin, contributing approximately \$35 million dollars per year to the local economy. Most of the recreational activity is water related. Altering the current flow regime by depleting stream flows would dramatically reduce recreational opportunities, resulting in a significant blow to the Basin's economy. Examples of the economic value associated with water-based recreational uses include:

- Taylor River Fishing - \$6.3-\$13 million
- Taylor River Boating - \$3.8 million
- Curecanti National Recreation Area Visitation - \$21 million

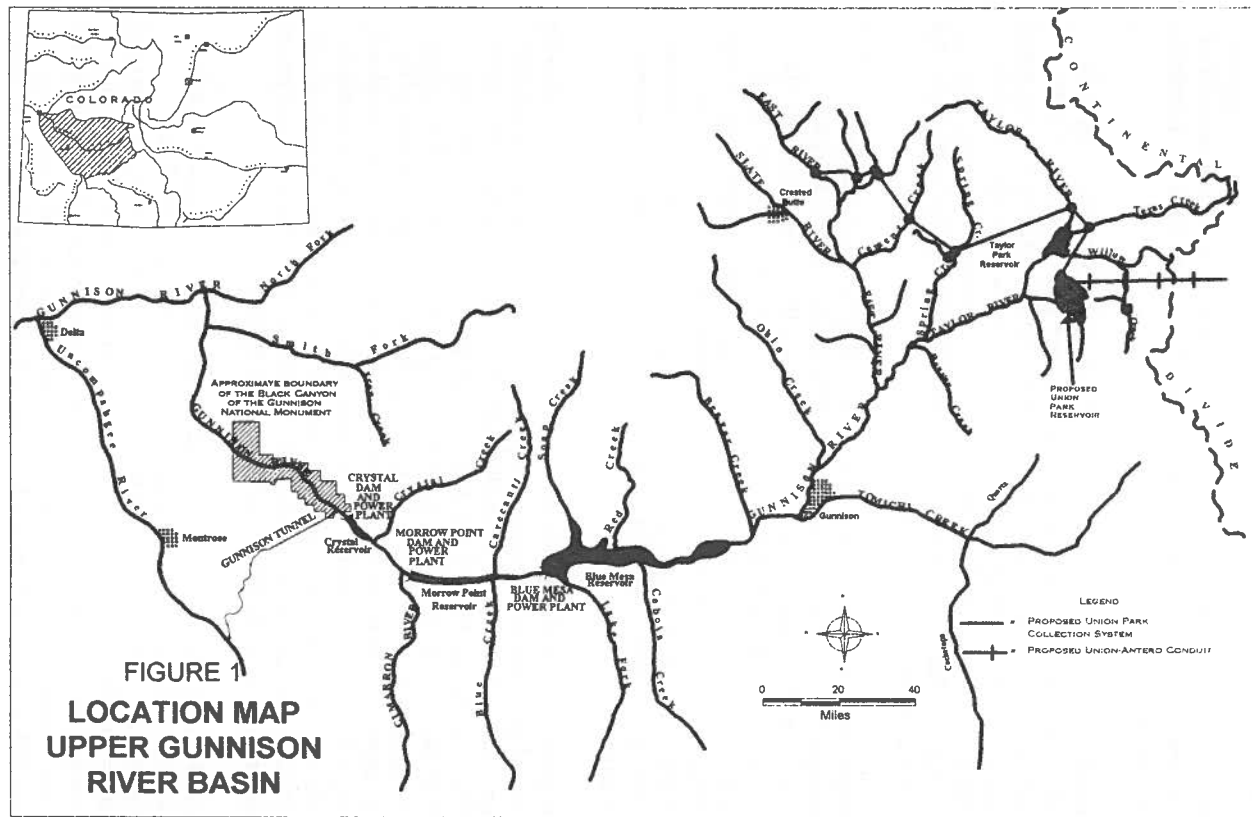
Reducing stream flows would have indirect adverse effects, as well. For example, reduced inflows to the reservoirs of the Curecanti National Recreation Area would lower storage levels, affecting flatwater recreation such as fishing and boating, and reducing water available for hydropower generation at each reservoir's powerplant. Less water in storage also reduces water available for downstream water needs associated with the Black Canyon of the Gunnison National Park, and the Colorado River Endangered Fish. The net loss of high quality water at the headwaters would have an impact on downstream water quality.

Existing studies regarding the impacts of out-of-basin diversion projects in the Gunnison Basin are focused on the Taylor and Gunnison River drainages. The available studies make the assumption that fishery and recreation resources on the Taylor and Gunnison Rivers would be impacted in the event that the current flow regime in these rivers was significantly changed due to an upstream storage reservoir and subsequent out-of-basin transfer. This paper summarizes the conclusions of these previous analyses and provides estimates of economic losses that would be expected if a transbasin diversion project is constructed.

## **UPPER GUNNISON RIVER BASIN – GENERAL DESCRIPTION**

### **Hydrologic Features**

The Gunnison River originates in the headwaters of the Taylor and East Rivers north and east of the city of Gunnison. The river is formed where the Taylor and East Rivers combine at Almont, approximately nine miles north of Gunnison. From this location, the river flows generally west to the point where it discharges an average of 1.9 million acre feet of water annually into the Colorado River. (USGS, Water Resources Data, Colorado, Volume 2, Water Year 1999).



Approximately one-third of the total discharge of the Gunnison River originates in the Upper Gunnison River basin, above the confluence of the Gunnison River and Tomichi Creek. (Upper Gunnison-Uncompahgre Basin Phase 1 – Feasibility Study, Final Report, p.5-1).

Precipitation in the basin varies generally with elevation, with the valley floor typically receiving less than 10 inches annually, and the high mountain areas receiving in excess of 40 inches annually. Most of the runoff occurs as the result of snowmelt, with elevations in the basin ranging from over 14,000 feet in the headwaters to 4,500 feet at the mouth of the Gunnison River. Stream gaging records indicate that approximately 60 percent of the annual flow in the Gunnison River occurs between May and July.

The prominent hydrologic features in the basin include the Aspinall Unit (consisting of Blue Mesa Reservoir, Morrow Point Reservoir, and Crystal Reservoir) located on the mainstem of the Gunnison River, approximately 10 miles west of the City of Gunnison, and Taylor Park Reservoir, located at the headwaters of the Taylor River. The Upper Gunnison River Basin is generally defined as the area tributary to Blue Mesa Reservoir, including portions of Gunnison, Hinsdale, and Saguache Counties. Major tributaries to the Gunnison River include Tomichi Creek, Ohio Creek, Cochetopa Creek, and the East and Taylor Rivers.

The Aspinall Unit (formerly the Curecanti Unit) was constructed in the 1960's for a variety of purposes including providing water for hydropower generation and storage to allow for upper basin development of Colorado River Compact water. The Unit is made up of Blue Mesa Reservoir and Power Plant, Morrow Point Reservoir and Power Plant, and Crystal Reservoir and Power Plant. The system covers approximately 30 miles of the Gunnison River from just upstream of the Black Canyon to west of the City of Gunnison. Blue Mesa Reservoir, completed in 1965, is the largest in the state of Colorado, with a capacity of approximately 940,000 acre-feet. Morrow Point and Crystal Reservoirs, located downstream of Blue Mesa, have a combined capacity of 143,190 acre-feet. The combined power generation capacity at the three reservoirs is 248,000 kw.

Aspinall Unit operations are currently undergoing Section 7 consultation under the Endangered Species Act to determine impacts to the Colorado River endangered fish. The U.S. Fish and Wildlife Service (USFWS) has released draft flow recommendations for the Gunnison River that would require operational adjustments and use of stored water. Also affecting operations at the Unit will be the flows needed to meet the purposes of the Black Canyon of the Gunnison National Monument (now National Park) when it was established in 1933. This process was re-activated on January 18, 2001 with a filing in water court by the National Park Service identifying the flow requirements needed for the Black Canyon. The water sought for both the endangered fish and the Black Canyon

reflects undeveloped conditions on the river. Meeting the proposed flow requirements would result in changes to storage levels and the timing of releases at the Aspinall Unit.

Taylor Park Reservoir has a usable capacity of 106,230 acre-feet. It serves as a storage facility for the Uncompahgre Valley Water Users Association (UVWUA), and provides agricultural, recreational, and fishery benefits for the Upper Gunnison basin. Prior to the 1960's, Taylor Park Reservoir was operated primarily to meet the UVWUA irrigation needs downstream. With the construction of the Aspinall Unit, an opportunity was created for the reservoir to be operated not only for supplemental irrigation, but also to accomplish fishery, irrigation, and recreational beneficial uses. Taylor Park Reservoir and the Aspinall Unit are currently operated in a coordinated manner by releasing water from storage at rates designed to optimize storage levels in the reservoir, optimize fishery and recreational flows in the Taylor and Gunnison Rivers, and provide supplemental irrigation water to users in the Upper Basin. These operational practices were codified in the form of an exchange agreement signed in 1975 by the Upper Gunnison River Water Conservancy District, the Colorado River Water Conservation District, the UVWUA, and the U.S. Bureau of Reclamation.

In 1986, the Upper Gunnison River Water Conservancy District sought to adjudicate water rights in Taylor Park Reservoir for additional beneficial uses, and received a decree for a second fill in the reservoir for irrigation, fishery, and recreational purposes. The Taylor second fill water right provides for optimal flows in the Taylor and Gunnison Rivers for fishing and recreational purposes.

The State of Colorado, through its Instream Flow Program, has adjudicated numerous instream flow water rights in the Upper Gunnison basin for the purpose of protecting the environment. There are over 195 stream segments totaling approximately 1,219 stream miles protected in the Gunnison River basin. Also decreed for instream uses are several privately held instream flow rights on the Taylor River and its upper tributaries.

There are currently no significant out-of-basin transfers of water from the headwaters of the Upper Gunnison River.

### **Economic Characteristics**

The Gunnison River drainage is noted for its fishing, boating, hunting, scenery, and general recreation uses. Historically ranching and mining were the major economic contributors to the area, however, the importance of recreation and tourism related industries has steadily increased over the years. In 1999, recreation and tourism was the primary revenue source for Gunnison County, bringing in over \$35 million to the area.

Popular recreation opportunities in the basin include boating, reservoir fishing, stream fishing, hunting, hiking, sightseeing, and skiing. In 1986, the Gunnison County Chamber of Commerce surveyed summer tourists and found that 44% of those surveyed went fishing, 31% went camping, and 12% went on a raft trip. The survey also found that the majority of visitors were from the Front Range of Colorado.

Water-based recreation contributes significantly to the region's economy. United States Department of Agriculture, Forest Service data from 1986 indicates that in the Taylor River District, there were over 176,000 water based recreation visitor-days that year. (The Taylor River District covers the area North and East of Gunnison, extending to the Continental Divide).

It is estimated that the rafting industry contributes over \$4 million dollars a year to the Basin's economy, with the Taylor and Gunnison Rivers being the primary focus of that activity. Commercial user days in the basin were in excess of 18,000 in 1999, up from approximately 8,000 in 1989. (CROA, Commercial River Use in the State of Colorado, 1988-1999).

Fishing continues to grow in popularity in the basin. According to Colorado Division of Wildlife creel survey data for the Taylor River and Lottis Creek, more than 8,000 individuals visited these areas over a two-month period in 1999. (Colorado Division of Wildlife, 1999-2000 Creel Census Projects)

Approximately 1,000,000 people visit the Curecanti National Recreation Area annually. Fishing is the primary draw for most recreationists, but visitors engage in other water-based activities such as boating, jet skiing, sailboarding, and waterskiing as well. A 1995 study prepared by the National Park Service found that the total combined sales in the area associated with recreational visitation exceeds \$ 21.3 million dollars per year. Total increased tax revenue was estimated to be in excess of \$1.8 million dollars per year. (Black Canyon of the Gunnison National Monument and Curecanti National Recreation Area, General Management Plan, p. 158-159).

Agriculture is the third primary producer of revenue with market value of agricultural products sold in 1997 exceeding \$8.4 million dollars. Irrigated acreage is in the range of 52,000 acres, not including irrigated pasture. Grass hay is the primary agricultural crop grown. State statistics for 1997 indicate that the cattle and calf inventory was in excess of 29,000 head. (USDA, National Agricultural Statistics Service, 1997 Census of Agriculture).

## TRANSBASIN DIVERSION IMPACTS

### Description of Transfer Concepts

Numerous transbasin diversion concepts have been proposed to export Gunnison Basin water to the Front Range of Colorado. These proposals have generally involved diversion of water from the headwaters of the East and Taylor Rivers, through a series of tunnels and pipelines, to storage reservoirs in either the South Platte or Arkansas River basins. (See Figure 1). The 1989 Phase I Feasibility Study of the Upper Gunnison and Uncompahgre Basins analyzed the likely impacts of several transbasin proposals on the Upper Gunnison area. The analysis focused on how the proposed transfer schemes would affect flows in the Taylor River. The projected flow regime can in turn be used as a basis for drawing conclusions regarding impacts to the Basin, including economic, environmental, and downstream implications. Two transfer project concepts are addressed in this paper, and are described below:

Union Park Project: The Union Park Project as proposed by Arapahoe County (one of five Denver metro-area counties located on the Front Range of Colorado) would have exported an average of 110,000 acre-feet annually to the South Platte River Basin through a series of pipelines and tunnels. The Taylor and East Rivers and their tributaries would have been the sources of the transferred water. The project involved construction of a large storage reservoir in Union Park, at the headwaters of Lottis Creek. Union Park Reservoir would have stored up to 900,000 acre-feet, capturing most of its water in wet years and during peak runoff periods. The water court considered a conceptual design that would have provided for the release of a minimum of 200 cfs in the summer and 50 cfs in the winter to the Taylor River, below Taylor Park Dam. In wet years, diversions would be in excess of 200,000 acre-feet, while in dry years no diversions were proposed.

Taylor Park Project: The 1989 Phase I Feasibility Study outlined another transfer concept that would not have involved construction of a new storage reservoir. The scenario considered would have used water stored in Taylor Park Reservoir for direct transfer to users East of the Continental Divide through a system of pipelines and tunnels. Storage capacity East of the Continental Divide would have been needed to regulate the timing of flows and deliveries. The concepts outlined included using existing senior storage rights in Taylor Park Reservoir, enlarging the reservoir, obtaining new junior rights, and supplementing storage by pumping water up to Taylor Park Reservoir, via pipeline from Blue Mesa Reservoir.

The following bypass flow scenario in the Taylor River was identified as the optimum for achieving yield for the Taylor Park Project concepts, resulting in an average annual yield of 41,828 acre feet. If Taylor Park Reservoir were enlarged,

the average annual yield would be 59,873 acre-feet under this bypass flow scenario. If Blue Mesa Reservoir water was to be purchased and pumped up to Taylor Park Reservoir, the potential yield could be 100,000 acre-feet, without impacting the minimum flow regime in the Taylor River.

Minimum flow regime associated with Taylor Park Project proposals:  
(Instream Flow targets below Taylor Park Dam)

October-March	75 cfs
April	100 cfs
May-July	150 cfs
August-September	100 cfs

### Recreation Impacts

A transbasin diversion that would remove water from the headwaters of the Gunnison River would have significant impacts on recreation and tourism activities in the region. As was noted above, recreation and tourism is the primary source of economic revenue in the upper basin. Revenues associated with water-based recreation have not been specifically estimated, however, existing studies indicate that approximately one half of the tourists visiting the Gunnison area participate in some form of water-based recreation. A transfer project at the headwaters would clearly impact activities such as boating and fishing, which in turn would impact general revenues to the area associated with those activities.

**Boating:** Boating activities in most rivers require certain flow levels. If flows are insufficient to meet minimum floating requirements, which in the Taylor River are approximately 250 cfs, then boating becomes infeasible. As can be seen above, in order to optimize the yield for projects which would transfer water out of the headwaters, bypass flows would be reduced to levels below minimum boating requirements. A transbasin diversion could well end boating on the Taylor River except in very wet years.

The Colorado River Outfitter Association estimates that the direct economic benefit to the area from commercial rafting on the Taylor and Gunnison Rivers was \$3,800,000 in 1999, based on application of a multiplier intended to represent dollars spent by individual boaters on the trip itself, in addition to lodging, food, and other incidentals. This estimate of direct economic impact does not include the expenditures of the many private rafting and kayaking enthusiasts in the area.

Another way of estimating the value of water for recreational purposes is to estimate users' willingness to pay to use water for a particular purpose. This type of analysis is often used in situations where the market value of a resource is not easily quantifiable. For example, water used for municipal purposes is more



easily assigned a dollar value, whereas the value of water for protecting endangered species, fishing, and general recreation is less readily estimated. Resource economists use several methods to develop estimates of economic value for these types of uses.

The value of water for boating purposes in the Taylor and Gunnison Rivers was evaluated using a widely accepted method called contingent valuation in the early 1990's. A 1994 report prepared by Edward Sparling, David Harpman, and Jim Booker described users' willingness to pay for various flow regimes for rafting purposes (Final Report, Upper Gunnison Basin Instream Flow Project, CSU, 1994). The objective of their analysis was to estimate the value of the resource by surveying users. A number of conclusions were presented regarding willingness to pay for various flow rates. The authors used the assumption that a transbasin diversion project would remove 60,000 acre-feet per year from the basin, primarily during the spring and summer boating season. They assumed that the average flow over the boating season would be reduced by at least 300 cfs.

In this report, the authors surveyed local rafters and found that the expected incremental value of additional flows for rafting ranges from \$257 per boater for 200 cfs to \$525 per boater for 600 cfs. This study estimated the value of water used for rafting purposes, at various flow levels. Hypothetically, the boaters surveyed identified a dollar value of \$525 for a flow rate of 600 cfs. That "willingness to pay" value multiplied by the average number of people rafting on the Taylor and the Gunnison Rivers is equivalent to \$9.45 million. Average flows in the Taylor for the 1952-1988 period of record during the peak boating season were 600 cfs. If 18,000 people float the Taylor and Gunnison Rivers annually, a reduction of flows to non-boatable levels, i.e. less than 250 cfs, would result in a loss in value of the resource of nearly \$5 million.

Fishing: Expenditures related to reservoir and stream fishing are also an important source of revenue to the Upper Gunnison River basin. The health of the fishery resource is dependent on flow conditions that would be impacted by the transfer of water out of the basin. A comparison of the bypass flows anticipated for each of the proposed transfer projects described above with the range of flows needed to protect the fishery resources in the Taylor and Gunnison Rivers indicates potential negative impacts on winter flows. Testimony by the Colorado Division of Wildlife in the Taylor Park Reservoir second fill water right case (86CW203) demonstrated that a minimum flow of 100 cfs is needed in the winter to protect the fishery in the Taylor River. As contemplated by the Union Park proponents, winter flows could fall below this minimum level, resulting in detrimental impacts to the fishery resource.

As noted earlier, the Colorado Division of Wildlife Creel Census surveys indicate that in 1999, visitation during the peak angling season on the Taylor River was in excess of 8,000 individuals. Statistics developed by the American Sportfishing

Association in cooperation with the United States Fish and Wildlife Service regarding the economic value of sportfishing on a statewide basis were used to develop the following estimates of the economic value of fishing the Taylor River.

The economic output associated with 8,000 angler days would be approximately \$6.3 million dollars, based on direct expenditures on the trip, as well as equipment. If other economic benefits such as earnings, jobs, sales and income taxes were taken into account as well, then the total economic benefits to the local area associated with 8,000 angler days would be approximately \$13 million. (The 1996 Economic Impact of Sportfishing in Colorado, by Vishwanie Maharaj, Janet E. Carpenter, 1997). If the fishery resource is degraded, local revenues associated with fishing activities would also be reduced.

As noted above, recreational visitation at the Curecanti National Recreation Area brings in over \$21 million dollars per year in related expenditures to the area. If the recreational value of the Recreation Area's reservoirs are negatively impacted by an out-of-basin diversion, reduced visitation would cause an associated impact to the local economy. In a less than average year, storage in Blue Mesa Reservoir would be reduced by nearly 20% under a scenario such as that proposed for the Union Park project. The reservoir's fishery resources could be negatively impacted by lower water levels, which in turn could reduce visitor use. Lower storage levels could also result in negative boating and aesthetic impacts.

If a transbasin diversion project were constructed that did not provide for maintenance of adequate flows for fishing and boating purposes, the direct economic impact to the local region associated with a reduction in these activities would be extremely significant.

### **Existing Shortages**

The water resources of Upper Gunnison Basin are currently over-committed for existing uses. Water demand for agricultural purposes is currently in excess of supply, with shortages existing throughout the Basin. During the irrigation season, total diversions exceed virgin flow, indicating that available supplies are used and reused. Agricultural shortages in portions of the Basin most likely to be affected by a transbasin diversion, i.e. the East River drainage, occur relatively high in the Basin, at and above the point of diversion for the East River Ditch No. 2, on the Slate River, and in the lower part of the drainage in the Jacks Cabin area.

Projected new water demand for domestic purposes in the East River Basin is estimated to be in excess of 3,600 acre-feet over the next 35 years, indicating a need for development of additional supplies. The removal of water from the basin would reduce water availability for meeting these demands.

### **Environmental Impacts**

Fully consumptive diversions from the headwaters would result in adverse environmental impacts and water quality degradation. Reduced base and peak flows would impact the fishery, riparian habitat, wetlands, and wildlife that rely on the health of the riparian ecosystems. Although existing water quality in the basin is generally high, the loss of high quality water at the headwaters could impact downstream ambient water quality.

### **Downstream Impacts**

Removal of water from the basin would also reduce the amount of water available to produce hydropower, meet the downstream water needs of the Colorado River endangered fish species, and meet the needs of the Black Canyon of the Gunnison National Park. Although the latter two demands are currently in the process of being quantified, it is anticipated that there will ultimately be impacts on operations at the Aspinall Unit. If reservoir storage is needed to provide water to meet the requirements of the Endangered Fish Recovery Program, and or the Black Canyon, then hydropower production and other uses of the facilities could suffer. Reduced inflows to the reservoirs could affect water availability to meet these competing needs. Changes in water availability at the Aspinall Unit will also increase the likelihood of strict administration on the Gunnison River, resulting in upstream water shortages.

## **ALTERNATIVES TO TRANSBASIN DIVERSION**

In 1999, the Colorado Water Conservation Board received the final report of the state-funded Metropolitan Water Supply Investigation (MWSI), which identified and evaluated four cooperative water supply options that provide solutions to future Front Range water needs without construction of additional transbasin diversion projects: conjunctive use, effluent management, interruptible supply arrangements and other system integration opportunities. (Not included in the MWSI was evaluation of additional water conservation measures as a potential source of supply.)

Conjunctive use involves use of Denver's available surface water supplies from existing Blue River and South Platte water rights in average and wet years to meet demands of communities in Douglas and Arapahoe counties and for recharge of Denver Basin aquifers. The report estimates that such a conjunctive use project could yield up to 60,000 acre-feet per year.

Effluent management involves cooperative management strategies among the Denver area water providers for use and reuse of return flows to increase water supplies. The MWSI final report concluded that significant opportunities for cooperative effluent management exist in the Denver metropolitan area, which

currently generates excess reusable return flows of 80,000 acre-feet per year. The report projects that these flows will increase to approximately 120,000 acre-feet per year as the area grows.

Interruptible supply involves arrangements between water providers and agricultural water users in the Front Range area which would allow the cash purchase of the use of agricultural water by the cities during drought periods. MWSI estimates that up to 190,000 acre-feet per year of dry year high quality water is available from this source.

The MWSI identified, but did not study, a number of system integration opportunities involving "the cooperative use or enhancement of several water supply systems in a manner designed to synergistically increase or maximize total combined yields or operational efficiencies." The report makes a preliminary estimate that potential water supply from these sources could range from 30,000 to 50,000 acre-feet per year.

While acknowledging that geographically within the Denver metropolitan region, sources of supply and future demands vary among different sub-regions, the study concluded that metro- area water providers have more than adequate supplies to meet existing needs, and that future needs can be met through cooperative water supply management options that do not require construction of new transbasin diversion projects.

## CONCLUSIONS

Diversion of water from the headwaters of the Gunnison River would have severe economic and environmental impacts on the region. The primary source of economic revenue in the basin is recreation and tourism, and most recreation and tourism activities are water-based. As conceived, the diversion projects discussed above would have provided inadequate flows to support the current boating and fishing industry, and would have reduced water available for other downstream purposes such as recreational activity at the Curecanti National Recreation Area. The economic benefits to the area associated with in-basin water uses such as boating (\$3.8 million), fishing (\$6.3-\$13 million), agricultural production (\$8.4 million), and use of the National Recreation Area (\$21 million) would be reduced if water is removed.

It is the opinion of the authors that alternatives to new transbasin diversions have been identified and should be thoroughly explored prior to consideration of such diversions. Resources should be directed toward the removal of obstacles and implementation of options such as those set forth in the Metropolitan Water Supply Investigation, rather than toward development of additional sources of supply from the Gunnison Basin.

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## THE MEASUREMENT OF EXTERNALITIES OF FARMLANDS: AN APPLICATION OF CONTINGENT VALUATION IN TAIWAN

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### ABSTRACT

After a certain degree of industrialization many countries find that agricultural production appears to result in negative economic profits due to the substantial opportunity cost of keep land in use for agriculture. The value of the land in non-agricultural uses rises considerably with industrialization. This process is especially acute in small, densely populated countries, such as Taiwan. However, the profitability of agricultural production may be underestimated if the positive externalities associated with farmland are not included. A proper accounting for these positive externalities casts agricultural production in a more favorable light. This paper focuses on paddy rice fields in Taiwan. A double-bounded dichotomous Contingent Valuation Method (CVM) is combined with the selection-bias-correction procedure to estimate the extent of the positive externalities. The evidence suggests that the externalities of paddy rice fields are recognized by the majority of people in Taiwan. Each household is willing to pay on average about \$6351 NT annually to sustain the rice fields' water preservation and land protection functions, which is about 1.26 folds of the intrinsic economic value of rice. Thus, the rising opportunity costs of retaining land in agricultural production is not yet sufficient to justify a reallocation of this resource from agriculture to other uses. The policy prescription favors retention of the land in agricultural production. In fact, if efficiency is the goal of policy makers, then more than half of the rice fields recently converted to other uses should have remained rice fields.

### INTRODUCTION

Land and water are basic natural resources of use in virtually all industries. When industries become the mainstream in a country's development, land allocated to agriculture declines. This decline is particularly dramatic in small, densely

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populated countries such as Taiwan, Singapore, and Switzerland.<sup>2</sup> The move towards free trade in recent decades has facilitated the decline in the extent of agricultural lands in these countries by making low priced agricultural imports available. This further motivates efforts to convert farmland to industrial uses.

The reallocation of land from lower-valued use to a higher valued use appears to be efficient. However, consideration of farmland's role in environmental protection and maintaining watersheds suggests that there is a significant positive externality associated with agricultural production. For purposes of environmental protection purposes, farmland is irreplaceable by the high-valued industrial parks. Because there is no existing market for the external benefits gained from farmlands, attempts to estimate the value of the external benefits arising from farmland production directly pose a significant challenge. This paper uses a contingent valuation method (CVM) to investigate that to what extent farmland provides value other than agriculture production to residents of the economy. A double-bounded dichotomous choice questionnaire was thus employed for the purposes of this study. The estimated value of the externality will then be added to the value of the agriculture products to be the final worth of paddy fields. This paper thus contributes to policy discussions by providing the first estimates of the value of agricultural production that include the externalities arising from farming activities on Taiwan.

This paper is organized as follows: Section 2 provides the theoretical foundations of the employed methodology for the externality estimation. Section 3 explains the data sources and collecting process for the empirical study. The empirical results are presented in the 4<sup>th</sup> section. The last section concludes the paper and makes some final remarks.

### RESEARCH THEORY

Over the past few decades, several methods have been developed in the field of environmental studies to evaluate environmental externalities (Davis 1963, Field 1994, Brookshire and Coursey 1987). This paper employs CVM due to its popularity for evaluating immeasurable economic benefit (Mitchell and Carson, 1989). Similar studies applied to environmental and non-environmental issues have been previously conducted include air quality, preservation of wildlife, and

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<sup>2</sup> According to Food and Agricultural Organization of United Nation, the falls in agricultural land area for the small open economies are evidential. For example, in the past three decades, the drop of agricultural land area is 27.3% in Switzerland, 7.08% in UK, 12.9% in Sweden, 7.3% in Netherlands, 14.4% in South Korea, 12.9% in Italy, 8.3% in Germany, 8.2% in France, 16.7% in Belgium, 12.1% in Austria, and 90% in Singapore.



the value of programs designed to reduce the risks of respiratory diseases.<sup>3</sup> In this paper we use a double-bounded dichotomous contingent valuation method to investigate the external benefit of farmland. Respondents are asked a series of questions with numerical values provided by the survey to induce the willingness-to-pay without losing much information (Boyle and Bishop, 1988). The formal theory follows.

The double-bounded model of CVM survey involves asking an individual if she/he would pay a specified amount to secure a given improvement in environmental quality with two bids. The level of the second bid is contingent upon the response to the first bid. If the individual responds "yes" to the first bid, the second bid (to be noted as  $B_i^H$  is some amount greater than the first bid if the individual responds "no" to the first bid, the second bid ( $B_i^L$ ) is some amount smaller than the first bid ( $B_i^L < B_i < B_i^H$ ). Thus, there are four possible outcomes with the likelihoods as  $\pi^{YY}$ ,  $\pi^{NN}$ ,  $\pi^{YN}$ , and  $\pi^{NY}$ . Under the assumption of a utility-maximizing respondent (Hanemann, 1984), the formulas for these likelihoods are as follow (Hanemann, Loomis, and Kanninen, 1991).

$$\pi^{YY}(B_i, B_i^H; \theta) = \Pr\{B_i^H \leq WTP\} = 1 - G(B_i^H; \theta) \quad (1.1)$$

$$\pi^{NN}(B_i, B_i^L; \theta) = G(B_i^L; \theta) \quad (1.2)$$

$$\pi^{YN}(B_i, B_i^H; \theta) = G(B_i^H; \theta) - G(B_i; \theta) \quad (1.3)$$

$$\pi^{NY}(B_i, B_i^L; \theta) = G(B_i; \theta) - G(B_i^L; \theta) \quad (1.4)$$

where  $G(B; \theta)$  is some statistical distribution function with parameter vector  $\theta$  and can be interpreted as a utility-maximization response within a random utility context where is  $G(B; \theta)$  the cumulative density function of the individual's true maximum WTP. Also suppose that  $G$  is logistic distributed, and  $G(B; \theta) = \frac{\exp(B - X\beta)}{1 + \exp(B - X\beta)}$ , where  $X$  is the explanatory variables, and  $\theta = \beta X$ , is the correspondent coefficients of  $X$ .

<sup>3</sup> See Bowker and Stroll(1988), Carson and Mitchell(1993), and Krupnick and Cropper(1992), Boyle and Bishop(1987), Grefle et al. (1998), Brookshire and Coursey(1987), Ready and Berger (1997), Schulze et al. (1983) for details.

With  $N$  respondents, where  $B_i^L, B_i, B_i^H$  are the bids used for the  $i$ th respondent, the log-likelihood function takes the form

$$\ln L(\theta) = \sum_{i=1}^N \left\{ d_i^{YY} \ln \pi^{YY}(B_i, B_i^H; \theta) + d_i^{NN} \ln \pi^{NN}(B_i, B_i^L; \theta) + d_i^{YN} \ln \pi^{YN}(B_i, B_i^H; \theta) + d_i^{NY} \ln \pi^{NY}(B_i, B_i^L; \theta) \right\} \quad (2)$$

where  $d_i^{YY}$ ,  $d_i^{NN}$ ,  $d_i^{YN}$ , and  $d_i^{NY}$  are the binary-valued indicator variables and the formulas for the corresponding response probabilities are as mentioned above. Applying the maximum likelihood (ML) method, we obtain the aforementioned estimation parameters of the dichotomous model. That is, we estimate  $\frac{\partial \ln L(\hat{\theta})}{\partial \theta} = 0$  to obtain  $\theta$  the coefficients.

The estimating model is now  $WTP_i = X_i \beta + \varepsilon_i$ , where  $WTP_i$  is the willingness to pay of the  $i$ th individual. Differing from  $B_i^L$ ,  $B_i$ , and  $B_i^H$  that are with observable discrete values,  $WTP_i$  is an unobservable continuous series. We assume that  $\varepsilon$  is normally distributed with zero mean and  $\sigma^2 I$  as the standard errors,  $\varepsilon \sim N(0, \sigma^2 I)$ .

When a survey method is employed to collect the data the problem of non-responses is encountered. If the values of environmental amenities to the individual that do not respond is different from the value of these amenities to those that do respond, then use of the survey data can result in biased estimates. To account for the potential selection problem, the Heckman two-stage selection bias correction procedure is used. Thus the estimated model becomes:

$$WTP_i = X_{11} \beta + \sigma_{12} / (\sigma_{22})^{0.5} \lambda_i + v_i \quad (3)$$

where  $\sigma_{12} / (\sigma_{22})^{0.5}$  is the inverse Mill's ratio and  $v_i$  is the residual. With the Heckman two-step procedure, if the estimated coefficient of  $\lambda_i$  is a positive number, the unadjusted regression may give an overestimated result. If it is negative, the unadjusted regression then tends to underestimate the impacts of the variables.

## DESIGN AND ENFORCEMENT OF SURVEY

There are many different types of agriculture fields and the environmental benefits provided by them differ one from the other. We select Taiwan's paddy rice fields as our sample in this study since they are known for several environmental benefit: ground water storage and recharge, green field

landscaping, polluted water purification, prevention for soil erosion, microclimate regulation, and habitats for wild animals, air purification, prevention of flood damage, transbasin water transfer stabilization, and prevention of salty water involving ground water system (Tsai, 1993). The coverage of the involved river basins is shown in Figure 1.

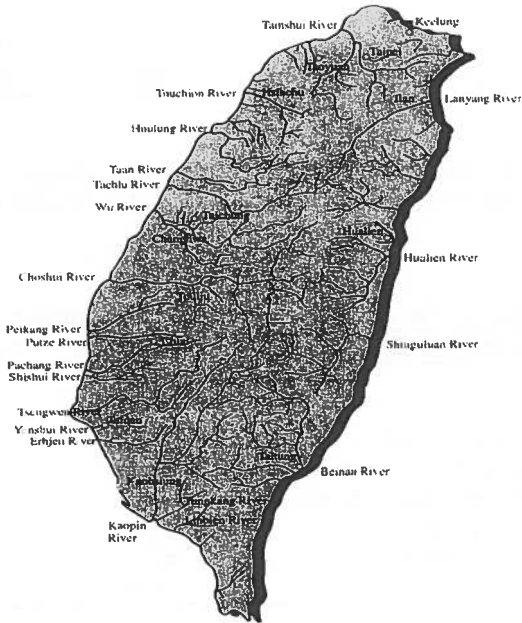


Figure 1 Studied River Basin Map

In this study, two functions are classified – water preservation and landscape protection – that are to be focused and studied as the external benefits of paddy fields.

The survey was conducted from April to May in 1999 over the entire island of Taiwan (total 21 district areas). We applied the computer-assisted telephone interviewing system (CATI) to conduct the interview. The sampling method is random and uses computerized phonebooks provided by the local telephone company to select the base sample. The usual demographic questions are asked during the interview. To induce each individual's WTP, five groups of bids are designed based on a pretest of a 900 sample-size open-ended question survey result. The WTP are divided into 5 categories by its standard deviation. The result is presented in Table 1.

Table 1 Alternative Bids for Paddy Fields (NT\$)

Water Preservation Function			Land Erosion Protection Function		
First round bidding	Second round bidding		First round bidding	Second round bidding	
B	B <sup>H</sup>	B <sup>L</sup>	B	B <sup>H</sup>	B <sup>L</sup>
33	50	17	21	30	10
85	40	125	121	180	60
151	225	75	162	243	81
203	304	102	263	394	132
320	480	160	404	605	202

Each respondent is randomly assigned into one of the five groups. The result of the attempted telephone numbers is summarized in Table 2 and the success rate is 16 percent.

Table 2 The result of attempted telephone number

Attempted telephone number	No. of Observation	Percentage (%)
1. Success	1,225	16.0
2. Refusal	1,318	17.3
3. No answer or busy tone	3,517	46.0
4. No adults around	159	2.1
5. Verbal communication problems	192	2.5
6. Out of service numbers	754	9.9
7. Business or fax numbers	473	6.2
Total	7,638	100%

The questions to induce the respondent households' WTP are based on a tax reallocation scheme. It is considered to be a more common means for financing environmental commodities and changes neither a disposable income nor a price of evaluated commodity. It does, however, reduce the amount of a household' tax money that has been spent on other public services. Thus, the following two questions are asked:

1. Given the paddy fields' ground water protection function, would you vote for the program if reduced the amount of your household's tax money<sup>4</sup> that spent on the other public services by \$ B<sub>w</sub> per year? Yes No

<sup>4</sup> Yabe, Bergstorm, and Boyle (1999) compare the effects of two payment vehicles of a special tax and a tax reallocation on willingness to pay. In this study, we use the tax reallocation method meaning that the residents do not need to pay out of their own pockets to finance the environmental protection program. Instead, the tax money allocated to other public services will decline along with the increase amount of money allocated to the environmental protection program.

If the above answer is "Yes", then the same question is asked again by changing the  $\$B_W$  to  $\$B_W^H$ . If the answer is "No", the amount  $\$B_W$  will be changed to  $\$B_W^{L5}$ .

2. Given the paddy fields' landscape preservation function, would you vote for the program if reduced the amount of your household's tax money that spent on the other public services by  $\$B_L$  per year? Yes No

If the above answer is "Yes", then the same question is asked again by changing the  $\$B_L$  to  $\$B_L^H$ . If the answer is "No", the amount  $\$B_L$  will be changed to  $\$B_L^6$ .

### EMPIRICAL RESULTS

The statistical summary of the interviewed sample is presented in Table 3.

Table 3 Demographic summary

Variables	No. of obs	Mean	Standard Error	Min.	Max.
Age	1013	39.71	12.03	20	89
Education	1186	12.82	3.90	6	25
Family size	1178	4.88	2.47	1	20
No. of working people in a family	1157	2.54	1.67	0	18
Tenure	947	11.99	10.60	1	60
Average expense ( $\times 10^4$ )	555	68.37	36.12	36	170
Marriage status	1225	0.72	0.44	0	1
Average income ( $\times 10^4$ )	695	82.07	42.67	36	170
Homeowner	1225	.72	.44	0	1
Urban residents	1225	0.46	0.49	0	1
Flood	1209	0.14	0.35	0	1
Gender	1225	0.51	0.50	0	1
Occupation:	No. of obs.	Percent-age			
Public worker	119	10.57			
Business	199	17.67			
Farmers	60	5.33			
Self-employed	139	12.34			
Blue collar	197	17.50			
Staff	145	12.88			
Other	206	18.29			

(Table continues on next page)

<sup>5</sup> The amount of  $B, B^H$ , and  $B^L$  are determined from pretest. They are presented in the table of next section.

<sup>6</sup> The amount of  $B, B^H$ , and  $B^L$  are determined from the pretest. They are presented in the table of next section.

Working position		
Owner of the business	62	9.66
Manager	168	26.16
Staff	412	64.18

The monetary values from the questionnaire are denominated in New Taiwan Dollars (NT), which convert to US dollars at a ratio of 33 NT dollars to 1 US dollar. Table 4 presents the summary of participants' responses to the initial and the second bids.

Table 4 Participants' responses to the initial and second bids

For water preservation function			
Answer type		Second bid	
		Yes	No
First bid	Yes	539 (54.94%)	158(16.11%)
	No	52 (5.30%)	232 (23.65%)
For land protection function			
Answer type		Second bid	
		Yes	No
First bid	Yes	408 (44.78%)	148(16.25%)
	No	71 (7.79%)	284 (31.18%)

It shows that more than 76.35 percent and 68.82 percent of households think that paddy rice fields require some degree of public subsidy due to their water preservation function and land protection function, respectively. The result of the maximum likelihood estimates of the respondents' double-bounded WTP is summarized in Table 5.

Table 5 Maximum likelihood estimates of the respondents' WTP

Variables	Water preservation	Land protection	Water preservation	Land protection
Education	20.77 (36.38)	22.05 (37.78)	-702.89*** (190.74)	-389.87** (202.48)
Income	-26.75 (24.59)	-18.94 (25.18)	-239.84*** (60.23)	-142.89** (64.86)
Tenure	4.44 (9.71)	12.39 (10.27)	67.50*** (18.96)	48.29** (20.16)
Marital Status	14.74* (22.58)	36.26 (23.14)	301.69*** (77.47)	202.86** (83.68)
Gender	20.54 (19.06)	15.32 (19.85)	89.08*** (25.99)	53.84** (27.21)
Urban	-.57 (19.57)	-14.75 (20.30)	-52.62** (23.52)	-43.49* (24.56)
Family size	-8.56** (3.59)	-9.11** (3.85)	-39.92*** (8.88)	-27.16*** (9.52)
Manager	-19.82 (27.27)	-27.01 (28.14)	-124.57*** (38.16)	-85.85** (40.38)
Farmer	10.36 (45.24)	58.82 (48.44)	130.46** (54.13)	123.65** (57.72)
Businessman	12.88 (23.60)	24.37 (25.13)	116.67*** (35.50)	82.45** (37.60)
News	12.76 (11.41)	1.82 (11.65)	13.57 (11.28)	2.43 (11.60)
Flood	9.76 (26.96)	20.10 (26.91)	-159.52*** (51.06)	-75.03 (53.16)
Mill's ratio	--	--	7046.71*** (1824.21)	4035.91** (1948.97)
Constant	352.83** (109.93)	301.97 (113.50)	4322.64*** (1034.22)	2577.48** (1104.94)
Log likelihood	-1081.26	-1131.21	-1073.87	-1129.08
Number of obs	705	707	705	707
Model $\chi^2(15)$	12.65	18.31	27.42	22.57
Prob > $\chi^2$	0.562	0.1932	0.0255	0.0936
Medium WTP	3253.08	3228.00	3370.92	3360.36

Note:

- 1, 5, and 10% level of significance are denoted by \*\*\*, \*\*, and \*, respectively.
- standard errors are in the parentheses
- Education, income, and tenure year are in natural logarithm form.
- The variable "News" represents the number of news sources where the respondents obtain their environmental knowledge.

The variable "flood" means the respondents with the experience of flood. Column 1 and 2 are the results of the WTP estimation without the selection bias correction and column 3 and 4 contain the estimates incorporating Heckman's two-step correction. Since the estimated coefficient for the inverse Mill's ratio is significant at 5% level, it appears that the appropriate estimates are those contained in columns 3 and 4. That is, incorporation of the selection bias correction is important.

The estimation results show that education and income level have a negative significant impact on the respondents' WTP for both functions of paddy fields, and both are statistically significant at 0.1% level. Also, respondents with larger family sizes tend to pay less for both the paddy fields' environmental protection functions. Other variables that have negative impacts on the households' WTP toward paddy fields include urban residents, manager status, respondents has more knowledge about paddy field's wildlife, and the respondents with flood experience. The latter two variables seem to give counterintuitive results. They are statistically insignificant, however. Male, married respondents, and farmers, and respondents who work in business sectors in general tend to pay higher for both type of paddy fields' function, and the results are statistically significant at 5% level.

The coefficients of the Mill's ratio in both estimate results are positive and statistically significant at 5% level meaning that the regression without selection-bias correction may be upward biased. The overall estimated WTP's for each regression function are shown at the bottom of Table 5 noted as medium WTP. They are estimated at the mean value of the explanatory variables. The results show that the average households in Taiwan are willing to reallocate their tax money from other public services to maintain paddy rice fields for their water preservation function by the amount of \$3370.92 NT (about \$102) annually. For land protection purpose, the average households in Taiwan are willing to reallocate \$3360.36 NT of their tax money in the reduction of other public services for paddy fields maintenance. The total WTP for the paddy fields maintenance in the form of reduction of other public services from their annual tax payment is \$6731.28 NT per household. With total 6,592,549 households in Taiwan area, the total amount of tax money needed to be reallocated for paddy fields maintenance is about \$4.66 trillion NT, equivalent to 1.26 folds of the value of rice production at the same period.

## CONCLUSION

In this study, the importance of the environmental protection function of farmlands is stressed and the value of these external benefits is estimated. Aside from the agriculture production purpose, farmlands are also recognized to be important in their environmental function. For simplicity, those benefits are roughly categorized into two types: water preservation and land protection



functions for further investigation in the paper. To evaluate the value of these external benefits, a double-bounded dichotomous contingent valuation method is employed. The majority of survey respondents feel that paddy rice fields exert a significant positive effect on water preservation and land protection. For water preservation and land protection the associated percentage of positive WTPs exceed three-fourths and two-thirds, respectively. The total willingness to pay obtained from tax reallocation for the paddy fields is \$4.66 trillion NT, which is equivalent to 1.26 folds of the market value of rice production in Taiwan. Also the WTP's are positively related to the respondents' tenure year, marital status, business sector status and male status. They are negatively related to the respondents' education and income level, family size, urban status, and manager status.

The results of this paper indicate that the majority of the households are aware of the external benefits of farmlands and are willing to pay certain amount of money out of their tax payment to maintenance them. With the technology improvement and the economic structural shifts, farming area is gradually shrinking especially in the small open economies, which even consider about abolishing agricultural production and mainly relying on imported products. In the ever decreasing in size of farmland in today's societies, this paper calls attention that only look at the internal value of one sector is not enough. When evaluating the priority of the development of a nation, the external benefits of farmlands and the external costs of industries development need to be evaluated along with their internal value. It is hoped that this paper can serve as a useful reference to the agricultural authorities for future policy considerations.

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# **EFFECT OF OPERATION PROCEDURES IN SEDIMENT TRANSPORT IN A TRANSBASIN CANAL SYSTEM**

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Ahmad Barari <sup>2</sup>

## **ABSTRACT**

The purpose of this paper is to discuss problems associated with performance of earth canals, designed for non-scouring and non-silting flow, and suggest operational procedures to minimize the sedimentation problem for transbasin projects, where adequate facilities for removal of suspended solids may not be available at the headworks. Remarks are based on observations of site characteristics, and analysis of field data for the Moghan Irrigation Project, as a part of the Mill and Moghan Project constructed jointly between Iran and the Republic of Azerbaijan (a former Soviet Union republic).

## **SCOPE OF MILL AND MOGHAN IRRIGATION PROJECT**

The Mill and Moghan Irrigation Project is a major water development project in the Aras River basin. The Aras River runs from west to east along the northern international boundary of Iran, from Ararat Mountains in Turkey to Kur River in Azerbaijan and finally to the Caspian Sea, a distance of approximately 1000 kilometers (km). The Aras River basin (approximately 124,000 square kilometers) is shown in Figure 1.

Along its route, various watersheds, primarily from the mountains in the northwest of Iran, and the Caucas Mountains, drain to the Aras, creating a water conveyance system across a multitude of basins. This multipurpose project supplies irrigation water to Moghan Plane in Iran and Mill Plane in the Republic of Azerbaijan. The construction of the project was started in 1960s at the peak of water development projects in the world, and was completed in early 1970s.

## **PRIMARY ELEMENTS OF THE PROJECT**

The joint project consisted of a 42-meter high earth-type storage dam with impermeable core, reservoir capacity of 1,350,000 hectare-meters (hm), and two powerplants with 44 MW electricity generating capacity. These facilities are located near the Azerbaijani City of Nakhjevan. Approximately 250 km

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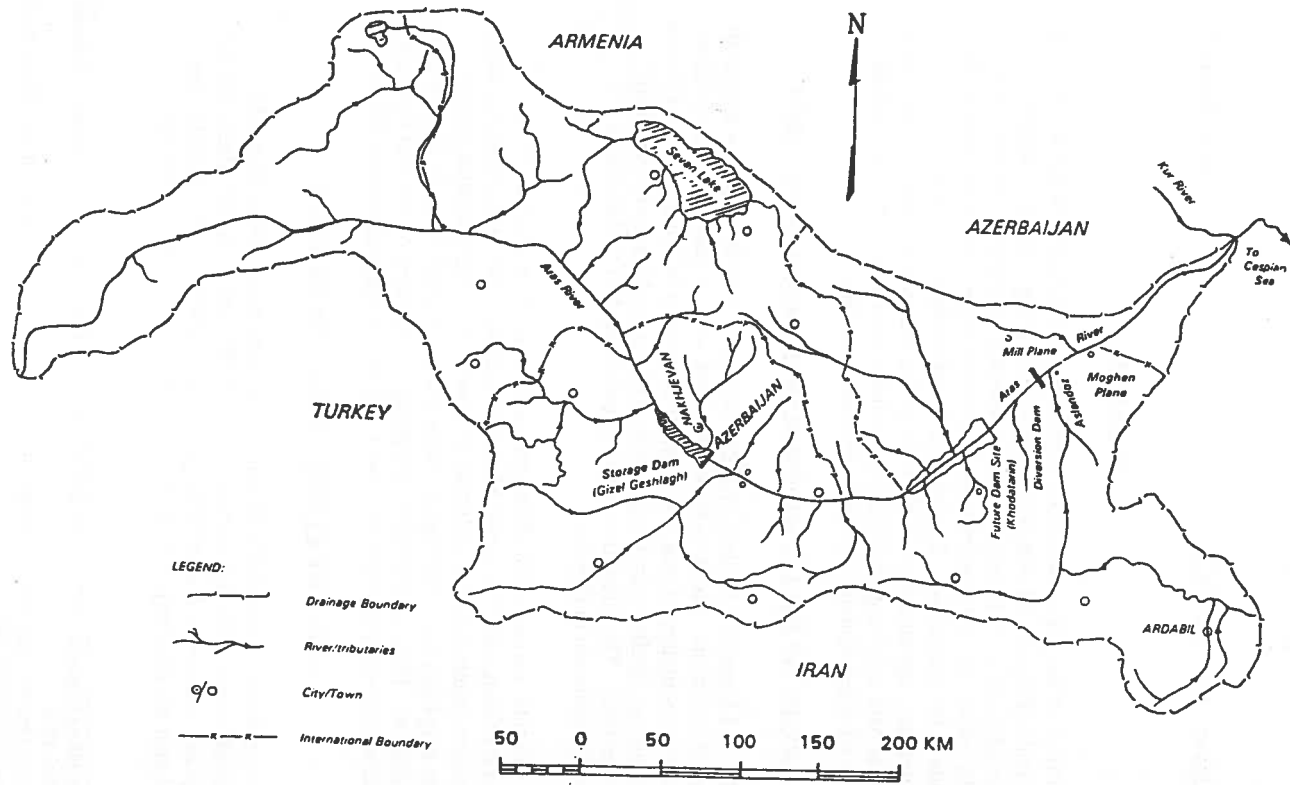


Figure 1: Aras River Basin (local dam project sites not shown)

downstream along the Aras River at Aslandoz (Iran), a diversion dam (earth-type) diverts water to the canal systems on both sides of Aras and, therefore, conveys water to farm lands in Iran and in the Republic of Azerbaijan.

On the Iranian side at the present time, the head structure at the diversion dam includes a sedimentation facility designed to trap suspended solids larger than 0.15 mm in diameter. Then, the water flows in a primary canal system (approximately 150 km) and secondary canals (approximately 250 km). The design capacity of the main canal at upper reaches is 80 cubic meters per second (CMS).

The land under irrigation in Moghan Plane on the Iranian side is approximately 90,000 hectares (ha) and the primary canal system is shown in Figure 2. From a historical perspective it should be mentioned that prior to the water project under consideration there was an existing canal system, namely A-canal and T-canal in the area which was supplying water to approximately 18,000 ha of the land. However, by construction of the main canal under the project described above, these two previously constructed canals, which were seriously affected by sedimentation, became an extension of the main canal system of Moghan Project, and their intake facilities at Aras River that consisted of temporary earth dikes, were abandoned.

### SEDIMENT LOAD IN ARAS RIVER

The sediment load upstream from the storage dam is primarily removed by the sediment pool of the reservoir. The sediment rating curve at a gauging station (Khazanghah) on the downstream side of the storage dam is shown in Figure 3. Based on average flow in this reach, the sediment load in the river below the storage dam is estimated to be 1.4 million metric tons per year. Downstream from the storage dam a number of tributaries join the Aras River as shown in Figure 1. These intermediate tributaries from abutting watersheds add a very significant amount of sediment load to the Aras River. The sediment rating curve for Aras River at a gauging station at Khodafarin, approximately 200 km downstream from the storage dam, is shown in Figure 4 (based on average sediment loads) and Figure 5 (based on high sediment loads). The relationship between water discharge and suspended sediment given in figures 3 through 5 are based on limited data and pertains to an intermediate region of Aras River Basin between the gauging stations mentioned above. Reportedly, approximately 13 percent of the total sediment in the Aras River may be assumed bed load. Regarding the suspended sediment, approximately 10 percent consist of particles larger than 0.15 mm that may be trapped in the sedimentation chambers at diversion dam.

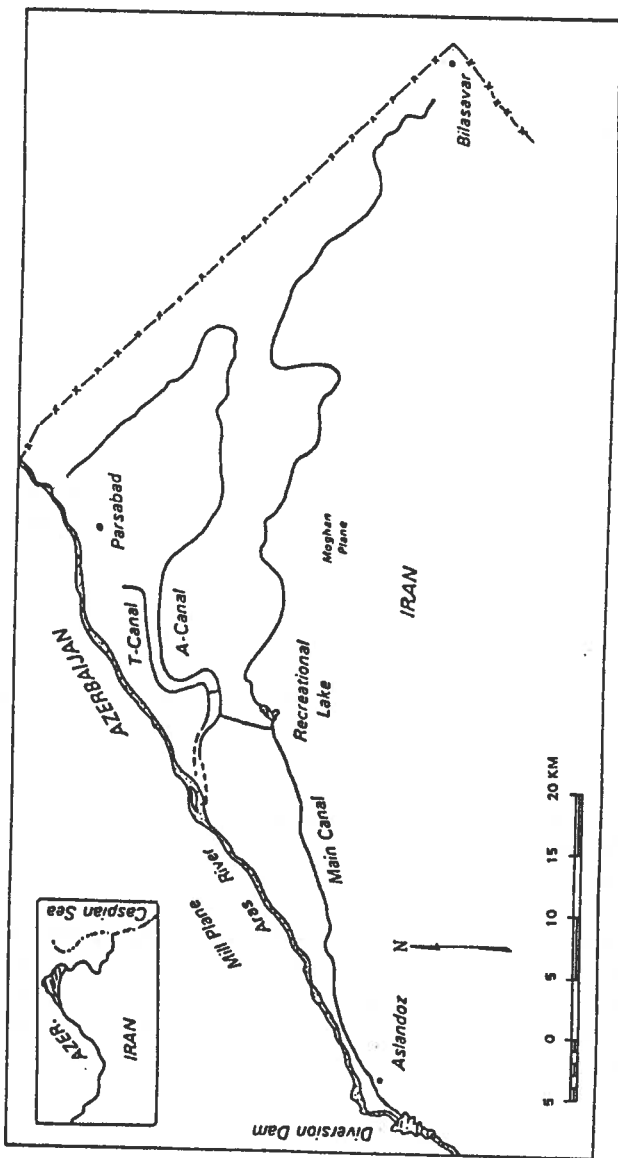


Figure 2: Moghan Irrigation Project

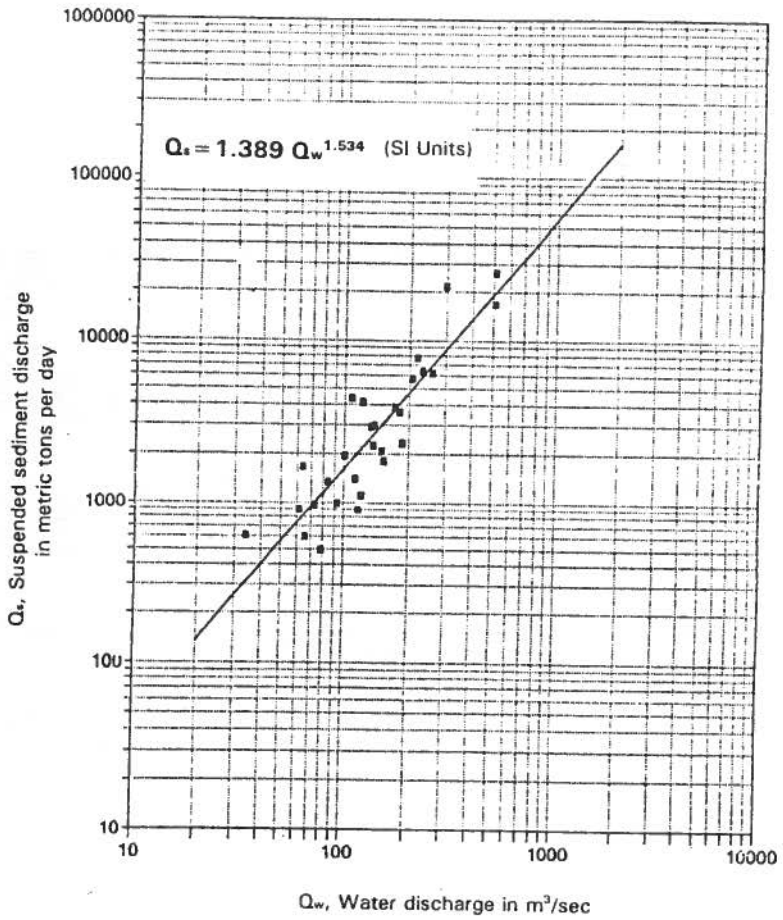


Figure 3: Sediment Rating Curve for Aras River at Khazanghah Gauging Station (Downstream of Storage Dam at Gizel Geshlagh)

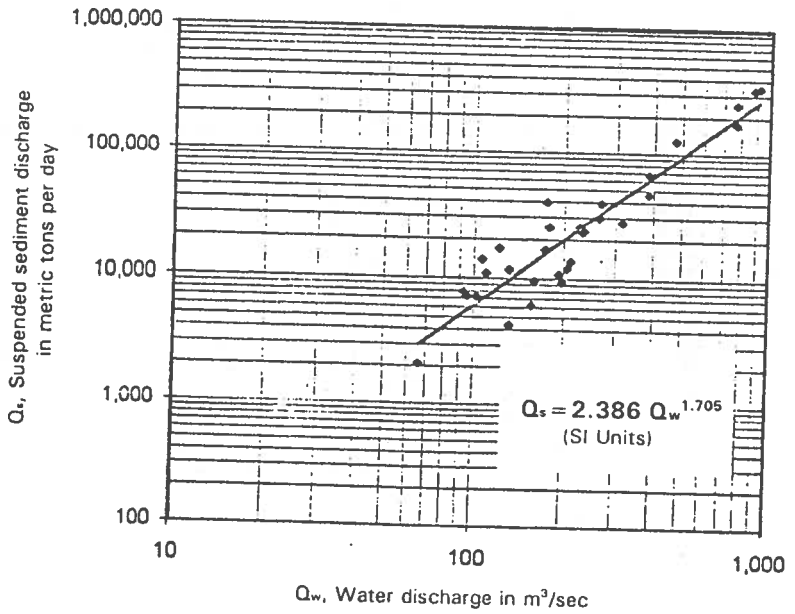


Figure 4: Sediment Rating Curve for Aras River at Khodafarin Gauging Station (Based on Average Sediment Loads)



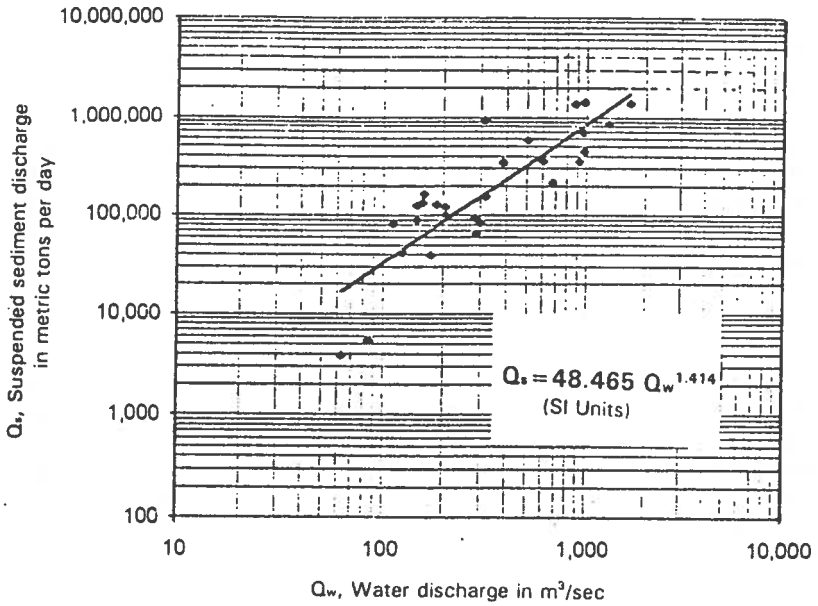


Figure 5: Sediment Rating Curve for Aras River at Khodafarin Gauging Station (Based on High Sediment Loads)

### DISCUSSION OF DESIGN CRITERIA

For the purpose of sediment removal, the head structure at the diversion dam includes a sedimentation facility with 4 chambers, each chamber with 5 galleries, 120 meters (m) long, 5 m wide and 3 m deep. Three of the chambers may be in operation while the 4<sup>th</sup> chamber is being flushed. Based on limited field data available, approximately 10 percent of the suspended load is particles larger than 0.15 mm (larger than fine sand) that may be trapped in the sedimentation basin under proper operational procedure. The canal design was based on tractive-force method (pioneered by U. S. Bureau of Reclamation), and the sediment capacity of the system was determined to be adequate under normal flow conditions. It is imperative to realize that in tractive force method the allowable tractive force is a function of median grain size (D50) of soil or canal material, and therefore, the maximum velocity of flow is restrained by the geometric design of a canal (to prevent scouring). However, it provides no provisions for minimum velocity of flow (to avoid silting). In fact the tractive-force method is meant for clear water or moderately sediment-laden water, in canals with uniform flow, at normal depth.

### OPERATING PRACTICE

Following completion of the water project described in this article, development of land remained incomplete and therefore, the system was operated at reduced capacity (approximately ½ capacity at most). This condition, in conjunction with the effect of check structures along the canal system designed to maintain the water surface elevation at desired levels, caused serious reduction in velocity of flow and accelerated silting process. The upper reaches of the main canal behaved, to some degree, as a regime canal and the sediment deposits were carried downstream by fluctuations in the position of regulating gates at the check structures. However, the lower reaches of the main canal, and A-canal as well as the secondary canals branching off from A-canal, with fixed check structures such as Duckbill-type weirs developed serious sediment problems. Admittedly, inadequate maintenance for an extended period of time compounded the problem, and approximately 1/3 of canal capacity was lost in the first 25 years of operation. Allowing excessive sediment in to the canal system is prone to cause problems. However, under the condition described above, the silting could be minimized by incorporating requisite criteria in the design of check structures and operating procedures to maintain adequate velocity of flow in the canals during water delivery.

### CONSIDERATION OF CORRECTIVE MEASURES

As shown in Figure 1, the project encompasses watersheds across international boundaries. Therefore, soil conservation methods in the numerous watersheds seemed to be ineffective due to lack of control over the vast area contributing to

the system. Construction of check dams below certain watersheds with high erosion was also considered. Furthermore, addition of a desilting structure on the main canal at a certain strategic location was considered to supplement the function of sedimentation facility at diversion dam. Construction of sedimentation basins at the headwork of some of secondary canals prone to silting were also considered by means of enlarging the depth and width of required length of canal (depending on maximum flow capacities). Improvements in the practice of mechanical removal of sediment were also considered.

Because a storage dam with adequate sediment pool is planned for construction at Khodafarin, approximately 50 km upstream from the existing diversion dam, other costly alternatives for sediment control were deemed unwarranted.

Maintaining a pre-determined minimum velocity of flow in the canals would be a viable means to minimize silting problem. This can be achieved by proper maintenance of the system including tertiary canals, and implementation of a water delivery plan based on hydraulic characteristics of the canal system. Needless to say, this method would require precise planning and management.

### CONCLUSIONS

For canals with sediment laden water source, the maximum (non-scouring) velocity and minimum (non-silting) velocity shall be determined for every reach of the canal and incorporated in the design. The tractive-force method should be used for canals with clear water source, or canals with adequate sediment removal facilities at the headwork. This method provides an upper limit for velocity of flow to prevent scouring. There is no provision in the method to prevent sediment deposition in the canal. Use of this method may work for canals with moderately sediment laden water, providing that the flow in the canal shall be uniform (normal depth flow). In case of check structures designed to maintain the water surface at desired elevations, a threshold velocity (lower limit of velocity) shall be determined and implemented in the operational plan to avoid deposit of sediment in the canal system. Social aspects such as water and transportation needs of communities in the immediate vicinity of the project and access restrictions should be seriously considered in the design phase. Operation and maintenance manuals should be prepared during the first year of the project operation and updated periodically thereafter.

### ACKNOWLEDGEMENTS

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Data on sediment studies came from project reports by a joint venture of Yekom Consulting Engineers of Iran, and Associated Consulting Engineers (ACE) of Pakistan. The canal system for the Iranian part was designed by a joint venture of Guide Engineering Firm of Iran and Associated Consulting Engineers (ACE) of Pakistan. The storage dam, powerplants, diversion dam and sedimentation basins were designed by Russian and Azerbaijani forces, including Hydro Project Engineering in Baku, Azerbaijan. Sincere thanks are due to Christine M. Ferrara, Chief of Hydraulic Division of the Engineering Department for the County of San Luis Obispo, California, for her review and comments on this paper. And finally, sincere thanks to Larry D. Stephens, Executive Vice President of the United States Committee on Irrigation and Drainage, for his encouragement in development of this paper, and his support and very helpful comments.

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# RECONNAISSANCE EVALUATIONS OF TRANSBASIN WATER TRANSFERS

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## ABSTRACT

This paper describes a proposed world-wide methodology for reconnaissance, identification, and evaluation of potential trans-basin water transfers. Existing and proposed water transfers are mentioned and/or described. Postel (1999) estimates that 2,000 km<sup>3</sup> of new water will be needed by 2025. This seems to be a reasonable and achievable goal. However, it is urgent that resources be evaluated so that the most economical and sustainable land and water developments can be selected. This goal is 8.8 times the existing and proposed water transfers indicated by Geraghty et al. 1973. It is also about ten times the annual flow of the Colombia River in the United States. Climate is described by seven classifications of climate. Depth of runoff for the U.S. for each classification is shown with some comparison with other regions. The classifications are derived from a World Water and Climate Atlas. Some proposed water transfers are described and other possible transfers are mentioned.

The possibility of building large dams in Bolivia to generate hydropower and irrigate a large area of arid and semi-arid lands in Bolivia, Paraguay, and Argentina is presented in order to illustrate the usefulness of the methods proposed. The information required for reconnaissance planning is available from topographic maps, a digital elevation model, and the World Water and Climate Atlas. It is proposed that the Atlas be used to map climate zones to show the location and extent of arid zones and those with water surplus. Topography can then be used to evaluate the potential for the desirable water transfers. The analysis is done in a GIS environment, using ArcInfo and ArcView.

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## INTRODUCTION

The world's population is increasing. Hunger and malnutrition are also increasing. More than one billion people live on less than \$ 1.00 per day and nearly three billion on less than \$ 2.00 per day (World Bank, 2000<sup>a</sup>). As population increase there is an urgent need to rapidly increase food production. There is increasing consensus that most of the future increase in required food production must come from irrigated agriculture. The World Bank (2000<sup>b</sup>) gives development statistics. Five countries with the highest gross domestic product (GDP) were selected and compared with 50 countries with the lowest GDP.

The five countries (United States, Japan, Germany, France, and the United Kingdom) produced 59 percent of the world's gross product (GWP) in 1998 of which 1.9 percent was derived from agriculture. The role of agriculture and arable lands (per capita) have been declining. Irrigated area is declining in Japan, The United Kingdom, Bolivia, and at least 10 other countries. In 22 countries the irrigated area has remained unchanged during the 1990s (Gleick, 2000).

Of the 50 low GDP countries, 33 record the changing role of agriculture—an increase in 12 and a decline in the percent of the GDP in 21. The 50 countries produced 0.6 percent of GWP in 1998 of which 28 percent was derived from agriculture. The World Bank (2000<sup>b</sup>) lists 15 countries that have purchasing power parity (PPP) below \$1 per day for 40.1 to 84.6 percent of the population. In 12 of the 50 countries the irrigated area is stable or is declining somewhat. As early as the 1970's the government of Japan recognized the need to promote agricultural production in the developing countries and funded water resources development studies. Low interest financing was offered. The Canadian International Development Agency, World Bank, USAID, Inter-American Development Bank and others have financed studies and resource inventories. Some private organizations have offered to build and operate water resource facilities. The resulting development has been disappointing.

This paper presents a methodology for reconnaissance studies to identify and partially evaluate transbasin water resource developments. The methodology includes the use of ArcInfo and ArcView to manipulate and analyze the data. Some comparisons among standard hydrology procedures and GIS based hydrology procedures are shown. It does not, however, provide a methodology for promoting privatization of development and management, the means for creating improved institutional capacities within the underdeveloped countries, or user participation in planning and management.

The irrigated area in Bolivia has declined from 140 thousand hectares in 1980 to 88 thousand in 1997 (Gleick, 2000). During this period the population has increased by more than one third. Bolivia was selected to illustrate the proposed reconnaissance methods because of the need for development and the large land

and water potential.

Postel (1999) estimated that 2000 km<sup>3</sup> of new water would be required by 2025 in order to meet food needs. The world's land and water resources are abundant. Many outstanding potential developments have been identified. Real and/or perceived environmental impacts have frequently discouraged development. However, the social and environmental impacts from poverty, slash and burn agriculture and insecurity are enormous and may indicate that negative impacts from delaying development may often be far greater than the impacts from development. An increase in slash and burn agriculture could have a very large negative impact resulting from flooding, soil degradation, and climate change.

### RECONNAISSANCE INVESTIGATIONS

Irrigation project investigations include an inventory of soils or lands suitable for irrigation, crop water requirements, water supply, flood risk, and the conditions that are favorable for the storage and transport of the required water. Some of these can be estimated from readily available sources. Methods of computation and/or estimation are given in Hargreaves and Merkle (1998) and are presented in this paper.

#### Irrigation Requirements

For purposes of planning, monthly irrigation requirements are frequently estimated as reference crop evapotranspiration ( $ET_o$ ) in excess of 75 percent probable precipitation ( $P_{75}$ ).  $ET_o$  can be computed from maximum and minimum temperatures and extraterrestrial radiation. The procedure for computing  $ET_o$  is given in Hargreaves and Merkle (1998), and the Atlas (described in a subsequent section).  $P_{75}$  can be calculated from a probability distribution or from the mean precipitation ( $P_m$ ) and the standard deviation (SD). The equation is:

$$P_{75} = P_m - 0.74 \times SD \quad (1)$$

#### Water Supply

A moisture adequacy index (MAI) can be used to estimate the depth of surface runoff from watersheds. MAI is  $P_{75}$  divided by  $ET_o$  ( $MAI = P_{75} / ET_o$ ). Seven MAI based classes of climate can be used to estimate surface runoff. The Water Atlas for the United States (Geraghty et al. 1973) was used to calculate the average annual depth of runoff in mm for each of the seven climate classifications. The results are given in Table 1.

Table 1. MAI-Based Climate Classification and Average Annual Runoff

Climate Classification	MAI Criteria	Water Constraints on Productivity	Average Runoff in mm
Very Arid	All months with MAI $\leq$ 0.33	Not suited for rainfed agriculture	15
Arid	1 or 2 months with MAI $\geq$ 0.34	Limited suitability for rainfed agriculture	35
Semi-Arid	3 or 4 months with MAI $\geq$ 0.34	Suitable for crops requiring a 3 to 4 month growing season	120
Wet-Dry	5 or more consecutive months with MAI $\geq$ 0.34	Suitable for crops requiring a 5 or more month growing season	200
Somewhat Wet	1 or 2 months with MAI $>$ 1.33	Natural or artificial drainage required	290
Moderately Wet	3 to 5 months with MAI $>$ 1.33	Good drainage required	440
Very Wet	6 or more months with MAI $>$ 1.33	Very good drainage required	935

Comparisons have been made with watersheds in Latin America. The results indicated more runoff in most other locations. Values of MAI for the world are available from the World Water and Climate Atlas of the International Water Management Institute (IWMI). The Atlas is available on the Internet at <http://www.iwmi.org/> or <http://www.cgiar.org/> or from CD ROM (available from [d.vaneyck@cgiar.org](mailto:d.vaneyck@cgiar.org) or [i.makin@cgiar.org](mailto:i.makin@cgiar.org)). It is recommended that an atlas be made using the seven classifications and that additional streamflow data be used to refine or locally calibrate the depths of runoff. Monthly values of the 75 percent probable runoff ( $Q_{75}$ ) in mm of depth were compared with MAI for various watersheds. Values of monthly  $Q_{75}$  were generally in the range of base flow plus 25 to 30 times MAI.

The World Water and Climate Atlas derives several climate related parameters from observed temperatures and rainfall. Calculated parameters include, mean temperature, precipitation probabilities, evapotranspiration and differences and ratios between the evapotranspiration and rainfall and rainfall probabilities. Ten-



day, monthly and annual summaries are available in the Atlas on approximately 2.5-minute grid spacing. This Atlas allows the selection of a particular area, and then data for that area is available in tabular form or as a spatial representation.

The MAI and  $P_{75}$  are developed in the Atlas but have not been applied to categories such as those listed in Table 1 above. The needed classifications could be developed from the World Water and Climate Atlas MAI and  $P_{75}$  and included in a new atlas without having to develop them again using the basic temperature and rainfall data. In addition, higher resolution DEM (Digital Elevation Model) values for most of South America have become available and could be included in the new atlas.

Weather station location coverage is fairly complete for the USA and for Asia. For these large areas, surface water flow can be calculated by assuming that the number of stations in each class indicates the area in each class. The mean annual streamflow computed from this assumption differ by 1% for Asia and 0.1% for the USA from the annual rechargeable amounts shown by Gleick (2000).

Hargreaves (1993) used monthly precipitation (P) monthly surface runoff in mm of depth (R) and the annual sum of monthly positive values of P minus  $ET_0$  (S) for 23 portions of the United States. The regression equation found with  $r^2 = 0.96$  was:

$$R = 61 + 1.31 S \quad (2)$$

The excellent correlation of runoff with the values of S indicates that Eq. 2 should become a useful world-wide tool for estimating water availability.

### **Flood Risk**

Many irrigation facilities and agricultural crops have been damaged or destroyed by unusual floods. This risk has been very significantly increased by the expansion of slash and burn agriculture. The 20 year return period extreme value ( $P_5$  or  $Q_5$ ) from a series of rainfall or flood data can be obtained from the mean (M) plus 2.04 standard deviations (SD). The equation is:

$$P_5 \text{ or } Q_5 = M + 2.04 \times SD \quad (3)$$

### **Irrigable Lands**

The alluvial lands usually have the most favorable topography and are potentially the most productive. The extent of these lands can frequently be determined from topographic maps. A digital elevation model (DEM) is available on the Internet at [www.usgs.gov](http://www.usgs.gov) and where available soils maps should be used. Hydrogeological, geological, and geomorphological maps are also useful.

Topographic maps at a scale of 1:50,000 with 20 meter contour intervals are available for most of the world. Unfortunately their use has sometimes been limited by security classifications.

### Storage Sites

Potential dam and reservoir sites can be selected from topographic maps or from a digital elevation model (DEM). Various proposed heights of dam can be evaluated. The upstream watershed area from the proposed location can be computed using the corresponding subset DEM. For a reconnaissance evaluation the volumes from various water depths can be calculated from the depth of water at the dam (D) and the water surface area (A). The equation for the volume (V) is:

$$V = (A \times D) / 3 \quad (4)$$

Also by using the subset DEM in a TIN (Triangulated Irregular Network) format one can inquire ArcView to compute the Planimetric area, the surface area, and the corresponding Volume for different dam heights.

Table 2 shows some calculations for the upper Beni River Basin. Figure 2 shows the graphic display of the corresponding flooded areas. Figure 1 shows the plotted Volume values.

The difference between both approaches is evaluated.

Table 2. Areas and Volume for different Reservoir water surface elevations.

<b>Water Surface Elevation</b> m	<b>Planimetric Area</b> m <sup>2</sup>	<b>Surface Area</b> m <sup>2</sup>	<b>Volume</b> m <sup>3</sup>
550	1973055782	1973959812	79586786540
600	2396249859	2398648208	1.88944E+11
650	2736615373	2741009062	3.18077E+11
700	3026813076	3033400551	4.62274E+11
750	3307375363	3316238538	6.20649E+11

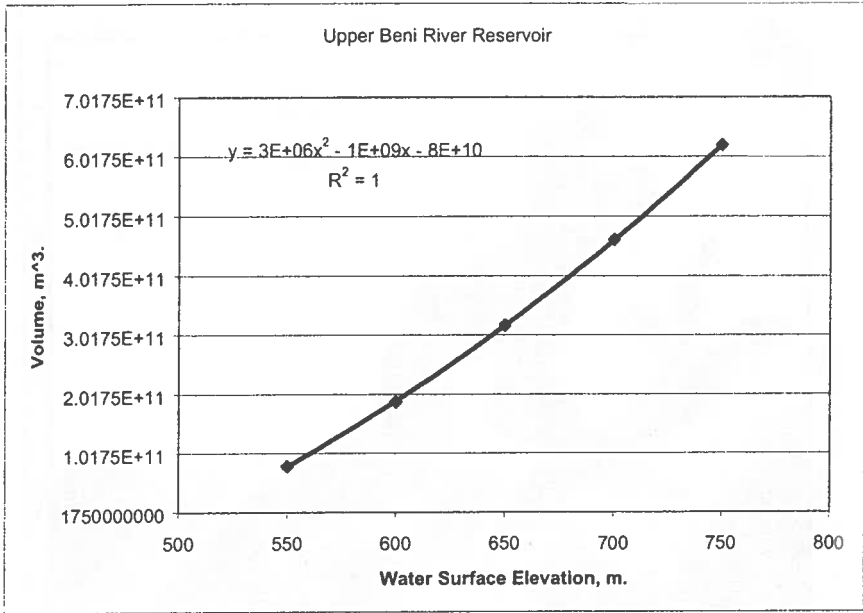


Figure 1. Plotted Volumes for different water surface elevations.

### RESOURCES FOR DEVELOPMENT

From a study of the climate data from 2147 locations (Hargreaves and Samani, 1986) it is indicated that nearly a third of the earth's surface is very arid or arid. About 40% is somewhat wet, moderately wet or very wet. For nearly a fourth of the earth's surface good drainage is required for good agricultural production, except for a few crops. Rice is an exception.

Table 3 is a summary of the land and water resources. The resources of the United States and of the world are compared. The projected requirement of 2,000 Km<sup>3</sup> of new water is less than the annual surface water flow to the ocean from the United States. Published estimates of arable land are probably low. For instance in Southern California, farmers are producing citrus, avocados and specialty crops on steep rocky slopes previously considered non-arable. Some of the farmers pay in excess of \$ 500 per acre-foot of water (one acre-ft is 1,233 m<sup>3</sup>).

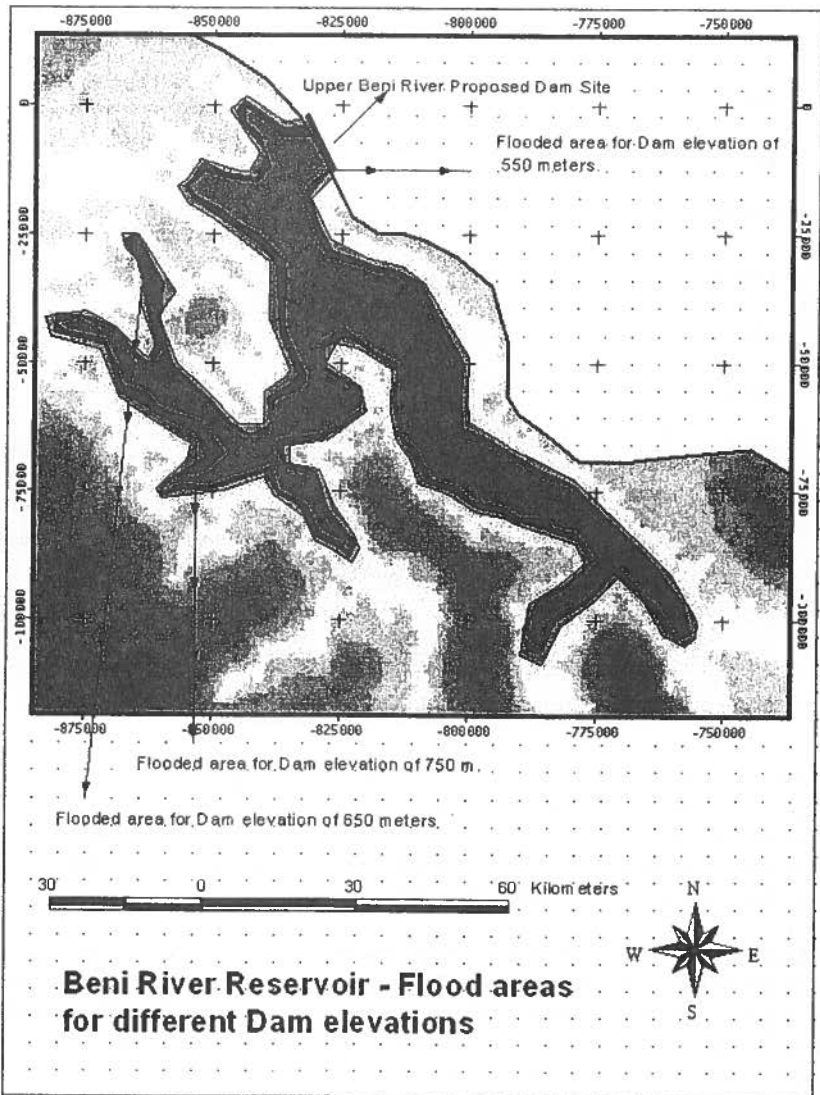


Figure 2. Showing the different flooded areas for a dam height full of water for the following elevations: 750, 650, and 550 m. Upper Beni river in Western Bolivia.

Table 3. The US and World's land and water resources.

Annual renewable water (surface water flow)	48,788 Km <sup>3</sup>
Annual withdrawal (6.1% of renewable)	2,957 Km <sup>3</sup>
Total land area (World)	13,357 million ha
Total arable land (11.5% of total)	1,435 million ha
Total irrigated land (1997)	267.7 million ha
USA annual renewable water	2478 Km <sup>3</sup>
USA annual withdrawal (18.9% of renewable)	469 Km <sup>3</sup>
Total land area (USA)	936 million ha
Arable land (USA 19.5% of total)	183 million ha
Total irrigated area (USA 1997)	21.4 million ha

Source: Gleick (2000) and World Bank (2001).

Very large areas of alluvial lands are suitable for irrigation development. Of an estimated 55 million hectares of alluvium in eastern Bolivia, Paraguay, and northern Argentina, about one fourth is arid and the rest semi-arid. The Araguaia-Tocantins River Basin in Brazil contains about 25 million hectares of alluvium.

A review of the areas in the classifications of climate indicate that about one third of the land area with suitable temperatures for agriculture is in each of three groups. These are moderately wet and very wet, arid and very arid, and the three intermediate classes.

The requirement of 2,000 km<sup>3</sup> of new water is only nine times the annual flow of the Yukon River, 10 times that of the Colombia, and 4.5 times the flow of the Mississippi. Alluvial lands and water are abundant. The potential for development is enormous providing transbasin diversions can be developed to take water for the arid and very arid lands from the areas of the other classes of climate. A world atlas showing the seven classes of climate would be a global planning tool that would facilitate the identification and evaluation of possible transbasin diversions.

### SOME EXISTING AND POTENTIAL TRANSFERS

Geraghty et al. (1973) shows existing and under construction water transfers in the United States of 8.77 km<sup>3</sup> per year. The interregional proposed transfers (including NAWAPA) are given as 218 km<sup>3</sup> per year. The North American Water and Power Alliance (NAWAPA) includes water for power and navigation. The portion proposed for irrigation in Canada, the U.S., and Mexico is 96 km<sup>3</sup> per year (Reisner, 1986). This proposal would divert water from some very wet areas to some very arid lands.

In China, the proposed South-North Diversion Project would take water from the Han and Jaling rivers to the Yellow River Basin - a transfer from a wet-dry climate to arid and semi-arid lands. If water from the somewhat wet area of Turkey can be diverted to the arid and very arid lands to the south and from the somewhat wet area along the Congo River north to arid and very arid lands served by the White Nile, these transfers might produce large benefits to the stability of these areas.

In Bolivia, Paraguay, and Argentina there is a large extension of arid lands. Large dams on three large rivers could produce much needed power and irrigate extensive areas of arid alluvial lands. A brief reconnaissance appraisal of this transbasin diversion project is presented to illustrate some of the procedures proposed in this paper.

The Sula Basin in Honduras is a large resource with 189,000 ha of alluvium. The arable land is given as 123,000 ha. About 20,000 ha are irrigated. Development is limited by severe flood and drainage problems. These problems can be largely resolved by the construction of large dams and the transfer of flood waters from one river basin to another by means of skimming weirs.

### POSSIBLE TRANSBASIN DIVERSIONS IN BOLIVIA

Bolivia has an area of 1,099,000 km<sup>2</sup>. Gleick (2000) gives an annual renewable water supply of 300 km<sup>3</sup> or a runoff of 273 mm based on 1987 data. MAI-based classification for Bolivia was made and the area calculated in each class. The United States average runoff for the classes given in Table 1 indicates a value of 213 mm. This indicates that for the same class the Bolivian runoff is 1.28 times that of the United States.

The average depth of runoff from the Rio Grande upper basin for a 19 year record is 136 mm. A calculation from Table 1 times 1.28 indicates 145 mm. A similar calculation for the Pilcomayo river indicates 91 mm. A three-year record averages 108 mm. A similar calculation for the Rio Beni is 239 mm. The runoff data supplied by the Servicio Nacional de Meteorología e Hidrología (SENAMHI) indicates much higher values for runoff. There remains significant uncertainty, but it is evident that the potential benefits from development could be very large. A summary of the climate classification, from the World Water and Climate Atlas, is given in Table 4. The corresponding zoning can be seen in Figure 3. Additional evaluation of the use of Table 1 and equation 2 is strongly recommended.

Studies sponsored by FAO, Rocha (1997), indicate about 500,000 Ha of lands of high agricultural potential located near Santa Cruz and 15 million Ha of moderate agricultural potential in the eastern plains of Bolivia. About 10 million Ha are shown as potential flood areas. With flood control and drainage the agricultural

potential could be greatly expanded.

Table 4. Percent of climate classification in each basin and surface runoff in mm per year computed from Table 1 and Figure 3.

Climate	Beni	Grande	Pilcomayo
Very arid			33.2
Arid		7.8	21.7
Semi-arid	32.6	92.1	39.8
Wet-dry	55.6	0.1	5.3
Somewhat wet	10.1		
Moderately wet	1.7		
Runoff, mm	187	113	71
Runoff x 1.28	239	145	91

The validity of Eq. 4 should be verified for large watersheds since the corresponding volume of water that can be stored in the reservoir indicated in the Beni River, for a given water surface elevation and using de DEM model, is much larger than the volume obtained by Eq. 4. This can be accomplished by use of the 1:50000 topographic maps and improved digital elevation models with much higher resolution, in the order of the 30 x 30 m cell size. Additional measurements and investigations are needed relative to the extensive flooding and to the different hydrologic variables for the Beni River.

A mission from China investigated the possibility of a large dam "El Bala" on the Beni River, estimated to have a hydro production of 3,000 MW (megawatts). This is more than nine times the present installed hydropower in Bolivia. The flood control and potential agricultural benefits from water storage would also be very large.

Sites for large dams on the Rio Beni, Rio Grande, and Rio Pilcomayo appear favorable. Data on streamflow are available for the Rio Grande for a period of 19 years. The area above the proposed dam site is 55,000 km<sup>2</sup>. The mean depth of runoff is 136 mm. The climate is semi-arid. The maximum monthly mean flow of 37.9 mm of depth is in February. The estimated 20 year return period flow for February is estimated to be 98 mm of depth. The average annual streamflow is 748 thousand hectare meters (HM).

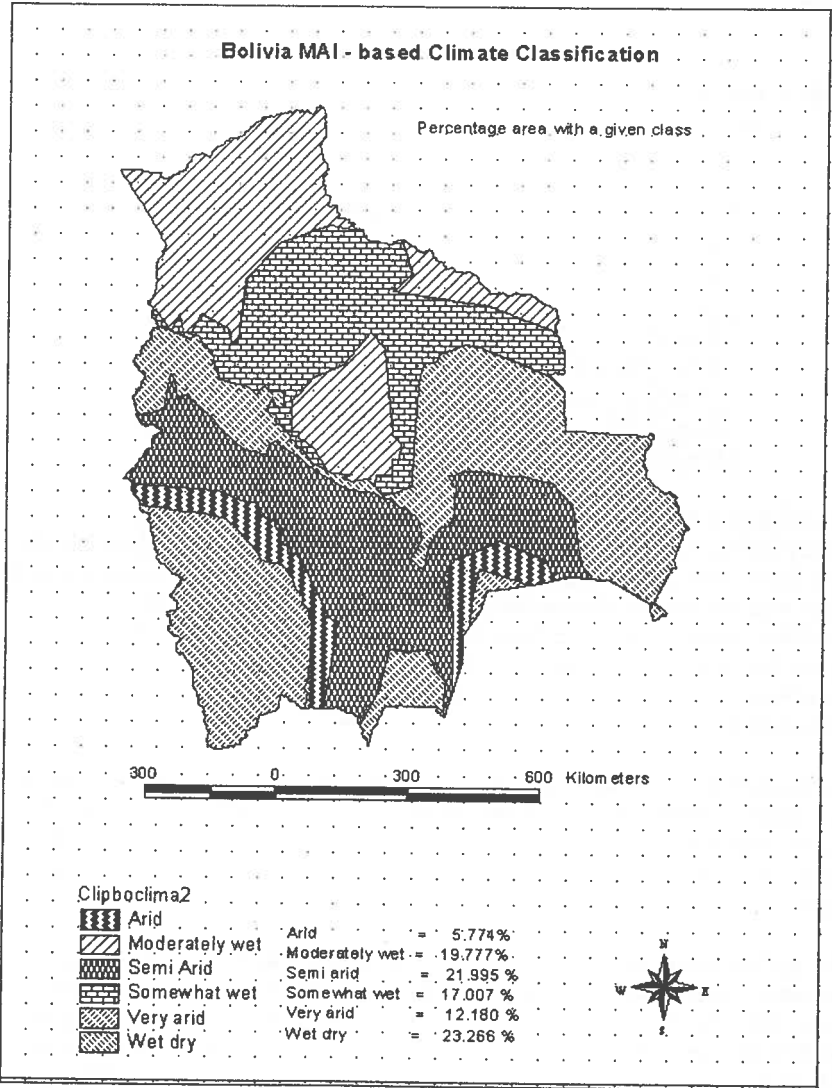


Figure 3. MAI-based Climate classification for Bolivia.

The watershed of the Rio Beni is predominately wet-dry with an estimated depth of annual runoff of at least 239 mm. The actual runoff may be significantly more. The watershed area from a 1:2,500,000 topographic map is 66,900 km<sup>2</sup> indicating a large annual runoff. The corresponding watershed area by means of GIS tools is 67,791 km<sup>2</sup>. The corresponding River Basin is shown in Figure 4.



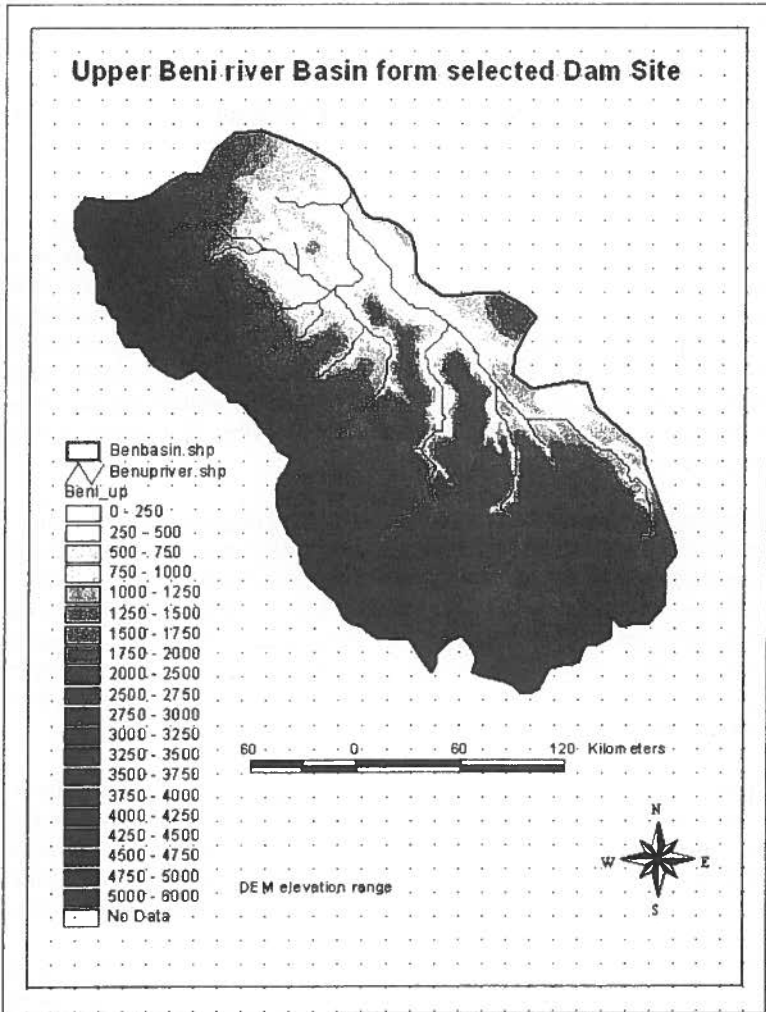


Figure 4. Upstream Beni river watershed area from proposed Dam Site. Using a 30-arc sec DEM (Cell size 1000 m) from USGS.

The Pilcomayo watershed is about 50,600 km<sup>2</sup> (75,103 km<sup>2</sup> from DEM). The estimated runoff depth is 100 mm indicating an annual runoff of 506 thousand HM.

Several upstream sites and a site on the Rio Parapeti should also be investigated. Principal benefits from the various dams would be for power production.

However, the benefit from flood control and irrigation would be very large. The flow from the four rivers should be connected to a canal system with main canals at elevations of approximately 500 and 300 m. Immediate improvement in the collection and evaluation of the required additional information seems desirable. Pre-feasibility of feasibility studies are strongly recommended.

### SUMMARY AND CONCLUSION

Hunger, poverty, and malnutrition are increasing in the world. Increases in food production must come principally from irrigated lands. However, the role of agriculture in the world economy is decreasing. Irrigated area is declining in Japan and the United Kingdom and in some of the poorest countries including Bolivia. Some of the developed countries have attempted to promote water resource development in the developing nations by inventorying resources, financing development planning, and providing credit. The results have been disappointing.

Procedures are presented for estimating irrigation requirements, the water supply, flood risks, extent of irrigable lands, and evaluating potential water storage sites using traditional and GIS methods. Global land and water resources are enormous. However, it will be difficult for agricultural development to meet future needs for food and employment. This is mainly a political and policy problem. There is a need to promote user participation, privatization, and improved institutions. A goal of 2,000 km<sup>3</sup> of new water supplies by 2050 has been proposed.

The increasing poverty resulting from the per capita agricultural decline is increasing slash and burn agriculture and insecurity. There are some negative environmental impacts from building large dams but these may be minor when compared to the negative social and environmental impacts resulting from hunger, poverty, unemployment, climate change, and resource degradation.

It is proposed that a climate classification atlas, a streamflow point coverage (ArcInfo), an agricultural potential polygon coverage, and a high resolution DEM be prepared for the World, in order to facilitate reconnaissance identification and evaluation of possible transbasin diversions. This should be considered as only one of the required activities. Policy and institutional reforms have produced many positive results and are needed to promote good investigation, planning, and the making available of adequate financial resources.

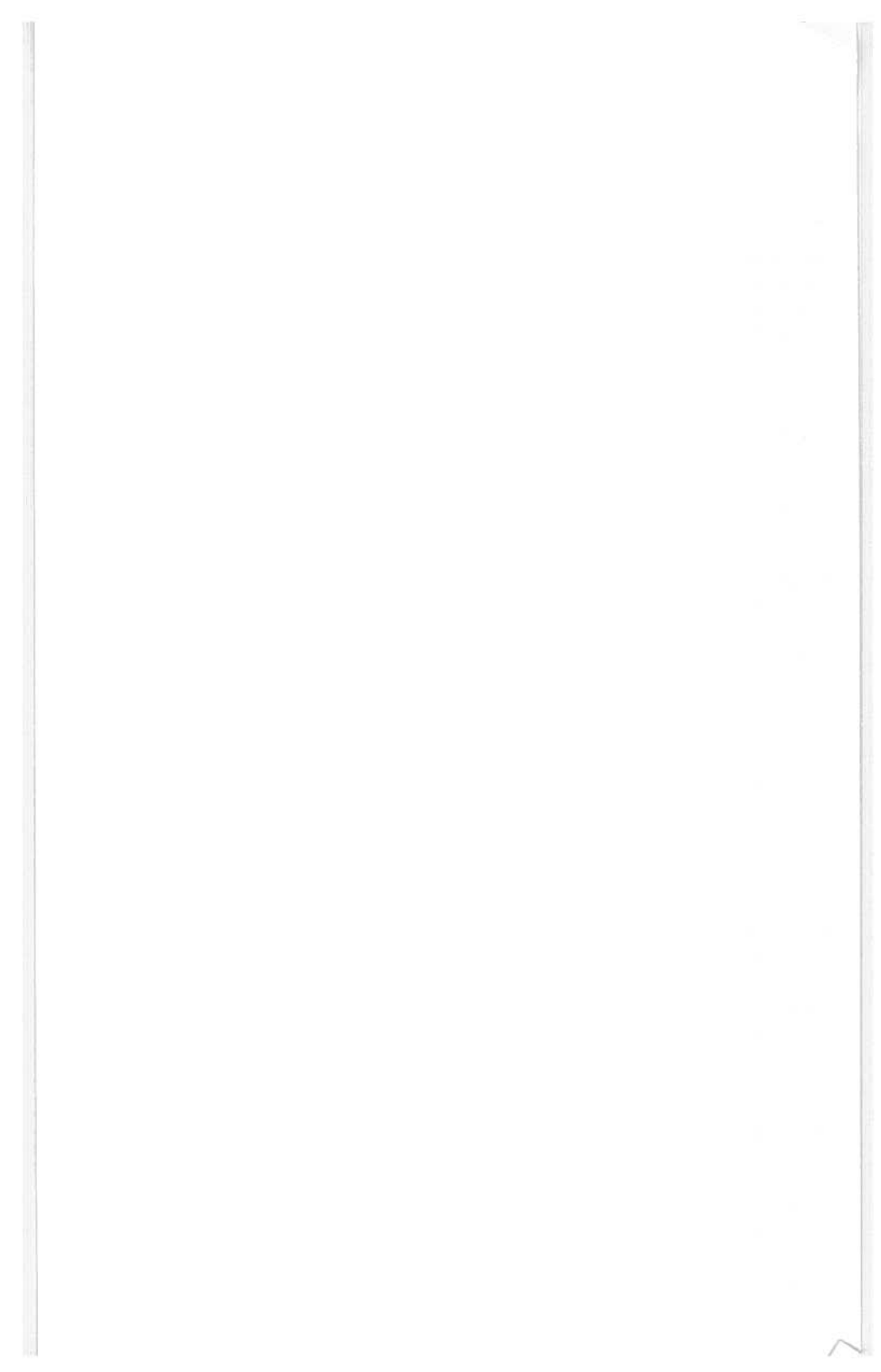
Further testing and evaluation of the equations and methods presented in this paper is strongly recommended.

## ACKNOWLEDGMENT

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## USING WATER TRANSFERS TO PROVIDE SAFE DRINKING WATER IN THE ARAL REGION – UZBEKIZTAN

Malika R. Ikramova<sup>1</sup>

### ABSTRACT

At present, the water economic situation in the Amudarya basin is complex. 3.6 million hectares are irrigated, 62.5 m<sup>3</sup> water is taken away from the river during high water level years. Transporting ability of water flow has been significantly reduced, and the alluvial mode of the river has changed with the increase in water intakes and because of cascade regulation of floods by reservoirs. The total number of the water intakes in the basin are 88 items, including 10 on the Vahsh river, 3 on the Pyandj river and 75 on the Amudarya river. Average monthly water intake rates have changed from 500 to 4000 m<sup>3</sup> per second. During 10 years the volume of water intake increased to 52 km<sup>3</sup>: in the upper stream - 1.5 km<sup>3</sup>; in the average stream - 28 km<sup>3</sup>; in the lower stream - 25 km<sup>3</sup>.

Inflow of drain water in the river reaches 10 km<sup>3</sup> per year. These waters are collected from fields, bringing to the river an additional 25 million tons of salts annually. Drainage water inflow to Amudarya is produced by 125 collectors. Average monthly rates of collectors are: upper - 20-125 m<sup>3</sup> per second, average stream - 15-175 m<sup>3</sup> per second, and lower - to 30 m<sup>3</sup> per second. This drainage water causes an increase in river water mineralization and pollution.

Due to the situation in the Amudarya basin, the Government of the Republic Uzbekistan started a long-term program known as "Pure water" in the region of the lower Amudarya river, intended to solve the drinking water quality problem.

To this end, researchers of SANIRI designed a technical project to use the Kaparas Reservoir for water supply to the population of Aral Region. Full capacity of the Reservoir is 960 million cu.m, and useful capacity is 680 million cu.m. Drinking water users from the Kaparas Reservoir are the populations of the Khorezm area (250 million cu.m per annum), Karakalpakstan (190 million cu.m per annum) and the Tashaus area of Turkmenistan (100 million cu.m per annum).

Researchers offered to build a special hydrotechnical facility complex on Kaparas, which would allow it to fill to capacity during flood periods with less mineralized water and transport it through the purifying system to pipelines Tuyamuyun-Urgench, Tuyamuyun- Nukus and Tuyamuyun-Tashaus.

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The quality of water in Kaparas would be ensured, because the reservoir would be filled when water in the river is clean, satisfying the State Quality Standard. Mathematical models have been designed and forecast calculations developed, to define the terms and volumes of filling and discharge from reservoir.

At present the first part of Tuyamuyun-Urgench pipeline, with a capacity of 75 million  $m^3$  per annum, is ready to accommodate the Kaparas water. The population in the lower region gets water directly from the Amudarya River in the amount of over 200 million  $m^3$ , i.e. drinking water to 30% only is ensured by Kaparas. However, the construction of additional pipeline sections and unfinished hydrotechnical facilities would require considerable materials and technical costs, making a decision to proceed highly difficult now.

As far as present situation is concerned, existing water intakes from the river and purifying facilities are being reconstructed. A "program for improving the Aral Region Population with high quality drinking water and improving the living conditions" has been developed (Resolution of Cabinet of Ministers of the Republic of Uzbekistan on implementing the project "Pure water, sanitation and population health ", 15.10.1998.).

The following actions are planned:

- development of water supply in towns and rural areas, decrease in leakage and water losses in the system; control of demand for water supply;
- strengthening of operational water supply organizations in the Karakalpakstan and Khoresm area.

These measures are planned for the long-term period to 2015.

Implementation of these actions would require funding in the amount of 300 million US dollars. It would allow the construction of over 2500 km of pipe lines in towns and rural areas of Aral region, to serve 400,000 people.

Results of studies on the given subject will create reliable a database for the present water economic situation in this region and develop an operating regime for the Kaparas Reservoir, taking into account water supply for drinking and irrigation.

## INTRODUCTION

Technical decisions for using the Kaparas water reservoir of the Tuyamuyun hydrosistem were developed to supply the population of Aral region with high-quality drinking water, based on studies of the modern water resource situation in the lower part of the Amudarya River. Full volume Kaparas Reservoir forms 960 million  $m^3$  on the normal watermark (NWM=130m), but useful - 680 million  $m^3$ ,

when the watermark is 116m. Construction of a special complex of hydraulic works on Kaparas was proposed, allowing it to fill to capacity in flood periods with fresh water and then transport it through treatment works by the pipelines Tuyamuyun-Urgench, Tuyamuyun-Nukus and Tuyamuyun-Tashauz. The quality of water in Kaparas is ensured due to filling it in the summer period, when the water in the river has the least mineralization and the majority of the standards satisfy the requirements the all-Union State Standard. Mathematical models were designed and forecast calculations were executed, to define terms, volume capacity and spillover from the reservoir.

The drinking water users from Kaparas reservoir are Khoesm region, Karakalpakstan, Tashaus area of Turkmenistan. Scheduled amounts of water intake for drinking water supply are provided in Table 1.

Table 1  
Volume of the water intakes from Kaparas  
reservoir for drinking water supply

million m<sup>3</sup> per year

Region	1990-1995	1995-2000	2000-2005
Khorezm	73	250	250
Karakalpakstan	120	190	190
Tashauz	-	40	100
Total	193	410	540
% of using of the useful capacity of Kaparas	28	60	79

At present, one of three pipelines – only the first turn of the pipeline Tuyamuyun-Urgench with a capacity of 73 million m<sup>3</sup> per annum is ready to accept Kaparas water. Since construction of the transition through the river has not begin, the pipeline Tuyamuyun-Nukus is not connected with Kaparas. Moreover, the water treatment facilities have not all been built.

The population in the lower regions gets water from both from the Kaparas and Amudarya Rivers, totalling over 200.0 million m<sup>3</sup>, i.e. the Kapara provides approximately 30% of the drinking water requirements for the lower population. However, termination of the construction of additional pipeline turns and unfinished hydrotechnical facilities (pumping station, treating facility, water conveyance structure of the pipeline Tuyamuyun-Nukus, etc.) are associated with great material and technical expenses, making it a very difficult proposition at present. Though some actions have been undertaken, ensuring a supply of drinking water for the population is a distant prospect.

### Hydrological, Hydrochemical and Alluvial Conditions in the Lower Section of the Amudarya River

It is known that the natural flow of the Amudarya-river in the lower, which has been observed for 60 years, is at present significantly changed due to the growing number of offtakes from the river and putting into operation the cascade of facilities in the upstream and midstream part of the river.

Systematic observations over the run-off cycle in the lower stream are taken at the river stations Darganata, Tuyamuyn, Beruny, Kipchak, Samanbay. Data of hydrological yearbooks, irrigation systems, SANIIRI expeditions, etc. was used for the analysis of water flow and mineralization.

Results of perennial observations (1961-2000) of the changes in river flow in the lower Amudarya show that the average annual discharge rate in the region at hydropost Darganata varied between 580 m<sup>3</sup>/sec to over 2000 m<sup>3</sup>/sec, under average annual water flow 37,0 km<sup>3</sup>/year. Observations have shown that in the Tuyamuyn region average annual discharge rates varied from 531 m<sup>3</sup>/sec - 1640 m<sup>3</sup>/sec. At the same time, average monthly maximum discharge rates were 1417 m<sup>3</sup>/sec - 3970 m<sup>3</sup>/sec, and minimum values varied within 22 - 490 m<sup>3</sup>/sec. Accordingly, annual volume of flow grew from 16,7 m<sup>3</sup>/sec to 54,1 m<sup>3</sup>/sec at the average annual value in this period 30,07 km<sup>3</sup>/year.

The flow at the river station Kipchak varies between 9,02 km<sup>3</sup> and 52,2 km<sup>3</sup>. Maximum discharge rates were within 750-2530 m<sup>3</sup>/sec, and minimum - 55-220 m<sup>3</sup>/sec.

The flow at the river station Samanbay varies between 0.34 km<sup>3</sup> and 24.2 km<sup>3</sup>. But in some months of low water years the discharge not was observed at all (1981, 1985, 1986, 2000). Maximum and minimum discharges were accordingly within 50-1700 m<sup>3</sup>/sec and 0,3-16 m<sup>3</sup>/sec.

Maximum annual volume of inflow to the delta Amudarya for a period 1981-1997 was in 1988 - 16.0 km<sup>3</sup>. Inflow to Aral sea was realized only at full water years in the volume 3-5 km<sup>3</sup>, but in low water years it is absent.

Analysis of the average annual discharge rates for the period 1961-97 in the lower Amudarya shows its regular reduction. Moreover, a significant reduction of the discharge rate occurred in the period 1961-80. Since 1980 a reduction rate of flow was reduced approximately 10 times that allows to divide this process into two periods:

- Darganata, accordingly, 1,05 km<sup>3</sup> per year and 0,16 km<sup>3</sup> per year;
- Tuyamuyn – 0,75 km<sup>3</sup> per year and 0,22 km<sup>3</sup> per year;
- Kipchak - 1,3 km<sup>3</sup> per year and 0,38 km<sup>3</sup> per year;



- Samanbay - 1,35 km<sup>3</sup> per year and 0,25 km<sup>3</sup> per year;

After putting into operation the Tuyamuyun hydrosystem, clarified water started to arrive to the lower, and the intensive sedimentation process began in the channel basin. At the end 2000 total volume of the reservoir sedimentation was 1100 km<sup>3</sup>. Flow turbidity is reduced to 0.03-0.20 kg/m<sup>3</sup> (ten times more). When water level of the in-channel reservoir falls below the mark of 118 m, a flow with the alluviums up to 1.2-1.3 k/m<sup>3</sup> enters to the lowers. Average annual value of water turbidity below dam was 0.11-0.20 k/m<sup>3</sup>, but at vegetation period varies within 0.40-0.55 k/m<sup>3</sup>, which is 7,5 times less than normal. Volume of suspended alluviums forms about 4 -10 million t.

At Kipchak river station the flow has a turbidity of 0.03-2.30 kg/m<sup>3</sup>. Water turbidity has maximum values in the summer period. Average annual turbidity is 0.3-0.8 k/m<sup>3</sup>. Value of the suspended alluviums forms 4-25 million t.

At Samanbay river station turbidity does not exceed 0.05-1.00 kg/m<sup>3</sup> under normal average annual values - 0.1-0.3 kg/m<sup>3</sup>. Value of the suspended alluviums is 0.03-4.10 million t.

Data show a gradual increase in the turbidity rates, which began in 1980. At the Tuyamuyun river station average annual turbidity increased by 5 g/m<sup>3</sup> approximately, in Kipchak - by 0.15 g/m<sup>3</sup>.

### **The Water Intake Cycle And Collector Drainage Discharges in the Amudarya River**

At present 3.6 million ha are irrigated in the Amudarya basin and water intake from the river consists of 62.5 km<sup>3</sup> during high water years. The drainage water inflow in to the river reaches 10 km<sup>3</sup> a year. This water brings up to 25 million t of salts to the river annually. With the increase in water intakes and cascade regulation of flow by reservoirs, transportation ability of flow is vastly reduced and alluvial conditions of the river significantly changed.

The water intakes in the basin consists of 88 items, including on Vahsh river- 10, Pyange river - 3, Amudarya river - 75. Monthly discharges of water intakes varied between 500 and 4000 m<sup>3</sup>/sec. Total value of the water intake varied within 40 ... 52 km<sup>3</sup>, including at the upper stream 1.0...1.5 km<sup>3</sup>, at the mid river – up to 28 km<sup>3</sup>, at the lower to 25 km<sup>3</sup>.

Drainage water is drained from fields and is put back into the river. It is a main source of increase in river water mineralization and water pollution. The drainage water is produced by 125 collectors. Average monthly discharge rates of the collectors are varied: at upper stream within 20...125 m<sup>3</sup>/sec which consist

annually  $0.25 \dots 0.5 \text{ km}^3$ ; at the mid river it varied within  $15 \dots 175 \text{ m}^3/\text{sec}$  and up to  $4.0 \text{ km}^3$ ; at the lower up to  $30 \text{ m}^3/\text{sec}$  and  $1.0 \text{ km}^3$ .

### Mineralization Dynamics of River Water, Kaparas and Bed Reservoirs

The water mineralization study on the Amudarya stream has shown that the river flow has a mineralization level of  $0.41 \dots 0.85 \text{ g/l}$  in the upper stream (Termez city). At the border of mid and lower stream –Tuyamuyun- mineralization riches up to  $0.53 \dots 1.65 \text{ g/l}$ , and at the lower flow –Samanbay- it increases to  $0.68 \dots 2.06 \text{ g/l}$ . Minimum mineralization is observed in the June-September. Average annual water mineralization increases 2 times at lower part, but in shortage water seasons it increases 3-4 times due to the drainage water.

Measurements of the water mineralization in the Tuyamuyun region are taken at hydroposts: Darganata - 90 km and 0,2 km above the dam, and 0.5 below. Observational data show that in autumn-winter period the mineralization water in Amudarya river before falling into the bed reservoir varies within  $0.8 \dots 1.2 \text{ g/l}$ . Herewith, the water discharge rates varied between  $550 \dots 1000 \text{ m}^3/\text{sec}$ . Water mineralization increases from January, and continues until the second half of March up to  $1.9 \text{ g/l}$ . Water discharge varies from 420 to  $650 \text{ m}^3/\text{sec}$  in this period. From the middle of March mineralization gradually falls and by the end of August it is at  $0.6 \text{ g/l}$  and at the same time the water discharge is increasing and an inverse dependency between values of the mineralization and water discharge in the river is observed. In September the water discharge begins to decrease, however mineralization goes up to  $1 \text{ g/l}$  by October.

However, another situation arises around the dam. The mineralization is about  $1.0 \text{ g/l}$  from second decade of October until the last third of February with little change in the water flow level. From March the water discharge from bed reservoir begins into the river with mineralization up to  $1.9 \text{ g/l}$ . This promotes an increase in mineralization in this region up to  $1.6 \text{ g/l}$  by the end of March. From April water with the smaller mineralization enters. Water mineralization varies in May-October period between  $0.5 \dots 1.1 \text{ g/l}$ . Minimum mineralization is observing in July -  $0.6 \text{ g/l}$ .

Water mineralization dynamics in the upper depends on the operating regime of the bed reservoir, i. e. on runoff into the lower and volume of the inflow.

In the lower stream water mineralization dynamics depends on the influx of river water from Sultansandjar and bed reservoirs through clarified channel. Mineralization is fluctuating from  $0.8$  to  $1.2 \text{ g/l}$  in October-February period, in March – April period it is  $1.6 \text{ g/l}$ , from May till October it is  $0.5$ - $1.2 \text{ g/l}$ . Changing dynamics of the mineralization in the lower stream has great importance not only for irrigation, but also for water supply. At present, the water intake realises with the treatment facilities.

Water mineralization of the Kaparas reservoir is fluctuating within 0.7...1.5 g/l at average 1.1 g/l a year. There are observed the stratification of the mineralization along depth of the reservoir with difference 0.2...0.4 g/l between surface and ground films. Maximum mineralization is revealed in the dam area at a distance 15 km from the entrance of Kaparas.

### **Variant Calculations of the Tuyamuyun Hydrosystem Operating Regime**

The development model is based on outlining of the river net structure, which includes a stem, its main influxes, discharges, as well as beds and intersystem reservoirs. Dependencies were used in the models, allowing the calculation of parameters of the flow and features of the riverbed, the water loss due to evaporation and filtration, as well as amounts of bed regulation.

Water balance is the main basis for evaluation of saline and alluvial regimes of the reservoirs. To this effect results of natural studies were used, for the lower part of the Amudarya river - Tuyamuyun hydrosistem- in 1997- smallwater, 1998 - fullwater and 1999 – midwater years. They cover an area Darganata - Tuyamuyun. According to calculations and graphs, an influx of water to Tuyamuyun will change in significant limits: at low water years 20...25 km<sup>3</sup>, and in fullwater - 45...65 km<sup>3</sup>. In the midwater year an influx will form 30...35 km<sup>3</sup>, that 4...5 km<sup>3</sup> more of lower region requirements for provision that forms 25...27 km<sup>3</sup>.

For the first stage of calculation were elaborate water loss for the evaporation from the river and reservoirs. Herewith it was taken into account an increase in losses in low water years due to transparency by water vegetation.

For the second stage amounts of the water regulation with take into account reducing of the useful capacity of the bed reservoir due to sedimentation was defined for a working period from 1981 till 2000 and on this basis the discrepancy of flow with filtration losses was defined.

For the third stage it was defined hydraulic relationships reservoirs with underground horizons and was determined amounts of the filtration flows. On the fourth stage water balance was defined for the area Darganata - Tuyamuyun and actual discrepancy of the flow was determined.

### **Calculations of the Water Saline Balance**

Analysis of the results of water balance calculations revealed the following:

- Average values of water loss for the evaporation from the river part Darganata and bed reservoir for the last five years varied from 22 ... 142 million m<sup>3</sup>; in

1997 - 16 ... 138 million m<sup>3</sup>, 1998 - 34 ... 198 million m<sup>3</sup>, in 1999 - 22 ... 170 million m<sup>3</sup>.

- Filtration flows at low water years were directed towards the reservoir and at full water years flow moved opposite from the reservoir and at their intensive filling it had significant values of about 22 ... 249 million m<sup>3</sup>.
- Results of the water-saline calculations were used as a basis for performing water saline balances. At hydropost Darganata average annual amounts of salts for last five years formed 20,36 million t, and average monthly value of the salts for a considered period varied from 1,437 million t up to 2,120 million.t. In to the lower of Tuyamuyun hydrosistem including left-bank main channel has enter 21,629 million. tons salts.
- Average annual mineralization varied within 0.61...1.22 g/l.

The river water, of which anappreciable share forms collector-drainage water, flowed in to the river from the areas located above. 3.5... 4.5 km<sup>3</sup> collector-drainage water enters from the regions of the midstream. According to calculations, range of changing its monthly values is:

- at fullwater years - 0.6 ... 1.8 g/l at average annual 0.95 g/l;
- at midwater years - 0.7 ... 2.0 g/l at average annual 1.1 g/l;
- at small-water years - 0.85 ... 2.2 g/l at average annual 1.5 g/l.

### **Calculations of Alluvial Regime**

Results of the water balance calculations were used as the basis for performing the calculations of alluvial regime of the bed reservoir. The main aim was to establish the monthly sedimentation intensity. Requirements for such calculations stipulated that natural measurements of the bed capacity depths were executed by the expedition SANIIRI once per annum. So installation of the sedimentation by natural data gives a picture only about annual values and does not illuminate an internal sedimentation dynamics in the considered capacities during the year. In order to solve this problem, a calculation method designed by SANIIRI was used. Its essence is the complex development of the mathematical models that described the sedimentation process in the bed capacity depending on the river discharge in the upper and lower stream, as well as water levels at the dam. Formula gathered by natural observation of the water cleaning factor in bed reservoir was used, which depends on the water level in this capacity, fixed at the dam. Total volume of suspended and ground alluviums at hydropost Darganata for 1997 has form 81,5 million. tons, of which 95% forms at full water period - 76,9 million tons; in 1998 volume of alluviums has formed 129,7 million tons and at full water period - 122.0 9 million tons.

Alluvial features on the approach to Tuyamuyun hydrosystem varies from:

- at low water years 30...40 million t,
- at mid ater years 70...90 million t
- at full water years up to 150...170 million t.

Sedimentation for 1981 - 2001 has form 1100 million m<sup>3</sup>. As a whole, sedimentation dynamics of bed capacity significantly exceeded planned volume for the working period of the hydrosystem.

The most sedimentation intensity of the bed capacity, according to calculations, is observed in the July...August period, when the water horizon at the dam above 125m. The least intensity is observed in February - March.

### Practical Recommendations

The issue of water quality for the lower Amudarya river delta is a big state problem, complex resolutions. A difficult situation has been created. It is not possible to resolve all the problems by using only the Kaparas Reservoir. It is necessary to incur greater expenses to provide high quality drinking water. Water systems Tuyamuyun-Urgench and Tuyamuyun-Nukus have been executed hastily and their construction is not finished.

Study of the demographic conditions in lower till 2010 shows that the use of Kaparas water does not completely solve a supply problem with drinking water in the lower region of Amudarya river. Moreover, there is no guarantee of filling Kaparas with less mineraled water. The shoals are created at a reduction of the water level in Kaparas. It is observed moving active stratum up to 10-12 m, in which salts will be dissolved, that will influence upon water mineralization. To resolve the water quality problems is necessary to avoid an influx into the river of the collector drainage water and take away Karshi flows from the Amudarya river. The problems of the water quality in Kaparas reservoir are complicated for low water years.

The operating regime of the Tuyamuyun hydrosystem depends basically on hydrological, hydrochemical and alluvial regimes of the river and on a first filling of the reservoirs and on water requirements of the lower region, both for irrigation and for water-supplying. So terms of the runoff and filling of Kaparas and bed reservoirs is changed:

- **at fullwater and midwater years**, when excess of flow exceeds a total useful volume of the reservoirs, the optimum regime for both variants will be, during the first half of year, to increase discharge rates May-June. By the first flood period of June-August, reservoirs are filling. Hereinafter water levels are supported at near NWM till the end of year.

Sequence of the runoff and filling regimes must be such: at first Bed reservoir, then Kaparas, and afterwards Sultansandjar and Koshbulak.

Under such regime it is ensured full satisfaction of the water requirements of the lower region and maximum filling possibility of all reservoirs. Aside from that, floods are regulated, filling of the reservoirs with the least mineralization river water is realized. Also, a reduction of sedimentation intensity of the bed reservoir is reached with the spring discharges of this capacity.

The water regulator constructions influences for following factors: satisfactory quality of drinking water is ensured during the year; water mineralization decreases 1.4...1.6 times in Kaparas; sedimentation volume is less by 1.0...1.5 million m<sup>3</sup> per annum; water turbidity in lower part is more 0.05 kg/m<sup>3</sup>.

- **At low water years**, according to calculations, Tuyamuyun hydrosystem under not full reservoirs must be used so that run-off is at a minimum, and filling is maximum any time when water is plentiful. Under the independent regulation of Kaparas, the water mineralization becomes less by 0.5 g/l. Year round satisfactory quality of drinking water is ensured. The water deficit in lower region decreases by 80 million m<sup>3</sup>, as well as more then semi-annual water reserve 180 million m flood is available for drinking water supply.

The transfer of Kaparas to the independent regulation is an action, which must complement other actions to prevent a worsening water supply situation in the lower region. The realization of further actions requires significant capital and operating costs.

One possible technical decision, which requires detailed study, is the work on reconstruction existing channel water intakes only from the river and treatment facilities within the framework of the improvement program for supply of the Aral region population with good quality drinking water and raising its living standards.

# MISSOURI WATERSHED INFORMATION NETWORK – WATERSHED STEWARDSHIP IS OUR RESPONSIBILITY

Tabitha Madzura<sup>1</sup>

## ABSTRACT

There are approximately 174 water bodies listed on the 303 (d) list for Missouri, diverse water quality impairments: pesticides in drinking waters, wastewater treatment plant problems, channelized streams and nutrient enriched water bodies (Clifford, 2000) that need immediate attention to restore them to their approved uses. There is a critical need to better coordinate and target programs and activities where water quality is impaired by nonpoint sources of pollution. Easier access to existing related information and data is a major key. The Missouri Watershed Information Network (MoWIN) is well positioned to collect, compile and disseminate natural resources conservation information. Anticipated impacts include: a) More Missourians taking action to protect, conserve and enhance shared natural resources, b) Greater acceptance of the watershed stewardship concept of natural resources conservation, c) Healthy watersheds with sustainable soil, water, plant, animal and air resources as indicated by improved water quality, and d) Impaired waters removed from the 303 (d) list. MoWIN a University of Missouri Outreach & Extension water quality project, collaborates with state and federal agencies and non-governmental organizations to help landowners and natural resource interest groups find the information they need for improved natural resources conservation.

## INTRODUCTION

“Clear, accurate, and timely information is the foundation of a sound and accountable water quality program. Informed citizens and officials make better decisions about their watersheds.” (Clean Water Action Plan, 1998). Good watershed information and stewardship provide:

- socioeconomic values related to future reduction in restoration costs,
- sustainable natural resources for future generations,
- increase citizens’ knowledge and awareness of watershed conditions, and
- promote diffusion of nonpoint source pollution resulting in economically healthy watersheds.

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MoWIN a University of Missouri Outreach and Extension project, in partnership with state and federal agencies and non-governmental organizations, locates, accesses and compiles information about Missouri watersheds, and presents it to citizens via the Internet, telephone, e-mail, mail, fax, conferences, workshops and personal visits. Our aim is to increase awareness of landowners and interested citizens about the state of their watersheds, impact their actions or non-actions on shared natural resources, and help them find the information they need to make informed decisions regarding natural resources stewardship.

Natural resource stewardship is not an isolated issue, neither is it a government only responsibility. Rather, it is an important "component of complex human-environment system interactions that may together bring the world to the edge of catastrophe or create improvements in welfare and equity for all people." (Niemczynowicz, 2000), and it's everyone's responsibility.

### Objectives

Specific objectives of the Missouri Watershed Information Network project included:

- develop and maintain a fully-functional, easily-searchable web site for agricultural and natural resources information and data,
- compile an electronic natural resources conservation directory for Missouri which lists all the entities that are involved in watershed stewardship,
- compile a comprehensive bibliography of existing electronically available publications and guide sheets pertaining to the management and use of Missouri's watersheds.

### About The Missouri Watershed Information Network

MoWIN was developed to assist citizens in locating and accessing information relative to Missouri watersheds (Fig. 1), with a goal of increasing knowledge about watershed conditions and best management practices. MoWIN, a partnership of 29 state and federal agencies, non-governmental organizations and natural resource interest groups, realizes that effective management of water resources requires reliable information. It is also important to communicate this information to the public for their use in watershed maintenance and/or restoration. Furthermore, information technology has created opportunities to provide people with significantly improved information about the quality of their watersheds. Therefore, collaborating with governmental agencies and citizen



groups, we have the opportunity to empower citizens and foster a dramatic increase in public awareness regarding the state's environmental management.

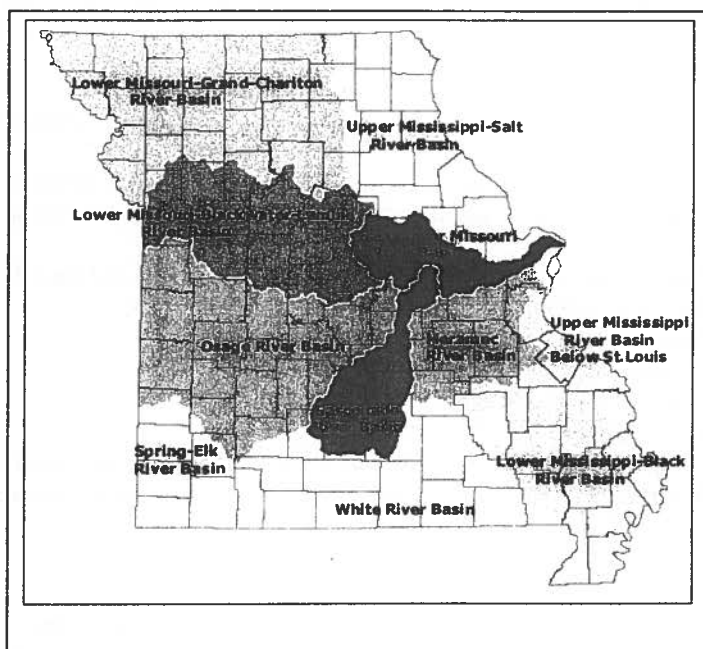


Figure 1. Missouri 8-Digit Hydrologic Units

Note: Image adapted from Center for Agricultural Resources and Environmental Systems (University of Missouri-Columbia).

<http://www.cares.missouri.edu/cwic/mowater.html>

Watersheds need to be managed with an indefinite future outlook: MoWIN activities are guided by these principles: Citizens will always have the need for safe, clean, fresh drinking water, everyone lives in a watershed, people will do the right thing given the right information, more information is available than has been used to improve water quality, and the health of our watersheds is everyone's responsibility. To achieve these principles, MoWIN has become a first point-of-contact for watershed information for Missourians offering a service that is not located elsewhere in the state. We are rapidly reaching the point where more data is becoming electronically available, and MoWIN's challenge is searching through data and getting it in readily useable form for citizens use to promote healthy watersheds.

### MoWIN Features and Activities

To date, MoWIN has developed a website (<http://outreach.missouri.edu/mowin/>) with projects to gather, compile and distribute watershed information. It has become a center for gathering and makes accessing watershed information very easy for Missourians. Current features include:

- MoWIN Features - the web site tutorial;
- Acronym City - an alphabetical list of often-used acronyms related to watershed stewardship;
- Missouri Agricultural and Natural Resources Conservation Directory - access to agricultural and natural resource agencies, state and federal entities;
- Announcements - current information about agricultural and natural resources, water quality regulations and funding sources;
- About MoWIN - general information about MoWIN;
- Drought Information;
- Meetings/ Events Calendar;
- Watershed Projects;
- Educational Resources - water-related and environmental education links;
- Watershed Resources - Links to other watershed and natural resources;
- Grants and Funding Sources;
- Glossary of Water-Related Terms;
- Ongoing Agricultural and Natural Resources Projects;
- Watershed Management, Planning, Restoration and Research Data - information sources related to watershed management, planning and restoration;
- Comments, Suggestions, Questions - designed for feedback to/from MoWIN's users;
- Watershed-Related Information by County (for all Missouri Counties) – compilation of watershed information from various state, federal and non-governmental agencies;
- MoWIN's Pantry – includes MoWIN's documents and
- The Missouri Conservation Assistance Guide Project, a major collaborative effort with USDA Farm Service Agency, Missouri Department of Agriculture, Missouri Department of Conservation, Missouri Department of Natural Resources, University of Missouri Outreach & Extension, USDA Natural Resources Conservation Service, and the Missouri Association of Soil and Water Conservation Districts, to publish a hard and electronic copy of technical, financial, educational and informational assistance programs available to Missourians

MoWIN is not just a web site; staff provide information using the Internet, phone, fax, mail, e-mail, workshops, conference presentations and personal visits. MoWIN staff responds to telephone and e-mail requests on topics such as:

regulations pertaining to building waste water lagoons, waste disposal into creeks, streams/ivers, information regarding dam facilities, reservoir levels and updates, scholarly research on watershed health, point/non-point source pollution, dam and flooding problems. Drinking water information in specific cities, counties and watersheds, re-channelizing of streams, vacancy announcements, water use permits, water testing, educational materials, floods and watershed projects are additional inquiries.

### **Impact**

Impact is based on web site hits, telephone, e-mail and personal consultations. Follow-up impact surveys mailed to the original 162 workshop participants revealed that MoWIN is a good source and tool for watershed planning, initiatives, water quality, services and assistance providers as well as natural resource agencies contact information. The web site information is diverse, easy to use, saves respondents time and frustration, and has exceeded respondents' expectations. Links to the other involved agencies and offices are very helpful, the website is easy to use yet contains an incredible amount of information, and that MoWIN has evolved beyond the original expressed interest. Evaluations completed by participants at the end of Professional Implementation Experiences indicate that MoWIN is a useful and convenient watershed information tool.

### **The Partnership**

MoWIN's Partners (Table 1) make significant contributions financially and in-kind. Examples include the invaluable amounts of time spent by their staff working on various web site features. Partners' designated representatives spend considerable reviewing MoWIN's needs, activities, web site information, attending committee meetings, representing MoWIN in various environmental discussions and assisting in the dissemination of information to Missouri's citizens and natural resources agency personnel through various informational forums.

Table 1. MoWIN Partners.

Center for Agricultural Resources and Environmental Systems  
 College of Agriculture, Food and Natural Resources  
 Conservation Federation of Missouri  
 Missouri Association of Soil and Water Conservation Districts  
 Missouri Department of Conservation  
 Missouri Chapter of the American Fisheries Society  
 Missouri Chapter of The Wildlife Society  
 Missouri Department of Natural Resources  
 Missouri Water Environment Association  
 Missouri Watershed Association  
 Missouri Department of Agriculture  
 Show-Me-Chapter, Soil and Water Conservation Society  
 U.S. Geological Survey, Biological Resources Division  
 U.S. Geological Survey, Water Resources Division  
 U.S. Environmental Protection Agency, Region VII  
 U.S. Forest Service, Mark Twain National Forest  
 University Outreach and Extension, University of Missouri-Columbia  
 USDA-Farm Service Agency  
 USDA-Natural Resources Conservation Service  
 Watershed Committee of the Ozarks  
 Member At Large  
 U.S. Army Corps of Engineers - St Louis District  
 Missouri Agricultural Community  
 MU Extension  
 U.S. Fish & Wildlife Service  
 Lincoln University Cooperative Extension  
 Missouri Environmental Education Association  
 USDA - Agricultural Research Service

### **Future Direction**

MoWIN has a long-term goal of prevention and management of non-point sources of pollution to ensure water quality and availability while protecting the environment and restoring impaired watersheds.

Water is an integral part of life, it is important for good health, which is tantamount to socioeconomic development. As an educational tool designed to meet environmental, social and economic needs, MoWIN's long term goal will offer easier accessibility to the widely scattered water-related information, and training on how to best utilize the resources available through the website.

Our future outlook relates directly to the University of Missouri Outreach and Extension's 21<sup>st</sup> Century Strategic Direction: MoWIN staff shall:

1. Design and implement training workshops (educational) that shall include Missouri citizens, professional individuals, educational institutions etc.
2. Continue to locate, access and compile research-based natural resource information relevant to Missouri watersheds to raise citizen awareness about best management practices
3. Disseminate compiled information through workshops, conferences, meetings, brochures, e-mail, mail and personal visits plus scholarly publications
4. Collaborate with grassroots watershed-based groups and support environmental stewardship efforts and offer assistance based on citizen needs
5. Collaborate with state and federal agencies, non-governmental organizational groups, business and industry to encourage citizens to take action to protect, conserve and enhance shared natural resources.

We are rapidly reaching a point where more data is becoming electronically available. The challenge is searching through data and getting it in readily useable form to the client's domain to promote healthy watersheds. In the long run, working with data from MoWIN's partners, we envision a "point and click" map of Missouri's 66 hydrologic unit codes (see Fig. 1. above) linked to all available information where clients can bring up their watershed on the screen and pose questions to the MoWIN system and to related linked web sites. For more information, see the web site at <http://outreach.missouri.edu/mowin>.

### **Conclusion**

The benefits through MoWIN's activities are:

- healthy watersheds with sustainable soil, water, plant, animal and air resources
- healthy environments for Missouri citizens
- increased citizen knowledge, awareness and actions that enhance environmental quality

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# CONTROL AND CENTRAL MONITORING OF A LARGE SCALE MULTIPURPOSE WATER DELIVERY SYSTEM — A CASE STUDY

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Miguel Prado<sup>(2)</sup>

V. Paulo<sup>(2)</sup>

## ABSTRACT

This paper presents the first approach to the centralized SCADA system and automation of the Multipurpose Alqueva Project (MAP). MAP is located in the South of Portugal, mainly in the Guadiana River Basin. It will transfer water to the Sado River Basin. The MAP water delivery control system will guarantee on-line water demands and minimizes water operational losses and energy costs due to pumping. A general modular and hierarchical configuration for the control system is presented. Each component is described and automatic/manual control loops at higher levels are discussed. In the MAP central monitoring, one of the main issues is the communication system that links the remote sites to the central room. According to the specific characteristics, an economic and technical analysis is conducted for several possible architectures. The necessary equipment at the remote sites to link them to the central room is described. The architecture for the central monitoring room is also presented.

## INTRODUCTION

There is an increasing awareness that water resources are limited and have to be managed more carefully. Water issues are becoming a major source of conflicts in many countries and regions.

In the near future, the European Union's Water Directive Law will establish the principle of user – payer. All users must compete for this limited natural resource and pay the same price per unit of volume used. In Portugal, agriculture uses about 85% of the water and therefore must increase water use efficiencies drastically. For the moment, most farmers pay a tax per area irrigated. Consequently, water use efficiency can be very poor.

Usually, an open-channel water conveyance and delivery system is very difficult to manage, especially if there is a demand-oriented operation (Clemmens 1987).

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Remote monitoring and control systems are becoming cost-effective water management tools because reduced costs of computers, software, controllers, remote terminal units, communication equipment and sensors.

The supervisory control and data acquisition facilities of the SCADA and automation systems allow the water manager to continuously compare the real with the desired hydraulic states, and to take appropriate corrective steps as required. These innovations also allow the manager to react rapidly and effectively to changing conditions, thereby accommodating both high and low flow conditions and reducing canal spillage and seepage. On the other hand, the local and/or the central controllers are allowed to automate several decision functions in a very rapid and efficient way.

The Multipurpose Alqueva Project (MAP) is a large scale open-channel water conveyance and delivery system. For the moment, a few structures are being built and other components are being designed. The paper presents a first look at the centralized MAP / SCADA system and automation.

### **BRIEF DESCRIPTION OF THE MULTIPURPOSE ALQUEVA PROJECT**

Main Purposes: MAP (see Figure 1) will be the main water source for the Alentejo Irrigation Plan (South of Portugal). It will also deliver water to municipal and industrial users. At the same time, it will provide hydroelectric energy and flood control. Touristic and fishing activities can also be permitted by the project.

The Guadiana River will be the main water source to meet the deficits of the Alentejo water streams, through storage at the Alqueva and Pedrógão reservoirs (see Figure 1).

In summary, the main purposes of the project are the following:

- irrigation of 110 000 ha of good capacity soils;
- urban/industrial supply in an area with serious water shortage;
- hydroelectric energy production;
- maintenance of a strategic water reserve, in a region affected by drought.

Water Supply: The main sources of water are the Alqueva reservoir (4150 hm<sup>3</sup>) and the Pedrógão reservoir (80 hm<sup>3</sup>).

There are three independent hydraulic sub-systems: Alqueva (70 000 ha); Pedrógão (30 000 ha); Ardila (10 000 ha). The Alqueva sub-system begins at the Alqueva dam and benefits directly approximately 70 000 ha, 15000 ha at the Guadiana river and 55000 ha at the Sado river basins. Pedrogão dam will be the water source for the Ardila and Pedrogão sub-systems.





Alqueva sub-system: this hydraulic system will allow the irrigation of approximately 70 000 ha. It will also allow water delivery to 5 existing dams (Monte Novo, Alvito, Odivelas, Vale do Gaio and Roxo) and supply to Sines (near Lisboa) and to several towns, including Beja (see Figure 1). Its main water source is the Alqueva reservoir, where  $644 \text{ hm}^3$  of water will be pumped, in an average year. The system will integrate 10 main and 98 secondary pumping stations and the water delivery system will integrate about 288 km of canals. The main canal is designed for a discharge of  $39 \text{ m}^3/\text{s}$ .

The water intake to the tunnel, that will deliver water to the Alvito reservoir, at the Odivelas' stream, is located at the Loureiro dam. This tunnel will transfer  $574 \text{ hm}^3$  of water, in an average year, from Guadiana to Sado watersheds (see Figure 1).

Pedrogão sub-system: this system begins at the Pedrogão reservoir and will allow the irrigation of approximately 30 000 ha (see Figure 1). It begins at the Pedrogão pumping station, which elevates water to a main canal designed for a discharge of  $32 \text{ m}^3/\text{s}$ . The system will integrate 4 main and 33 secondary pumping stations and 105 km of canals.

Ardila sub-system: the main goal is to benefit, in the left bank of Guadiana, approximately 10 000 ha. The water source to the irrigation systems is the Pedrogão reservoir. This sub-system is not considered in the present study because, for the moment, there are doubts about technical alternative feasibility.

## MAP CONTROL SYSTEM

### Control structure

The MAP system for control purposes, presented in Figure 2, can be seen in a more abstract way, as a set of water storage units (WS) connected by hydraulic structures (HS). The water storages can be dam reservoirs (DR) or canal pools and the hydraulic structures can be gates (G) or pumping stations (PS) (see Figure 3).

The MAP system consists of approximately 60 WS interconnected by 90 HS (40 WS/ 60 HS for the Alqueva sub-system and 20 WS/ 30 HS for the Pedrogão sub-system) (see Figure 2). The MAP control system has the following main purposes:

- guarantee the desired flows at the offtakes level;
- control the flow within the canals and maintain water levels near the gates;
- manage the dam reservoir water volumes, optimizing system performance.

Therefore, the control system needs to know the hydraulic state of the system in real time, which can be obtained by a discrete number of measurements of water levels and flow rates along the system.

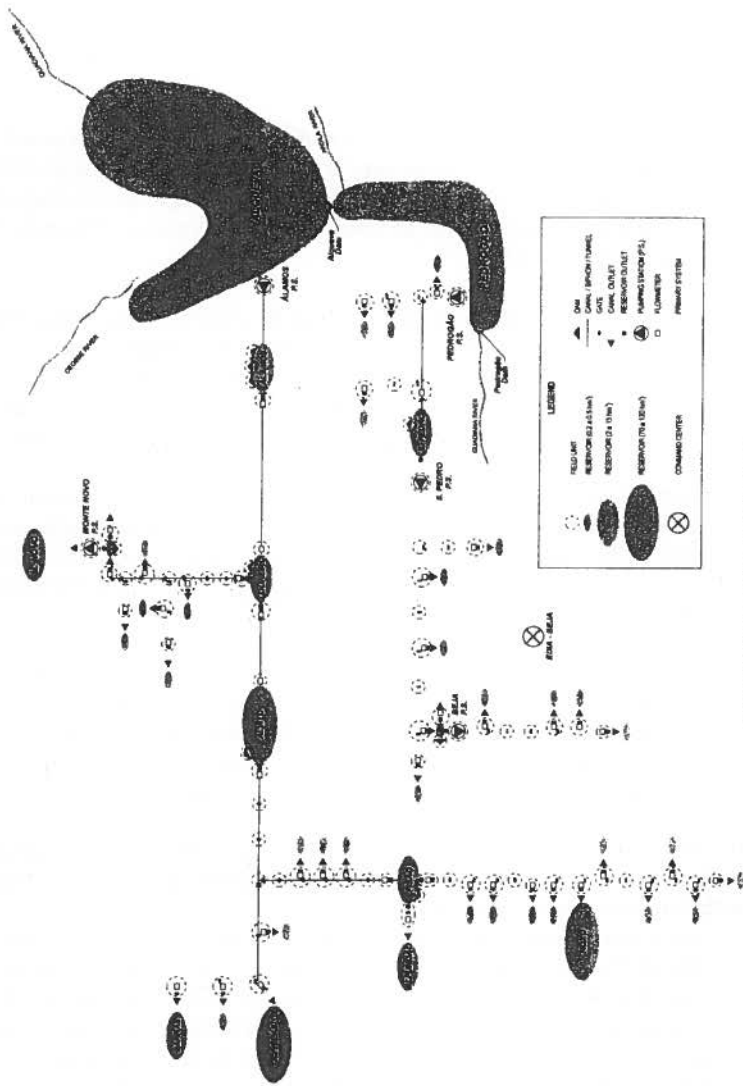


Figure 2 Multipurpose Alqueva Project (MAP) Diagram

The MAP control system should also be:

- robust to local failures, in order to not compromise the functioning of all the system;
- modular and flexible, to permit an easy expansion. This aspect is particularly important since the MAP system will be built during a period of 25 to 30 years.

Basically, there are two distinct configurations for a control system:

- 1) centralized, with all control decisions concentrated in one central controller. The main advantage of this configuration is the possibility to implement sophisticated and complex control algorithms using all available hydraulic measurements to achieve high performance. However, there are some disadvantages:
  - i) no flexibility and modularity, since for each new extension of the hydraulic system the central controller needs readjustment;
  - ii) no robustness, since a failure in the central controller or in the communication system that links the controller to the hydraulic structures and sensors compromise the functioning of the system;
- 2) distributed, where the control decisions are distributed by several controllers. Each controller may command one or more HS based on local hydraulic information (usually water depths near HS). If the controllers exchange information, overall system performance can be improved. The main advantages are:
  - i) flexibility and modularity, since for each new extension of the hydraulic system the existing controllers do not need to be altered;
  - ii) robustness, since a failure in one of the controllers or in the communication system that links the controllers to the hydraulic structures and sensors affects just a part of the system.

Based on the above considerations, the authors think that the most appropriate configuration for the MAP control system is a distributed control configuration with two hierarchical levels (see Figure 4):

- slave level, consisting of a set of slave controllers (one per HS) that command the HS in order to regulate the flow rates according to desired target values;
- master level, consisting of a set of master controllers (one per WS) that manage the WS according to specific control criteria. Each master controller generates a flow rate reference to the slave controller that adducts to the WS based on the existing water level/volume in the WS and the outlet flow.

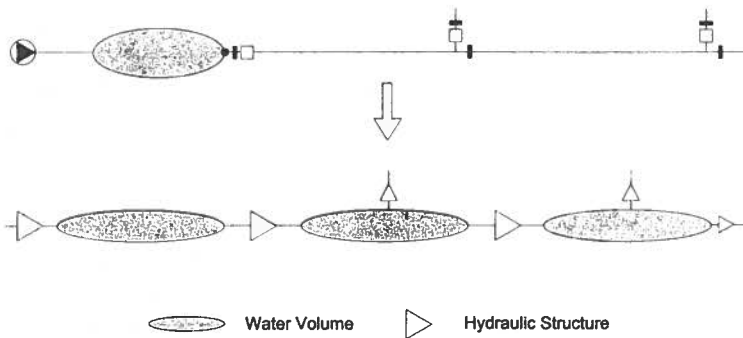


Figure 3. Water-Storages – Hydraulic Structures System Representation

### Slave controllers

Gate slave controllers - These controllers have to determine gate positions in order to control gate flow rates according to reference values. Controllers may consist of static feed-forwards of the desired flow rates and the upstream and/or downstream water levels that compute gate positions based on the discharge curves of the gates.

When there is a flow rate measurement near the gates (eg. canal outlets or dam reservoirs outlets), the slave controllers can be complemented with closed loop feedback control laws of the flow rates errors (eg. a classical PI law, with gains scheduled according to the functioning point of the gates in order to compensate the non-linearity of the discharge curves).

Pumping station slave controllers – The PS slave controllers are more complex than the gate slave controllers because they have to manage several pumps and valves in order to guarantee desired pumped flow rates.

For PS with constant speed pumps, the pumped flow can only vary by steps. In this case, the slave controller usually consists of a sequential digital system that generates binary start/stop commands to the pumps and open/close commands to the valves, according to a desired flow rate step.

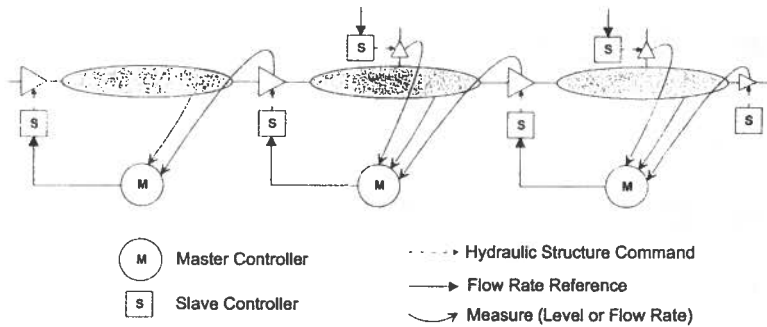


Figure 4. Master – Slave Control Configuration

For PS with variable speed pumps, the pumped flow may vary continuously. In this case, the slave controllers need to adjust to the speed of the pumps. This can be done (in a similar way to the gate slave controller) by feed-forwarding the desired flow rates through a non-linear static control law, based on the characteristic curves of the pumps. If a PS has flow measurement, the feed-forward controller can be compensated with a closed loop feedback control law of the flow rate error (eg: a classical PI law, with gains scheduled according to the functioning point of the pump in order to compensate the non-linearity of the characteristic curve).

In the MAP system, the Álamos and Monte Novo PS pump directly to dam reservoirs. So, there is no need for variable speed pumps since the reservoirs filter the high frequency content of the pumped flow. On the other hand, the Pedrogão, S. Pedro and Beja PS pump directly to canals. In this case, the pumped flow should be able to vary continuously or in small steps to prevent strong transitory regimes in the canals.

### Master Controllers

Dam reservoirs master controllers: There are two basic control criteria that can be used for the management of dam reservoirs:

- low pass filtering of downstream flow, in order to guarantee a slowly varying upstream flow with small peak values. This criterion is particularly suitable for reservoirs that receive water from canals in order to reduce the transient flows and conveyance capacities of the canals;
- energy cost minimization of upstream PS, reducing the pumped flow during high cost periods and increasing it during low cost periods.

The choice of one of the above control criteria for each dam reservoir is intimately related to its location in the MAP system. In the Alqueva sub-system, the Alvito, Loureiro and Álamos reservoirs should be managed to minimize the

Álamos PS energy costs. The Pisão reservoir and all the secondary reservoirs could work as low pass filters of canals flows.

In the Pedrogão sub-system, all the reservoirs (S. Pedro and the secondary ones) should be managed according to energy cost criteria, since all PS deliver water directly to canals.

The master controllers for the MAP dam reservoirs can be manually operated at the command center, due to the time (several days) required to change significantly the water surface elevation. On the other hand, the master controllers of the smaller reservoirs should be automatic, due to their number and faster dynamics (the water levels can take some hours to change significantly).

Canals master controllers: The control criteria of the canal master controllers are to maintain downstream water levels (near the gates), in order to assure:

- the correct functioning of the gates;
- a stock volume to respond rapidly to varying flow demands at the offtakes.

Canal dynamics is however rather complex and is usually described by a one-dimensional space model based on the St. Venant equations (Cunge et al. 1980), that relate the flow rates  $Q(x,t)$  and the water levels  $h(x,t)$  along the canal (both function of time  $t$  and space  $x$ ). Therefore, the design of a controller that verifies the above mentioned control criterion faces some difficulties mainly due to the high time delay between the upstream flow and the downstream water level. Many different approaches have been studied in the recent years (Molina & Miles 1996): predictive control, optimal control, classical frequency domain control, etc.

The typical behavior of the flow rates  $Q(x,t)$  and the water levels  $h(x,t)$  within a canal pool subject to a master-slave control are presented in Figure 5. The figure presents the numerical simulation results for the Pisão canal, considering the following conditions: initial steady flow of  $20 \text{ m}^3/\text{s}$ , a  $+5 \text{ m}^3/\text{s}$  step change of the downstream flow (at  $t = 0$ ) and a  $3.59 \text{ m}$  downstream reference water level. The simulations were done with an unsteady flow open-channel model that solves the St. Venant equations using a finite difference implicit scheme and considering a computational space step of  $150 \text{ m}$ . The master controller was based on a Smith Predictor with downstream flow feed-forward (Smith 1957).

The step change of the downstream flow originates an upstream traveling wave and a decrease of the downstream water level. The master controller counteracts imposing an upstream flow temporary higher than the desired downstream flow, which originates a downstream traveling wave in order to compensate the volume withdrawn downstream. After the downstream traveling wave reaches the end of the canal pool, the downstream water level starts to increase until it reaches the target value and the flow along the canal stabilizes around the downstream imposed value.

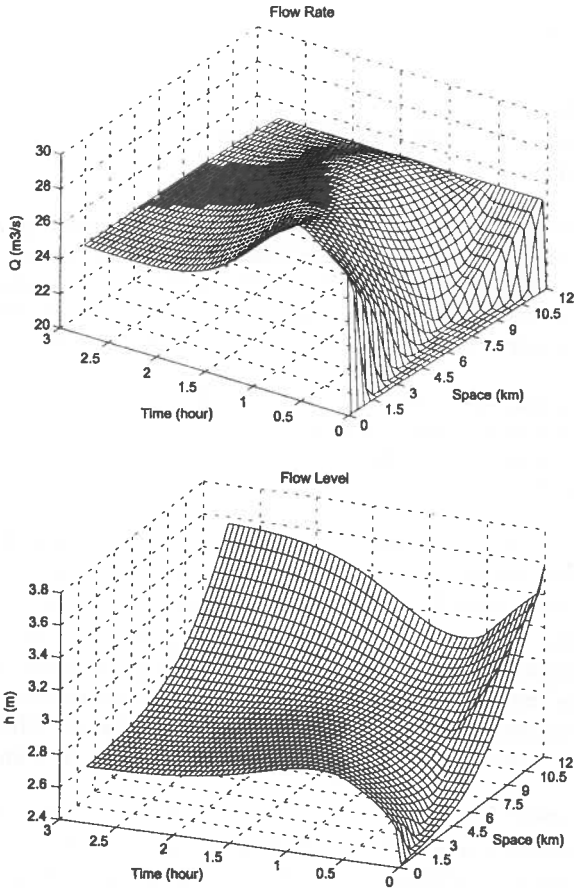


Figure 5. Flow Rates and Water Levels Along a Canal with Master-Slave Control

### MAP SCADA SYSTEM

The MAP SCADA (Supervisory Control And Data Acquisition) system is composed of:

- field units, to collect local data (water levels, flow rates, etc) and command local equipment (gates, pumps, etc);
- a command center, to supervise/manage all the field units;
- a communication system, to link the field units between them and to the command center.



### Field Units

There are seven different types of field units in the MAP system: canal gates, canal bifurcations, flow meters, canal outlets, dams, dam reservoir outlets and pumping stations (see Figure 2).

The following equipments compose each field unit: automation/control, surveillance, power supply, communication, actuators and sensors. Usually, a shelter protects the most sensitive equipment from the weather conditions and vandalism.

Automation/control: All field units will be equipped with a PLC, programmed to collect data from local equipments, perform control actions on the actuators and communicate with the command center. A data panel linked to the PLC will permit a human operator to access the field unit and command locally the actuators.

Surveillance: For security reasons, the direct access to the field units should be restricted only to credentialed staff. Therefore, each field unit should have a specific access control system linked to the local PLC.

In some field units (dams and pumping stations), its considered also important to install a set of fixed or remote operated CCTV cameras connected to a local video server that transmits automatically the images to the command center. This way the command center has a visual/acoustic contact with the field units, which can be helpful in different scenarios: intrusion, flood alarm, remote control of a machine (eg. gate, pump, etc).

Power supply: All the field units will be generally supplied by the national electrical power network (EDP).

Actuators: Along the MAP field units the following actuators will be installed:

- gates, to control the flow/water levels along the canals and discharges in dam reservoirs;
- valves, to control flow in pumping stations and regulate ecological flows in dams;
- pumps, to pump water to higher levels.

Sensors: A set of sensors will be needed on each field unit to evaluate the state of the system:

- water level sensors, in the canals (up and downstream of each pool, to control the water levels and to compute gate discharged flow) and in the reservoirs (to evaluate the available water volumes);
- flowmeters, at the canal and dam reservoir outlets and pumping stations to control the flows;

- vibrations sensors, in the pumping stations to protect the pumps against high vibrations.

### **Command Center**

The command center will be located in the EDIA main building at Beja (see Figure 1), with the following functions: master control of the reservoirs, monitoring of all field units and to record and analyze all collected data.

The command center will be constituted by a LAN (Fast Ethernet, TCP/IP) that connects the following machines (powered by a redundant UPS):

- two redundant SCADA servers, to collect data from the PLCs and distribute it through the LAN;
- two or more SCADA viewers, to allow human operators to view and interact with the data distributed by the servers and perform control actions;
- one SCADA Internet-Gateway PC, to support a WEB page with on-line data from the servers, allowing this way access to the system via INTERNET;
- one database PC (equipped with CD-ROM writer) for data recording;
- one surveillance PC, for accessing the CCTV servers installed at the field units;
- one central PC, to monitor the vibrations protection and condition monitoring systems installed at the pumping stations;
- one LAN/WAN Management PC, for monitoring/management the MAP communication system;
- one PC for remote setup and programming the field units equipment (eg. PLCs, UPSs, flowmeters, etc);
- two or more printers, for reports and alarms registration;
- a bridge, to connect the command center LAN to EDIA's main LAN;
- bridges/routers, to connect the command center LAN to the field units;
- a video projection system, that permits the visualization in a big screen of all applications running on the computers linked to the LAN eg. SCADA diagrams, graphics, CCTV images, etc.

### **Communication System**

The MAP communication system has to guarantee the communication between:

- field units and the command center (FU/CC), so the command center can supervise and remote control the field units. Voice transmission between FU/CC is also important to permit a vocal contact between a CC operator and a local FU operator;
- field units (FU/FU), so the downstream master controllers may transmit reference flows to the upstream slave controllers;

- secondary reservoirs and field units (SR/FU), so the master controllers of the secondary reservoirs may specify on-line the desired demands to the water outlets slave controllers.

Since the secondary reservoirs are located generally at some distance (several km) from the water outlets and the frequency of communication is rather low (around 4 calls per day), the SR/FU communication may be done via PSTN or radio modem.

Several different solutions for the FU/FU and FU/CC communication problems were studied, being the three most representative ones here presented:

- 1) Radio Trucking + ISDN, where all field units have a radio trucking modem connected to the PLCs to communicate between them. Each field unit communicates with the command center via the correspondent adduction unit (Dam or P S).

Each Dam and PS has a copper Ethernet (TCP/IP) LAN (eg: 10BaseT) that connects all the local equipment (PLC, CCTV server, etc). A local router connects the LAN and an analog telephone to the command center via ISDN BRI. At the command center a modular bandwidth manager links an ISDN PRI to three analog telephones and to the CC LAN via an E1 router.

- 2) Ethernet + Leased Lines, where all the field units are linked by three separated single mode fiber optic Ethernet (TCP/IP) LANs (eg: 10BaseFL):
  - one for the all the field units upstream Alvito Reservoir, with a total length around 70 km (50 km along the canals/siphons, 10 km underwater in the Álamos and Loureiro reservoirs and 8 km underwater in the Loureiro-Alvito Tunnel).
  - one for all field units downstream Alvito reservoir, with a total length 100 km installed along canals/siphons.
  - one for all field units of the Pedrogão sub-system, with a total length around 80 km installed along canals/siphons.

The three LANs are connected to the command center in a star configuration. The first two LANs are connected through routers (at the Álamos PS and Alvito dam) via 2Mbps leased lines and the Pedrogão LAN is connected through a bridge via a 4 km fiber optic cable installed along a public road to Beja.

All the LANs have ISDN routers installed at the end nodes, to provide communication backup in case of fiber optic failure. Each field unit has a copper Ethernet LAN (eg: 10BaseT) that connects all the local equipment (PLC, CCTV server, VOIP telephone, etc) to the fiber optic LANs through a media converter. Three VOIP telephones are connected to the CC LAN to permit vocal communication with the field units.

- 3) Ethernet + Microwave Radio links, where all the field units are linked by three separated single mode fiber optic Ethernet LANs as in the previous solution. The three LANs are connected with the command center in a ring configuration using the following three redundant microwave radio links (working on a licensed frequency): Pisão Dam – Command Center (14 km), Alvito Dam – Loureiro/Alvito Tunnel (10 km) and Álamos PS – Pedrogão PS (26 km with a retransmitter). The above mentioned fiber optic link between Pedrogão LAN and the command center makes also part of the ring. Different kind of networks can be used to implement this ring like: Fast Ethernet, PDH, SDH, etc. A SDH ring may be interesting to explore with a telecommunication company.

The Radio Trucking solution corresponds to a very simple and cheap communication system. However the implementation of this solution needs a field analysis of the local radio signal strength. According to previous tests done in the Alqueva area by a radio trucking company, the radio signal is generally sufficient although at some field units there is no signal at all.

The Ethernet based communication systems represent a more modern solution, with several advantages over the radio trucking solution: high flexibility and reliability, good quality video transmission, redundancy and short time responses. The Ethernet + Microwave Links solution corresponds additionally to a totally private communication system with a very high redundancy.

### Economical Analysis

The economical analysis presented, was based on the following assumptions:

- a 60 year analysis period (first 30 years for start-up/building the system + 30 years full operation) with a 5% constant rate of interest;
- all the costs presented include investment and maintenance costs and are reported to the year 2000;
- the pumping costs were excluded from the electrical energy costs;
- the life range of the equipments used.

The costs relative to the Field Units, Command Center, Man Labour and Electrical Energy to run the system are estimated in 11130 (1000 Euros).

The total costs of the SCADA system for each of the three different communication systems above mentioned are:

Costs (1000 Euros)	Radio Trucking + ISDN	Ethernet + Leased Lines	Ethernet + Microwave Links
Common	11130	11130	11130
Communic. System	1400	3800	4300
Total	12530	14930	15430

### MAIN CONCLUSIONS

Low-cost real-time instrumentation promises a revolution in improved water management in the water delivery open-channel systems. Today, real-time monitoring and control systems are within the cost range of almost all water user groups, including irrigators, canal companies and water districts. For the present case study, the main conclusions are:

- since the estimate of the MAP total cost is around 1500 million Euros, the SCADA system represents approximately just 1% of the total costs;
- although the Ethernet based SCADA systems are approximately 20% more expensive than the Radio Trucking solution, the technical advantages of the Ethernet solutions justify this difference.
- SCADA system will permit to reduce conveyance losses and waste, to increase ability of meeting real-time demands by the water users and to reduce operation and labor costs.

### ACKNOWLEDGEMENTS

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The first part of the report deals with the general situation of the country and the progress of the work during the year. It is followed by a detailed account of the various expeditions and the results obtained. The second part of the report is devoted to the study of the flora and fauna of the country, and the third part to the study of the geology and the mineral resources of the country.

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# WATER ACCOUNTING AND WATER INSTITUTIONS' STUDY OF MANUSMARA RIVER BASIN

Suman Sijapati<sup>1</sup>

## ABSTRACT

Manusmara River Basin, a sub-basin of the Bagmati River Basin, lies in the Terai of Nepal. It lies in the sub-tropical climatic zone. The topography is almost flat with a very gentle slope towards the south. Up to the mid 1960s, a large portion was covered by dense, *Sal* forest. At present, only 6% of the area is occupied by forest. Over the last few decades, consumption of water especially for agriculture has increased tremendously. This paper draws out the history of agricultural development in the basin and its interface with the efforts made by the farmers to use the basin water resources.

Water accounting has revealed that Manusmara is an "open basin" and it still offers ample scope for transbasin transfers and further harnessing of the available water. Even during the driest year, only 46% of the available water resources is depleted. This leaves more than half of the basin's yield for undeclared uses. The basin is at the initial stage of development. On the basis of the water account and an institutional analysis, the paper offers some suggestions for integrated development of the basin.

## INTRODUCTION: PHYSICAL AND SOCIAL SETTING

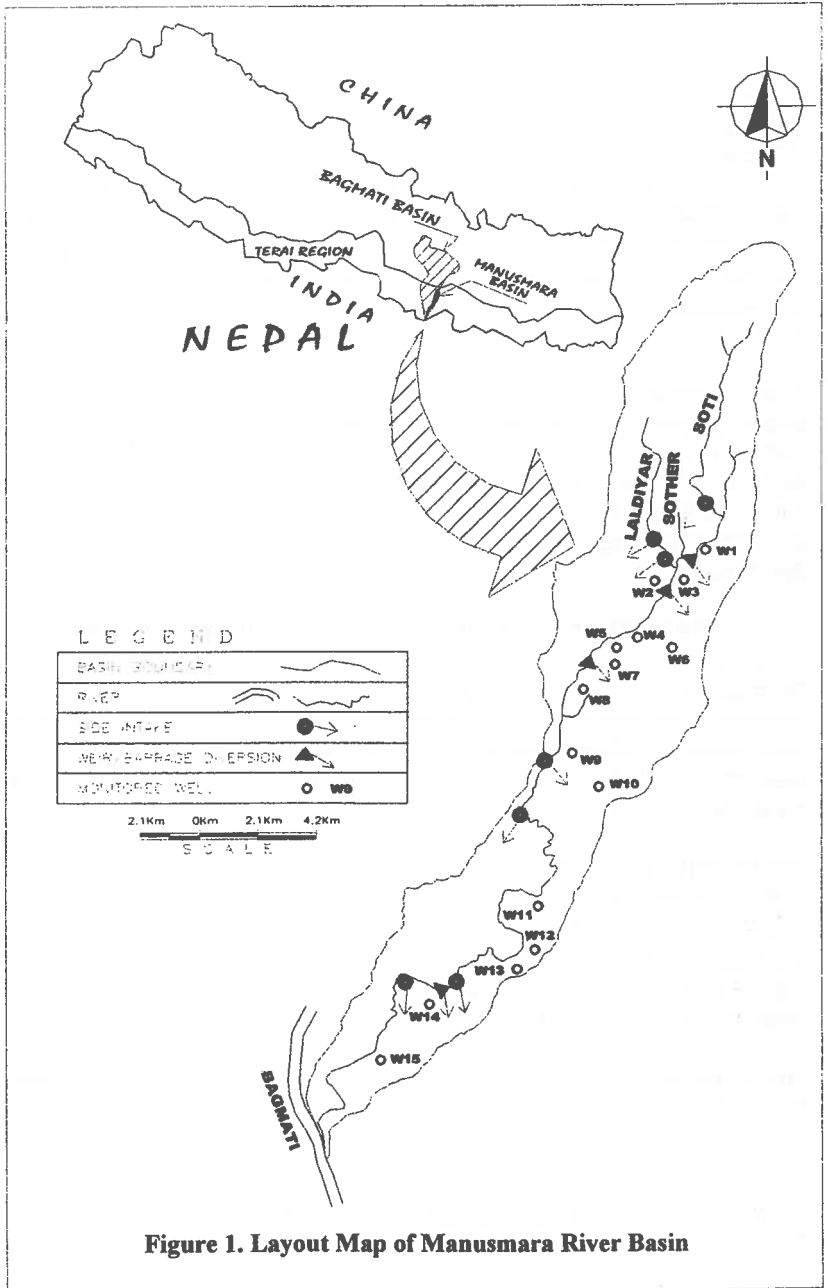
Manusmara River is a rain and spring fed perennial river originating from a forest area in the southwestern part of Sarlahi district. From its origin, the river runs south parallel to Bagmati River and joins it at Hathiul. The length of the mainstream is 53.7 km and its average slope is 1:2200. Laldiyar, Soti and Sother are its three tributaries.

The River Basin is a sub-basin of the Bagmati River Basin. The whole basin lies in Sarlahi district in the Terai of Nepal. The basin extends from Latitude 27°03' to 26°46' N and Longitude 85°20' to 85°29' E. Figure 1 shows the Location Map of the Basin. Total basin area is 156 Km<sup>2</sup>. The topography is almost flat with the highest point and lowest points at 107.8 and 74.6 m above mean sea level. The deep surface soil varies from loam to fine loam.

The climate of the river basin is sub-tropical. The mean annual air temperature, is 25°C, with a mean annual maximum of 31°C and mean annual minimum of 19°C.

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On the basis of the characterization of thermal regime, the study area lies in the verge of double rice based cropping system. The average relative humidity is about 75% and varies from 50% in the dry season to 90% in the rainy season. The daily sunshine hours averages 7 hrs/day, varying from 4 hrs/day in July to 8 hrs/day in April. The wind velocity averages 1.6 km/hrs.

The Average annual precipitation is 1427 mm. Computed by the WECS method, 80% reliable rainfall has been found to be 1054 mm. Rainfall occurs mainly from the middle of May to the end of October. It is concentrated during the monsoon, which occurs between the second week of June and the third week of September. Average monthly precipitation varies from a minimum of 6mm in November to a maximum of 422mm in July. Considering 1979 to 2000 as the period of analysis, 1980 was found to be the driest year, while 1987 was found to be the wettest year. The year 1993 was an average year.

Up to the mid 1960s, a large portion, especially of the northern part of the basin, was covered by dense forest. However, with the inflow of people into the basin during the 1950s and 60s, the forest was converted to agricultural land. Presently, only 6% of the basin area is occupied by forest. Even though the cropping pattern and cropping intensity vary significantly within the basin, the prevailing major crops are rice, sugarcane and wheat.

Except for Barathawa, which is gradually urbanizing, the basin area is mainly covered by rural settlement. The area, fully or partially, encompasses 24 VDCs<sup>2</sup> of Sarlahi district. The present population density is estimated to be 480/Km<sup>2</sup>. Average family size of household is about 6 persons. More than eighty percent of the population is involved in agriculture. Average farm-size per household is small (about 1 ha). However, land is not uniformly distributed and a small minority of rich farmers own most of the land while the majority of the poor farmers have very small land holding.

### NATURAL AND SOCIO-ECONOMIC LANDSCAPE CHANGES

History of human existence in the basin goes back more than 200 years. Archeological evidences of settlement ruins and legends of ethnohistory assure this fact. Huge and seemingly old *Pipal* trees are found peculiarly spaced in the locality standing alone or accompanied with Mango or *Sami tree*<sup>3</sup> amidst intensive agricultural land. Whether they were protected from the very beginning or grown by newer settlers, they suggest a long human occupation in the basin.

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<sup>2</sup> VDC stands for Village Development Committees. These are smaller political units of a district. In Sarlahi district there are 99 VDCs.

<sup>3</sup> These trees are celebrated in the Hindu religious life.

Oral lore of the local people of the *Yadav* community ratifies their historical presence in the area. Their livelihood based on cow herding probably existed before cropping was practiced in the locality, when the area was mainly covered by dense forest. The population density was very low and the sense of land possession was not developed. The people then are believed to have practiced subsistence farming with shifting cultivation of rainfed crops like *Aluwa* (Sweden Root), *Maduwa* (millet), *Kagono* (Barley), etc.

Rice is believed to have been introduced to the basin sometimes during the first half of the nineteenth century. With rice came the need for irrigation. Through the individual effort of local farmers, several *kulos* (indigenous irrigation systems)<sup>4</sup> were constructed. These simply consisted of an inundation earthen canal network dug from an appropriate location in the river. During the monsoon, the water level in the river would rise and the water would flow through these canals to irrigate the paddy fields. There was no mechanism to regulate the flow and only limited land could be irrigated. However, since the population density was low and rice initially was produced only for subsistence, this technology was sufficient for the time. Rice production is reported to have gradually increased towards the end of the nineteenth century as markets developed in nearby Indian villages. With the expansion of rice, the tradition of shifting cultivation gradually came to an end. People started to settle down in small clusters in slightly elevated areas in the vicinity of these paddy fields. Wells were dug in each village to fulfill their domestic water requirements.

Significant increase in crop coverage occurred during the Rana Regime<sup>5</sup>. During that period, more cultivation was encouraged by the state to generate more revenue. *Jimmidars* (local landlords who functioned as politico-administrative agents of the state for revenue collection from the peasants) were deputed for each village. Farmers were attracted from everywhere, particularly the Indian plain. The *Jimmidar* encouraged peasants to increase their agricultural production both by bring more land under cultivating and by practicing more labor-intensive agriculture in order to pay the high land revenue.

Increase in crop coverage resulted in the need for diversion of more water. Thus the technology of inundation canals was considered insufficient and was supplemented by earthen dams<sup>6</sup>. The main objective of these earthen dams was to

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<sup>4</sup> Among them, several, including "*Hakrai kulo*" (*kulo* having many branches) were constructed by Harkatawa people and are still functioning today.

<sup>5</sup> The Rana Regime prevailed in Nepal from 1846 to 1950.

<sup>6</sup> The tradition of earthen dam construction does not exist at present. It was very prevalent up until two decades ago. Among the earthen dams at that time, the one near Mahinathpur and the one near Hirapur constructed by the landlords and peasants of Gadaiya and Harkathwa respectively, were reported to be the most prominent.

address the critical requirements of rice during land preparation stage. Through initiative of local *Jimmidars*, earthen dams were constructed at appropriate locations of the river. Small tenants also contributed voluntary labor and grains. Dam construction was taken as a religious ritual. People found an auspicious day to initiate dam construction every year and performed rites to Gods and local spirits. Each year these dams would be constructed before the monsoon, sometimes during the month of May. They would survive until a major flood in the river would destroy them. Thus dam construction was a continuous process.

The first attempt to construct a permanent structure to divert water in Manusmara river took place during the 1940s. Following the petition of influential landlords of the area, a permanent dam was constructed south of Hirapur through the initiative of the Rana Prime Minister Juddha Samsher Rana. The canal was named Juddha Canal<sup>7</sup> after him. Juddha Canal (its ruins presently known as Choruwa Kottha) was constructed between 1945-47. Later, this dam was completely destroyed by the flood of 1954. However, the construction of Juddha Canal opened the door to a cultivation boom in the locality.

Infrastructure developments in the locality such as construction of irrigation and road networks that took place during and after the 1950s<sup>8</sup> also attracted the population from the nearby hills to the area. Construction of the East-west highway, eradication of Malaria and the effort of the Land Distribution Commission were instrumental to the immigrant boom in the northern part of the basin after 1965. All these developments increased pressure on the land resources in the basin. The land holding size became smaller. Small farmers cultivated rice in some part of their land and used the rest for other staple crops, pulses, vegetables and fruits. Consequently the coverage of rice was slowly replaced by other crops. Moreover, winter crops like wheat and maize were introduced. Thus the cropping pattern rapidly became more intensified and diversified. This crop diversification was also augmented by the introduction of higher yielding varieties of cereals but requiring stricter water management than traditional ones.

This shift in cropping resulted in the need to have more control over water. Thus, in 1965, the first modern diversion (barrage) with steel gates allowing regulation of flow was constructed at Hirapur, upstream of the old destroyed dam. It became operational in 1968. About a decade later, another permanent diversion was constructed 6 km downstream of the first in the form of a concrete barrage at

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<sup>7</sup> Juddha Canal is Nepal's second oldest irrigation system with a modern diversion structure. Chandra Canal constructed in 1923 is the oldest and is also named after another Rana Prime Minister Chandra Samsher Rana.

<sup>8</sup> Elderly key informants have reported that the settlements towards the north of Basworiya Camp only developed after 1950. It is said that only Gadaiya, Dumariya, Bakainiya, Sissautiya, Dhangara, and Dhankaul were in existence during the early half of the last century.

Manpur. This diversion became operational in 1982. Under the Irrigation Sector Project (ISP<sup>9</sup>) another diversion was constructed further downstream at Sudama to irrigate 1630 ha. Then in the year 1996/97 under SISF, Laukat Irrigation System irrigating 375 ha was constructed 3-km upstream of Hirapur. Thus, a series of diversions are currently in use in the river.

The present cropping pattern is a mixture of many crops. Figure 2 shows the existing land use pattern of the basin.

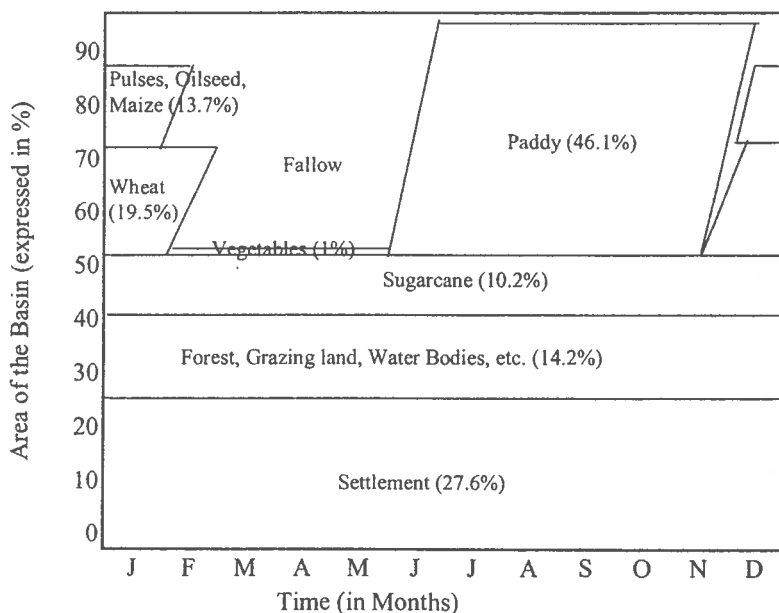


Figure 2. Landuse Pattern of the Basin

The intensity of sugarcane is presently increasing. This is thought to be a risk minimizing strategy against the potential failure of rice production for subsistence and market risks of sugarcane. Almost all the farmers, regardless of their social and economic status grow cane on about one third of their land. Other key crops

<sup>9</sup> Irrigation Sector Project (ISP) was launched in Nepal from 1989 to 1993 through the loan assistance of Asian Development Bank. It aimed to provide irrigation facilities in 25000 ha of land in 35 districts of Nepal including Sarlahi. Due to the encouraging progress of the project and increasing demands of the farmers, the scope of the project was further increased to 33000 ha and under the banner of Second Irrigation Sector Project (SISP) is underway.

are rice during the summer and wheat, oil seeds and maize during the winter. The prevailing cropping system also allows poor farmers to go to Punjab both as on-farm and off-farm migrant labor in winter.

Cropping intensity decreases as one moves from north to south along the basin. The major reasons for this are higher coverage of short-term crops like maize and vegetable in the north and long-term crops like sugarcane in the south. Moreover, big and absentee landowners are more prevalent in the south. In the south, farmers cultivate land on *Hunda* (contract) or *Bataiya* (share cropping) bases.

### WATER AVAILABILITY SCENARIO: INFLOWS AND STEAMFLOW

Inflow to the basin occurs from 3 sources: rainfall, ground water and irrigation supply from Bagmati Irrigation System. Rainfall in the basin is concentrated from the second week of June to the third week of September. Considering 1979 to 2000 as the period of analysis, 1980 was the driest year while 1987 was the wettest. 1993 was a normal year. Average monthly precipitation varies from a minimum of 6mm in November to a maximum of 422mm in July. On the basis of analysis of daily rainfall data from 1997 to 2000, the maximum 24-hr daily rainfall has been recorded to be up to 159mm on 21 June 1998.

Ground water is the second source of inflow to the basin. Inflow from the ground water table is observed to occur by three ways: firstly through river recharge, secondly through capillary rise into the root zone depth and thirdly through extraction by hand pumps. The ground water table over the basin area was observed and interpolated using 15 representative wells. In general, the ground water table of the basin is found to be quite high. On an average in a normal year, it was found to be about 2m below average ground level. Seasonal fluctuation was observed to be of the order of 1.8m. During the non-monsoon period (i.e., from October to May) the water table of almost the whole basin is below the average root zone level<sup>10</sup>. However, during the monsoon period (i.e., from June to September) the basin can be divided into 4 parts. The first part, comprising of 20% of the area of the basin, is the part where the ground water table never reaches the root zone level. The second part, comprising of 54 % of the basin, is the part where the ground water table reaches on an average 0.1m for about 12 days. The third and fourth part, comprising of 13 % each, is the part where the ground water table reaches on an average 0.6m and 1m for 50 days and 82 days respectively.

Irrigation supply from Bagmati Irrigation System is the third source of inflow into the basin. The designed discharge of the secondary canal entering the basin is 1.2 m<sup>3</sup>/s. Considering the operational schedule of the irrigation system, the discharge is estimated at 70% of this under normal conditions. Thus, for a normal year, the

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<sup>10</sup> Considering the existing crops average root zone depth has been taken as 1.2m.

annual inflow is  $26.5 \text{ Mm}^3$ . The operational period has been found to increase by ten percent during a dry year and decrease by 10% during a wet year.

Study of river's morphology has revealed that the river can be divided into three stages. From the origin up to Manpurgoth (a 13km stretch), the river has an average slope of 1:1000. It is quite straight and the alignment is significantly far away from Bagmati River. The 27.5 km stretch from Manpurgoth to Khairwa is very flat (average slope: 1:3300) and has a lot of meanders. Finally, the stretch (13.2km) from Khairwa to Hathiaul (the confluence point) with an average slope of 1:4200 is relatively straight. It appears that the first stretch gets its recharge from the spring line of the Bhabar zone, the second stretch gets recharge from the seepage water of Bagmati river and the third stretch gets surplus discharge by the flooding of Bagmati River.

Measurements of discharge carried out at the confluence point are found to vary between  $7.4 \text{ m}^3/\text{s}$  during the month of April to a maximum of  $14.9 \text{ m}^3/\text{s}$  during the month of August. The average discharge is found to be  $10 \text{ m}^3/\text{s}$  in a normal year. Thus the outflow from the basin is  $316 \text{ Mm}^3/\text{year}$ .

### WATER USE SCENERIO OF THE BASIN

Water in the basin is being used for irrigation, domestic purposes and for animal husbandry. These uses have been considered as the 'Process Depletion' of the basin. No industry exists within the basin. Among the various uses, irrigation is the most prominent in terms of volume. At present, a series of diversions exist in the river in order to divert water for irrigation purposes. These diversions can be broadly categorized into two types: permanent diversions and side intakes. Permanent diversions are concrete structures (barrage or weir) which divert water as per the requirements of the farmers while side intakes are off takes where water flows through inundation when the water reaches a certain level. For details of the diversions see Figure 3. As significant differences exist in the cropping pattern and cropping intensity within the basin, each irrigation command area has been treated differently for crop water requirement computations within the basin. The Penman Montheith method has been used for the computations. The diverted water is not only used within the basin but also goes beyond the basin boundary. This part has been counted as transbasin transfer.

For domestic purposes, no water supply system exists except for the hand pumps. Previously dugwells were used to fulfill domestic water requirements, and pumps were introduced in this area from the early 1970s. These were considered superior as they occupied less space, were less prone to contamination and were easier to operate. Thus, hand pumps slowly replaced the dugwells and their number is gradually increasing. Well-to-do families own up to 3 hand pumps, while in poor communities 3 to 5 families share one hand pump. Even though

some tubewells go as deep as 20m, most tube wells in the area are 8 to 12m deep. A total of about 2400 tubewells exist in the whole basin area.

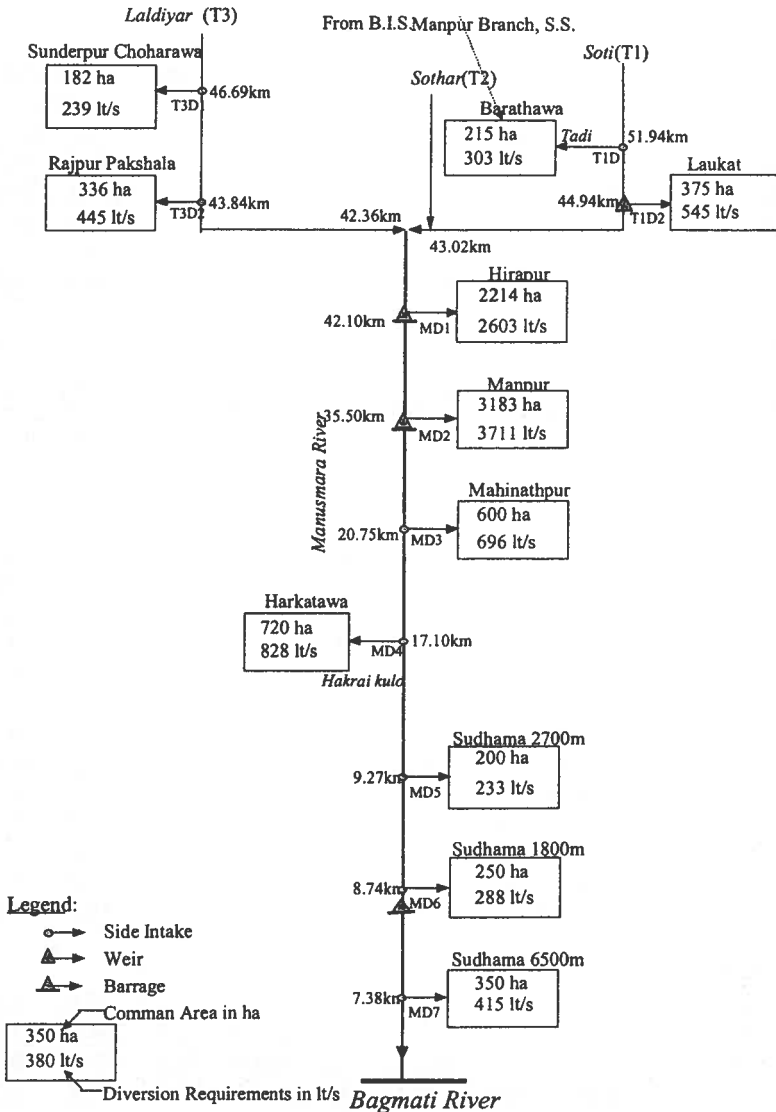


Figure 3. Schematic Diagram of Manusmara River

## WATER BALANCE OF THE BASIN

Water balance of the basin is computed considering all the inflows, depletions (process, non-process and non-beneficial) and outflows. Analysis has been carried out considering all three cases of dry, wet and normal years (Table 1).

Table 1. Water Account Results

Year Considered		Wettest Year (1987)		Normal Year (1993)		Driest Year (1980)	
Previous Year		Normal		Dry		Normal	
Components	Sub-Component	10 <sup>6</sup> m <sup>3</sup>	% <sup>11</sup>	10 <sup>6</sup> m <sup>3</sup>	%	10 <sup>6</sup> m <sup>3</sup>	%
1 Gross Inflow	a. Rainfall	387.8	60.4	221.8	46.8	156.6	39.8
	b. Groundwater	222.8	34.7	218.4	46.1	214.0	54.4
	c. Bagmati I. P.	24.1	3.8	26.5	5.6	29.2	7.4
	Sub total	<b>634.7</b>	<b>98.9</b>	<b>466.7</b>	<b>98.5</b>	<b>399.8</b>	<b>101</b>
2 Storage Changes	a. Surface storage	0.9	0.1	0.7	0.1	0.2	0.1
	b. Ground storage	6.3	1.0	6.3	1.3	-6.3	-1.6
	Sub total	<b>7.2</b>	<b>1.1</b>	<b>7.0</b>	<b>1.5</b>	<b>-6.0</b>	<b>-1.5</b>
3 Net Inflow		<b>641.9</b>	<b>100</b>	<b>473.7</b>	<b>100</b>	<b>393.7</b>	<b>100</b>
4 Process Depletion	a. ET Paddy	43.6	6.8	43.6	9.2	43.6	11.1
	b. ET Wheat	13.9	2.2	13.9	2.9	13.9	3.5
	c. ET Sugarcane	16.0	2.5	16.0	3.4	16.0	4.1
	d. ET Pulses	6.5	1.0	6.5	1.4	6.5	1.7
	e. ET Maize	2.7	0.4	2.7	0.6	2.7	0.7
	f. ET Oilseed	1.5	0.2	1.5	0.3	1.5	0.4
	g. ET Vegetables	1.1	0.2	1.1	0.2	1.1	0.3
	h. Domestic uses	0.8	0.1	0.8	0.2	0.8	0.2
	i. Animal uses	0.3	0.0	0.3	0.1	0.3	0.1
	j. Trans-basin diversions	22.1	3.4	20.1	4.2	18.1	4.6
	Sub total	<b>108.5</b>	<b>16.9</b>	<b>106.5</b>	<b>22.5</b>	<b>104.5</b>	<b>26.5</b>
5 Non Process Depletion (beneficial)	a. ET Forest	6.6	1.0	6.2	1.3	5.9	1.5
	b. ET Canal forest	0.2	0.0	0.2	0.0	0.2	0.1
	c. ET Grass land	2.8	0.4	2.6	0.5	2.5	0.6
	d. ET Homestead	30.0	4.7	28.2	6.0	27.1	6.9
	Sub total	<b>39.6</b>	<b>6.2</b>	<b>37.2</b>	<b>7.9</b>	<b>35.7</b>	<b>9.1</b>
6 Non Process Depletion (non-benefit)	ET Barren land, flood plain and water bodies.	<b>5.6</b>	<b>0.9</b>	<b>5.2</b>	<b>1.1</b>	<b>5.0</b>	<b>1.3</b>
7 Out-flow	Runoff	<b>461.0</b>	<b>71.8</b>	<b>316.0</b>	<b>66.7</b>	<b>242.0</b>	<b>61.5</b>
Sum of depletion & surface run-off		<b>614.7</b>	<b>95.8</b>	<b>464.9</b>	<b>98.1</b>	<b>387.2</b>	<b>98.3</b>
Deep percolation		<b>27.2</b>	<b>4.2</b>	<b>8.8</b>	<b>1.9</b>	<b>6.6</b>	<b>0.7</b>

<sup>11</sup> This value is the % of the component to Net Inflow into the basin.



Among the three sub-components contributing to inflow into the basin, rainfall has been found to be the most significant. However, this contribution is found to differ a lot between a wet and a dry year. On the other hand, contribution through subsurface inflow has been found to be more constant. "Storage Change"<sup>12</sup> is mainly due to change in ground water storage and change in soil moisture storage.

Process depletion includes depletion for use both within the basin and outside the basin through transbasin transfer. Committed flow has been assigned considering the environmental concern of fishes in the river. Since accurate assessment of deep percolation was not possible, the difference between total inflow and the sum of depletion and surface run-off has been taken as the value for deep percolation.

### WATER INSTITUTIONS

Institutional analysis of the basin, including both the rules as well as the organizations governed by such rules, has also been carried out in detail. Water use institutions of the basin have been found to evolve and their role to change through time. In the olden times as permanent structures for the diversion of water did not exist, the main challenge for farmers was to mobilize resources for the acquisition and allocation of water. Even though the labor requirements were quit high, the social structure and norms were instrumental for such resource mobilization and need to have a formal organization for this activity was not evident.

With the expansion of agriculture, the need to have more control over water increased. As a result, not only were permanent diversion structures needed but also more formal organizations required. Thus, in all command areas where permanent diversions have been constructed by the government, Water Users' Associations (WUAs) have been formed. These associations mainly function to distribute water within their command area. Analysis of the decisions and actions taken by these associations clearly reflect the fact that their major concern is water management and resource mobilization for operation and maintenance of the irrigation system. No associations exist for command areas irrigated through inundation canals.

At the basin level, no organization is found to exist for ensuring effective water use of the basin as a whole. Even though it is understood to be the task of the government, the mechanism for its achievement is found to be ineffective. Very little attention is being given to the issue of water rights. Upstream diversions are constructed without any discussion or consensus from the downstream users. Construction of Laukat Irrigation System just 2.8km upstream of Hirapur Barrage

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<sup>12</sup> Storage change is the difference between storage at the beginning of the year and at the end of the year.

has been found to affect the water availability situation of Hirapur but this matter was not explored prior to the construction.

### CONCLUSIONS OF THE BASIN STUDY

Historical review and the present water accounting computations of Manusmara River Basin indicate that within the last few decades many changes have occurred in the amount and pattern of water use in the basin. Process depletion has increased tremendously. Table 2 displays the present water account indicators of the basin.

Table 2. Computed Basin Water Account Indicators

S.N.	Indicators	Unit	Value	Remarks
1	Productivity of water	US\$/m <sup>3</sup>	0.1	@US\$1=NRs 70
2	Depletion / Available water	%	46%	Driest year
3	Beneficial Process Consumption / Available water	%	33%	Driest year
4	Beneficial Consumption / Available water	%	44%	Driest year
5	Utilizable flow	%	50%	Driest year

Even though the major share of depletion goes to beneficial process consumption, the productivity of water is still low (\$0.1/m<sup>3</sup>). This owes to the fact that the water is not at all being used for commercial purposes like industries. It has been observed that even during the driest year, only 46% of the available water is depleted, leaving more than half of utilizable outflow to move out of the basin. In the wettest year this value of depleted water reduces to 27%. As utilizable outflow takes place throughout the year, the basin is an "open basin". This implies that there is a potential to harness utilizable outflow and use it productively both within and outside the basin.

The basin water account indicators reveal that the basin is still at the initial stage of development. The institutional mechanisms for integrated development of the available water in the basin are still weak. Since the use of water has increased drastically and is projected to further increase in the future, the need to develop a proper mechanism for this task has been urgently felt.

The basin is found to have good potential for development of ground water. Ground water has been found to contribute significantly not only to inflows but also in fulfilling the domestic water requirements. Ground water potential can be further harnessed to fulfill irrigation requirements as well. Conjunctive use of

surface and ground water, with proper development of ground water during the winter is a good option.

No storage reservoir exists within the basin. In order to tap the high discharge during the monsoon, storage reservoirs would be an option. However, considering the flat topography, construction of storage reservoirs in this basin is not advisable. Rather, a more systematic development of diversions that further enhance water consumption not only within the basin but also to the neighboring basin is recommended.

In order to plan the use of outflows from the basin need of an appropriate institutional mechanism has been felt necessary. An institutional structure that enable participation of beneficiaries from each diversions with an apex body which works for the optimum use of the resources of the whole basin has been suggested to be formed in the near future.

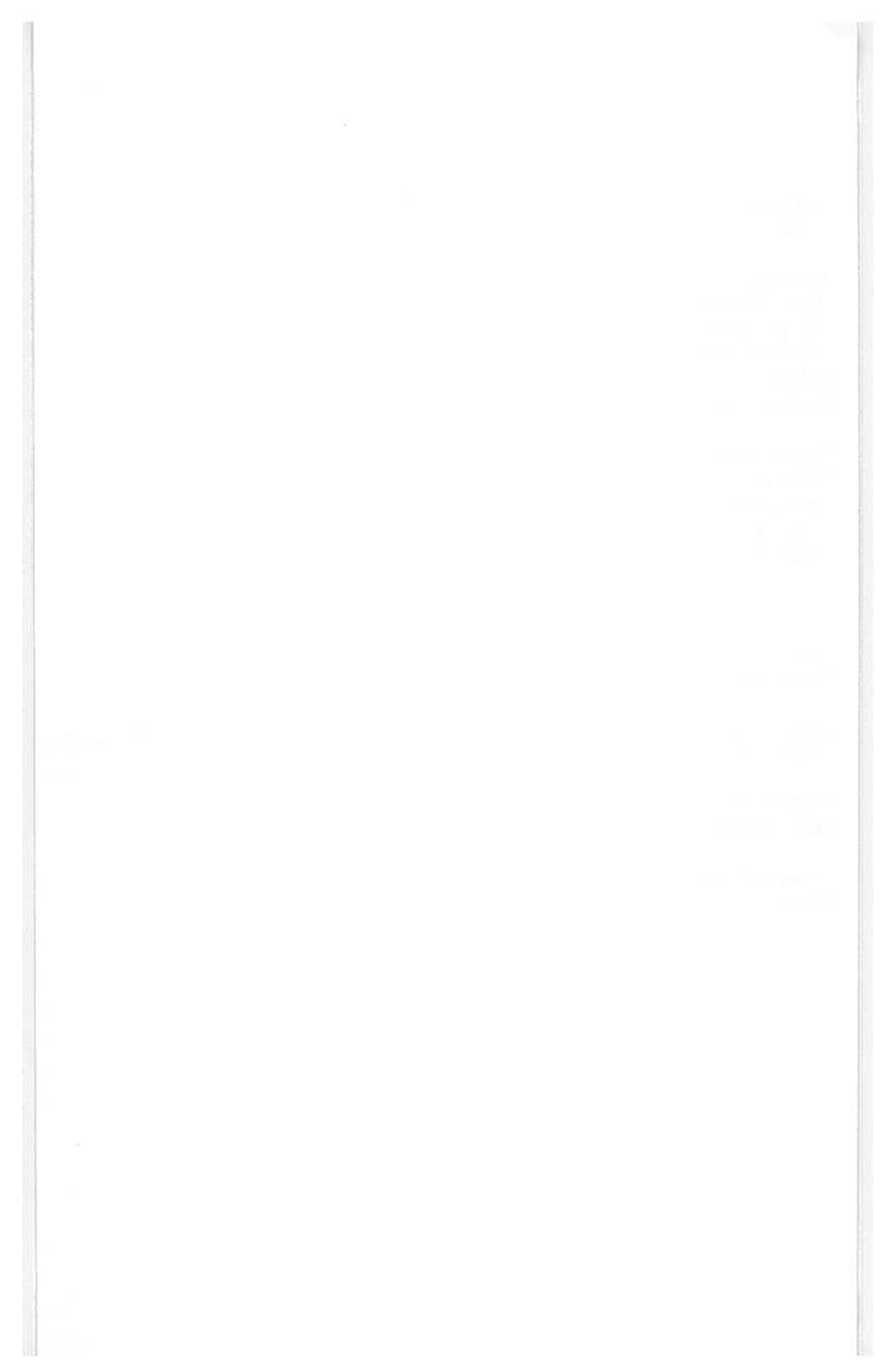
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# TRANSBASIN TRANSFER OF RIVER WATERS IN PUNJAB FOR OPTIMISING BENEFITS

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Rakesh Kashyap<sup>2</sup>

## ABSTRACT

To utilise the waters of the rivers Sutlej, Beas and Ravi flowing through Punjab, and which come to the exclusive share of India, as per the Indus Waters Treaty-1960 between the Governments of India and Pakistan, a number of projects have been planned, constructed or are under construction on these rivers. These projects have helped in gainfully diverting the waters of river Beas in Sutlej and of river Ravi to Beas, in addition to providing multi-purpose benefits. The projects have brought an agricultural and industrial revolution to the states of Punjab, Haryana and the desert areas of Rajasthan and transformed them into granaries of India. The paper briefly describes the various projects and their salient features. The impacts of the projects on the economy, environment, health, tourism and recreation etc. have been highlighted. Since these projects have enabled the diversion of surplus waters of one river to another, studies for integrated operation and management of waters of these rivers have been carried out for deriving optimum benefits. The paper also describes the real time integrated operation techniques, factors necessitating their adoption, and computer models used for integrated operation of the Bhakra Beas system of reservoirs. It is recommended that for effective utilization of the available waters, and implementation of the real time integrated operation techniques, an automatic data collection and transmission system be installed.

## INTRODUCTION

India is bestowed with abundant water resources, but their spatial and temporal distribution is quite uneven. About 80% of the annual runoff in Himalayan rivers and 90% in Peninsular rivers occurs during the four monsoon months from June to September. Due to this, floods and droughts are occurring almost every year causing extensive loss to the economy and suffering to people. A number of reservoirs have, therefore, been planned and constructed for the conservation of excess water during the monsoon period, its utilization during the lean period, and to derive multipurpose benefits. Average annual runoff of various river systems in India has been estimated at 188 million hectare metre (Mham). Only 69 Mham can be put to use, even if all the available storage is developed.

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The remaining water would flow unutilised to the sea due to temporal variations of rainfall.

The Sutlej, Beas and Ravi rivers in the Indus basin constitute a major source of water for irrigation to Punjab, Haryana and Rajasthan. A number of projects on these rivers have been planned and constructed for the optimal development of water resources to transfer the excess water from one river to another, and to derive multi-purpose benefits. These projects have contributed significantly in meeting irrigation, municipal and industrial demands and the generation of hydel power, in addition to mitigating the flood menace.

Optimal utilization of the waters of the three rivers came to the exclusive share of India as per the Indus Waters Treaty (1960) concluded between the Governments of India and Pakistan. Bhakra and Nangal dams were constructed on the river Sutlej. Pong and Pandoh dams, and the Beas-Sutlej link on the river Beas, and the Ranjit Sagar dam is under construction on the river Ravi. The construction of these dams and diversion structures has not only helped in the conservation of excess monsoon flows, but also created an agricultural and industrial revolution in the states of Punjab, Haryana and Rajasthan. Even the far flung desert districts of Rajasthan, like Bikaner, Jaisalmer and Ganganagar have been transformed into green and fertile lands. The excess waters of river Ravi are being diverted to river Beas and those of river Beas to river Sutlej, through the Beas-Sutlej link. This not only avoids water going to waste but also increases irrigation & hydro potential. Drinking water requirements of big cities like Delhi & Chandigarh are being augmented by the waters of Bhakra reservoir.

The Bhakra-Beas reservoir system is one of the largest multi-purpose, multi-reservoir systems in India. It utilises the waters of the three rivers in an integrated manner. Operation of reservoirs is complicated in the case of multi-purpose uses where joint use of storage for meeting competing and conflicting demands is required. Advancements in the field of System Engineering and the modern computer facilities now available, could be effectively utilised for integrated planning and management of water resources of the basin.

Real time hydro-meteorological data collection and inflow forecast procedures have been implemented in some projects. This provides real time flood forecasts into the reservoirs. However, the technique of real time integrated operation of reservoirs, using computer simulation as an aid for making operation decisions, has not been attempted in India. To develop the computer based techniques of real time integrated operation, a case study of Bhakra-Beas system has been carried out by the Central Water Commission with the assistance of USAID. As a part of this study, real time stream flow forecast and reservoir operation models, along with other associated programs for data storage, inflow forecast etc., were developed. The study used the HEC series of software packages, under the guidance of two expatriate consultants.

## BASIN DESCRIPTION

The Bhakra – Beas reservoir system is one of the largest multipurpose and multi-reservoir river valley systems in India. The rivers and major tributaries in the system have perennial runoff due to snowmelt in the summer months & rainfall during monsoon and winter seasons. The rivers have interstate implications and water sharing aspects. Inter-basin transfer of water from one river basin to another, and the integrated operation of various multipurpose reservoirs having competing and conflicting demands, is necessary to mitigate floods and to authorise optimum benefits for irrigation and power.

The river Sutlej has a catchment area of 2,04,258 Sq.Km. of which 54,000 Sq. km. is in Tibet. It rises at an elevation of 4750 m above MSL from Rakas Lake, near Mansarovar lake in Tibet (China). The total length of the river from its source to the India-Pakistan border is 1078 Kms. The upper part of the catchment is permanently snow-covered. The river Beas rises from the southern face of Rohtang pass at an elevation of 4063 m above MSL. It drains an area of 20,303 Sq.Km., of which about 780 sq. Km. is under permanent snow. The total length of the river is 460 Kms and is wholly in India. The river Ravi has a catchment area of 14,042 sq. km. It is entirely in India, and rises near the Rohtang Pass. It drains the southern slopes of the Dhauladhar. From its source to the Indo-Pakistan border ( about 2.6 Kms from Amritsar) the river has a length of about 370 Kms.

## PROJECT DESCRIPTION

A number of projects have been planned or are under construction/ constructed for the integrated development of these waters. The Bhakra-Nangal projects and the Ropar and Harike head-works have been constructed on river Sutlej. The Bhakra-Nangal projects comprise the Bhakra dam, the Nangal dam, the Nangal Hydel channel with Ganguwal and Kotla power stations and the Anandpur Sahib power channel and its two power houses. The Beas projects comprise the Pandoh dam, Beas-Sutlej Link (BSL) channel and the Beas dam at Pong. The excess waters of river Beas are gainfully diverted from Pandoh dam through BSL to Bhakra reservoir. This not only helps the waters of river Beas from going waste and causing flooding downstream but also in generating power at Dehar, Bhakra-Dam and Bhakra Canal Power houses in addition to supplementing the water supplies of Bhakra reservoir. The Ranjit Sagar dam on the river Ravi is nearing completion. Surplus Ravi waters are diverted to Beas from Madhopur headworks through the Madhopur –Beas link. The Ropar and Harike headworks are constructed on river Sutlej and a network of canals from these headworks provides irrigation to Punjab, Haryana and Rajasthan. (See map, Figure-1). The various projects are briefly described below and their salient features given in Table-1.

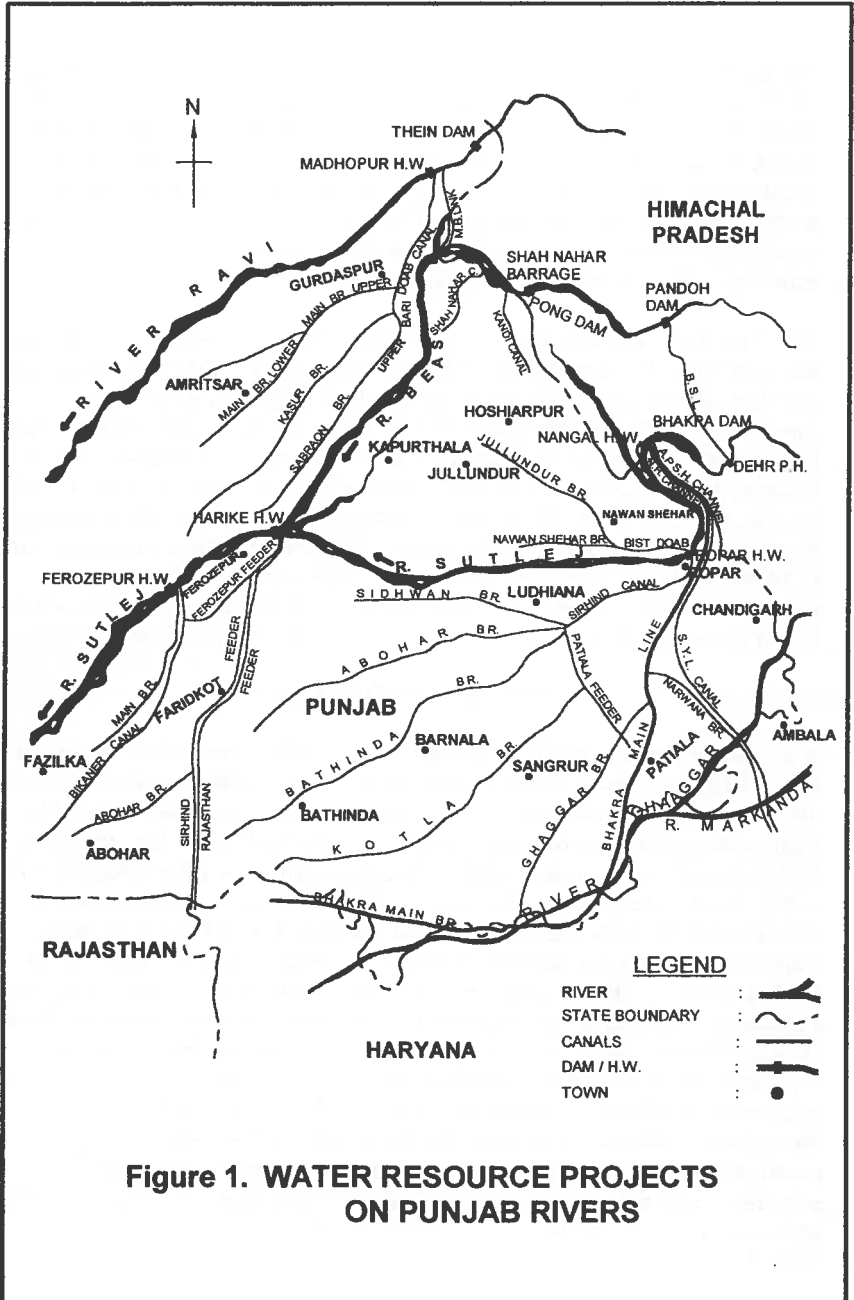


Figure 1. WATER RESOURCE PROJECTS ON PUNJAB RIVERS



Table-1

SALIENT FEATURES

	BHAKRA DAM	NANGAL DAM	PONG DAM	PANDOH DAM	R. SAGAR DAM
<b>Year of Completion</b>	1963	1954	1974	1977	Under Constn.
<b>Type of Dam</b>	Concrete Gravity	Concrete Barrage	Earth Cr.- c-gravel	Earth-c- rock fill	Earth Core cum gravel
<b>Height-(M)</b>	225.55	29	132.59	76.2	160
<b>Cost (Crores)</b>	218.24	27.04	325.88	449.17	3000
<b>Storage Cap. Mm<sup>3</sup></b>					
Initial Gr. Storage	9621	25.22	8570	41	3280
Present Gross Storage	8314	-	8040	-	-
Initial Live Storage	7191	-	7290	18.56	2344
Present Live Storage	6500	-	6392	-	-
<b>Installed Cap. (MW)</b>					
Left Bank	108	154	6x60'	6x165	4x150
Right Bank	132	-	-	-	-
<b>Design Head (m)</b>	122	28.35	72	360	-
<b>BENEFITS</b>					
Annual Generation of Elec. (Million Units)	7000	1000	1800	3600	1509
Value of Power Gener- Rated @ Rs.2/- per Unit (Crores)	1400	200	360	600	302
Water Supply ( Mm <sup>3</sup> )	16034	12334	-	-	-
New Area Irrigated Lakh Acres)	65	40	8	-	0.32 3.16
Area under improved Irrigation (Lakh acres)	22	-	-	-	-
Town Electrified	128	-	-	-	-
Villages Electrified	13000	-	-	-	-
Cost of Annl. Produce (Crores)	465	350	100	-	140

In addition benefits due to fisheries, milk production, development of major industries, tourism, improved communication, employment generation, relief from floods, increase in the rate of literacy, health & standard of living et

Bhakra Dam : The Bhakra multipurpose dam, a concrete gravity structure of 225.85 m height, is constructed across river Sutlej at the Bhakra gorge. The reservoir created by the dam, known as Gobind Sagar, has a storage capacity of 9621 MCM and a water spread of 168.35 sq. Km. The catchment area is 56,980 sq. km. The over-flow spillway and river outlets can discharge 11,326 cumecs of flood waters. There are two power houses at Bhakra, one on the left and the other on the right bank with initial installed capacities of 5x90 MW and 5x108 MW respectively. The turbines have now been renovated and the installed capacities increased to 5x120 MW & 5x132 MW respectively.

Nangal Dam & Nangal Hydel Channel: The Nangal dam situated about 13 Km down stream of the Bhakra dam has 26 bays of 9.14 m each. The pond created by the dam acts as a balancing reservoir to smooth out the diurnal variation in releases. It is designed to pass a flood of 9910 cumecs (3.5 lakh cusecs). Just upstream of the Nangal dam, two hydel channels, namely Nangal Hydel Channel and Anandpur Hydel channel, take off from the left bank of Sutlej. The Nangal Hydel channel diverts water for power generation at Ganguwal and Kotla Power Houses, by utilising the natural falls available along the channel. The Ganguwal power house is located 16 Km. from Nangal, and the Kotla power house at 10 Km downstream of Ganguwal. These two power houses together have an installed capacity of 77 MW. The water released after power generation is utilised for irrigation in Punjab, Haryana and Rajasthan through the Bhakra Main canal. The Anandpur Sahib Hydel Channel has two power houses of 67 MW each.

Pandoh Dam & Beas Sutlej Link : The Pandoh Dam is an earth rockfill diversion dam of 76 m height on the river Beas at Pandoh, 21 Km. upstream of Mandi town in H.P. on Mandi-Kulu road. In addition to generation of power, the project helps in meeting the irrigation requirements of Punjab, Haryana and Rajasthan. A chute spillway with a flip bucket for maximum designed outflow of 9939 cumecs (3,51,000 cusecs) has been provided on the left abutment. The spillway has 5 bays having radial gates of 13 m x 12m to regulate the flow of water. The Beas-Sutlej Link (BSL) envisages diversion of 4716 million cubic meters of Beas waters into the Sutlej for generation of power at Dehar Power house, and utilising a head of 320 m, producing additional power in Bhakra-Nangal reservoir system, and then utilising this water for irrigation. A tunnel of 7.62m in diameter and 13.1 Km in length, and capable of carrying 254.85 cumecs (9000 cusecs), has been constructed between the Pandoh and Baggi control works. The BSL comprises the diversion dam at Pandoh, the Pandoh-Baggi diversion tunnel, the Baggi control works, Sundernagar Hydel channel, the Sundernagar Balancing Reservoir, the Sundernagar-Sutlej tunnel and the power house at Dehar. The designed head and installed capacity of Dehar power house are 320 m and 6X165 MW respectively.

**Beas Dam at Pong:** Beas Dam at Pong is an earth core gravel shell dam of 132.59 m height across river Beas at Pong in H.P., about 25 Km from Mukerian. This is the highest earth fill dam so far constructed in India. It has a gross storage capacity of 8570 MCM of water, of which 7290 MCM constitute the live storage. Five concrete tunnels of 9.14 m in diameter and 5 Km in length constructed for river diversion during construction stage, are being used as penstocks & to control irrigation releases. After serving their function as diversion tunnels, two of these tunnels have been converted into outlets for controlled irrigation releases and three are used as penstocks. An ogee shaped chute spillway having 14.48 m x 12.34 m with six number radial gates has been provided on the left abutment of the dam. The spillway accommodates a design flood of 33,555 cumecs (11,85,000 cusecs) with a maximum discharge of 12,375 cumecs (4,37,000 cusecs). The installed capacity of Pong power plant is 6x60 MW.

**Ranjit Sagar Dam:** The project envisages the construction of a 160 m high earth core cum gravel shell type dam and a concrete spillway involving 24 million cubic meters of rock excavation and four diversion/irrigation and power tunnels of 12 m diameter each. The gross storage capacity is 3280 MCM, of which 2344 MCM is live storage. As per the Indus Waters Treaty(1960), India is entitled to utilise all the waters of rivers Ravi, Beas and Sutlej. Presently, lot of water of river Ravi is going to Pakistan. After the completion of the project, it would not only provide irrigation to 348,000 hectares in addition to generation of 600 MW of hydro-power, but the project would also help in utilising the waters passing into.

### IMPACT OF THE PROJECTS

Prior to the construction of the Bhakra-Beas projects, the Punjab State was facing famine, drought and floods year after year. Though the alluvial plains of the Indus Basin are fertile, people are subjected to periodical calamities of crop failure, loss of livestock, starvation & human lives. The farmers were at the mercy of weather. Most of the villages were not electrified and industrial development couldn't take place. After the construction of the Bhakra Beas projects, a vast network of canals now exists in Punjab, Haryana & Rajasthan to support irrigation. The plains of the Punjab have become the granaries of India. Waters of Bhakra are even reaching the desert districts of Rajasthan, such as Bikaner & Jaisalmer, where one had to travel miles in search of water. Most of the major towns of Punjab, Haryana & Western Rajasthan, along with Delhi & Chandigarh, depend on water supplies from these projects. People of Punjab have now forgotten about floods due to the mighty Sutlej and Beas rivers. They have in turn encroached upon river banks. Industrial and overall economic development of the area has taken place due to the availability of assured water, electricity and infrastructural facilities. Some of the effects of the projects are briefly described below:-

### Economy

The Bhakra Nangal project was completed in the year 1963 at a cost of Rs.245.3 crores(US \$53.3 millions), Pong dam was constructed at a cost of Rs.325.9 crores(US \$70.8 millions ) in 1974 and Pandoh dam at a cost of Rs.449.2 crores(US \$97.6 millions) in 1977. Many direct and indirect benefits have accrued to the people of the area, some of which are described below:

The projects are generating 12.8 billion units of electricity every year on an average. Using conservative rate of power at Rs.2/- per unit, the annual value of power generated is Rs.2560 crores (US\$ 556.5 millions). The projects are providing irrigation to 113 lakh acres of new land and have improved irrigation on 22 lakh existing acres. This has helped the country not only in meeting the food requirements but also providing surplus food production. The production of food grains and cash crops is estimated to be Rs. 200 billion every year. About 28,368 million cubic meters of water is being provided to meet drinking water requirements of major towns and a number of villages in the Punjab, Haryana and Western Rajasthan, including Delhi and Chandigarh. Milk production is valued at about Rs. 25 billion. There has been an increase in the development of fisheries in the Bhakra and Pong reservoirs, enabling the poor people of H.P. to earn their livelihood. Flood from rivers Sutlej and Beas in the Punjab plains were causing widespread loss of life, property, crops and land erosion, and these have been reduced. Better transport and communication facilities were created as part of the construction of these projects. Due to the availability of agricultural produce, water, power and other infrastructure facilities, industrial development in the region has increased. A lot of valuable temporary employment was generated for the construction of the projects. Additional and permanent employment opportunities have been created due to industrialisation and agriculture. A lot of indirect benefits have occurred due to increased the business activities, tourism, increase in rate of literacy and standard of living etc.

### Environment

The projects have helped to improve the environment of the whole area. Prior to the construction of these projects, the Sutlej and Beas rivers were eroding vast tracts of lands during floods. Storage available in the Bhakra and Pong reservoirs is utilised effectively for controlling floods and thus avoiding flood losses and land erosion. Production of fodder has reduced pressure on grazing lands. Earlier people were cutting forests for fuel, making coal for winter heating, etc. With the availability of electricity and cooking gas, the forests in the catchment help in reducing soil erosion. Afforestation and soil conservation measures are implemented in the catchment areas of the projects to prevent soil erosion. Earlier the sediment brought by the rivers was deposited in the river bed due to reduced velocities, thereby increasing the bed levels & reducing the carrying capacity of the rivers. With the construction of reservoirs and soil conservation measures, the

river beds in the plains are not raised & submergence of adjoining areas is avoided. Trees planted on the banks of canals and irrigation provide positive ecological effects. Earlier farmers were of the view that more irrigation water would give them more yield. This resulted in water logging and salinity problems in some areas. But the farmers are now educated in applying the required quantity of water. With proper drainage, the water logged areas have been reclaimed.

### **Health & Employment**

The projects have helped in raising the standard of living and increased the rate of literacy. A considerable amount of employment has been generated through the construction of the projects, due to the increase in agricultural production and industrialisation. Most of the villages have been electrified. The water earlier going waste and causing widespread damage during floods is being stored and later utilised for multipurpose benefits. Efforts are made to make this water available for irrigation and drinking purposes. Milk production has increased due to the availability of fodder & water. Even in the far flung desert areas of Bikaner & Jaisalmer of Rajasthan, Bhakra waters have been made available. Per capita income in the states of Punjab and Haryana is about Rs. 19,000/- and Rs. 18,000/- respectively against the national average of Rs. 11,000/-. The projects have thus helped in providing food, clean water, electricity, employment, and thus improved the health of the people.

### **Tourism and Recreation**

The Gobind Sagar Lake upstream of Bhakra dam, with a spread of 160 sq. km and a length of 90 kms, is a potential source of tourism. The lake is important to migratory birds from Siberia. A large variety of fish abound in the lake. Beautiful rose gardens, lawns at Bhakra, the natural views of the Shivalik hills, green forests, fresh air and calmness along the lake provide an ideal environment for tourism.

The Kulu, Manali, Manikaran and Rohtang pass are already the most forward tourist locations in the Beas valley, which is known for its scenic beauty. The construction of the Pandoh Dam and the Beas-Sutlej link channel have created small lakes at Sundernagar and Pandoh, which are easily accessible. The curvaceous and serpentine 11.80 Km, Sundernagar Hydel Channel, with a road on its banks, provides an enjoyable drive in the picturesque Suketi valley. The awe inspiring spectacle of Beas waters ski-jumping from the bye-pass chute at Slapper on Dehar Power Plant (Head 360 m) is another star attraction. The islands in the Bhakra and Pong Lakes could be developed into amusement parks and botanical gardens. Floating restaurants and boat rides could be introduced along with rowing, canoeing and yatching. Proper publicity given to the tourist facilities will go a long way towards developing the tourism potential of these projects.

## **REAL TIME INTEGRATED OPERATION OF RESERVOIRS**

The term 'Real Time Operation' is used to denote a mode of operation where reservoir release decisions are based on the condition of the system at that instant of time, combined with forecasts about the likely inputs over a specific time horizon. Decisions regarding releases are made relatively quickly and are based on short term information. Decisions depend on the initial reservoir storage, penalties for deviation from target storage, short term forecasts and the conditions downstream. More often, the definition of short term varies in accordance with the purpose of reservoir. If the reservoir is operated for irrigation, the short term can be a week or month. If the reservoir is operated for flood control, the short term may be daily or even hourly operation. The real time operation is especially suitable during floods, where the system response changes very fast and decisions have to be taken rather quickly and adjusted frequently.

### **Need For Computerised Operation**

In India, the existing practice of reservoir operation is generally based on empirical methods. Operation personnel make decisions based on experience and judgement. Obviously, the present practice of reservoir operation has its own disadvantages & involves certain inherent risks. It may not be possible to judge accurately the consequences of an operation decision for multipurpose reservoirs. There is danger of conservative and non-optimal utilization. Since operation decisions are to be taken relatively quickly in real time operation, high speed computers help in carrying out detailed hydraulic and hydrological simulation of reservoir systems for various possible alternatives, thereby assisting the operation in-charge in selecting the best feasible alternative. Also the operation of reservoir systems is generally based on certain operation rules, developed from historical or synthetic flow series and taking into consideration the past demands. The real time operation models are developed to react to the current situation, considering the stochastic nature of flows into the reservoir system, & serve as a powerful tool for managers in making optimal operation decisions.

### **Components of Real Time Operation**

Real time operation has great flexibility compared to the conventional methods of operation. It not only utilises the present set of available data for the system, but also takes into account meteorological and hydrological forecasts. For successful application of real time operation techniques, it is essential to have the following:

- i) a suitable network for data collection and transmission
- ii) Real time flow forecasting
- iii) Real time reservoir operation

## **REAL TIME OPERATION OF BHAKRA-BEAS SYSTEM**

Reservoir operation in the Bhakra-Beas system mainly constitutes controlled release of water downstream to various projects, depending upon the inflows, storage in the reservoirs, irrigation and power requirements and the condition of flooding downstream. The most crucial point in the operation of the system is the decision about releases, so as to ensure the filling of the reservoir by the end of the monsoon, and to derive optimum benefits from storage, while keeping in view the safety of the structures and multiple demands. For simulating integrated operation of the reservoirs, the following software packages developed by Hydrologic Engineering Centre (HEC) were found useful and have been adopted after carrying out necessary modifications to suit Indian conditions.

### **HEC Data Storage System (HECDSS)**

In real time operation, the HECDSS is a key component. It holds the data base for the reservoir system, checks its consistency and provides inputs to application programs and also stores outputs from application programs, which in turn may act as input to other application programs. Thus, the interaction between various software is accommodated through DSS. The HEC application programs retrieve or store data in DSS by referring to a system of pathnames. The DSS software does not sequentially search for data, but uses the pathname to index its position within the file. This helps in rapid storage and retrieval of data regardless of size. Several utility programs are available in HECDSS for entry, management, mathematical computation, display of data, report generation, etc. A typical pathname referring to Sutlej river daily observed flow data for the month of June, 1990 might be as follows: /SUTLEJ/RAMPUR / FLOW/01 JUN 1990/1 DAY/OBS/

### **Inflow Forecast Model (HEC1)**

The surface runoff response of a river basin to precipitation could be effectively assessed by representing the basin as an interconnected system of hydrologic and hydraulic components, and simulation of the model so developed. The HEC1 models an aspect of the precipitation-runoff process of each component, within a portion of the basin, commonly referred as a sub-basin. Representation of components requires a set of parameters, which specify the particular characteristics of the component, and the mathematical relation, which describes the physical process. The result of the modeling process is the computation of stream flow hydrographs at desired locations, which can be routed and combined to obtain the inflow forecast. Calibration and verification are obviously the essential parts of the modeling process. The HEC1 package has certain optimization techniques for the estimation of the parameters based on historical data of gauged sub-catchments.

### **Catchment Rainfall Model (PRECIP)**

One of the inputs for stream flow forecasting is the basin average rainfall, assessed from the real time rainfall data of the basin. Quite often, rainfall data from all the stations in the basin may not be available for estimation of inflow forecast, the due to practical problems, such as failure of the reporting station, delay in transmitting data, etc. Thus the station weights vary from time to time. The PRECIP program automatically calculates the basin average hyetographs from the rainfall data reported at any instant. PRECIP can retrieve data from a DSS file and write the calculated hyetograph into the DSS file.

### **Integrated Reservoir Simulation Model (HEC5)**

HEC5 is a comprehensive computer program for simulating integrated operation of reservoir systems for conservation and flood control. The flood forecast obtained from the HEC1 model can be directly input as inflow for simulation through the HEC DSS model, thus saving input time and avoiding data input errors. The program can be used in a variety of ways for planning studies and for evaluating proper reservoir releases on integrated real time basis. It can simulate the operation of systems comprising up to 20 storage reservoirs and 40 control points, and can incorporate most of the operating objectives generally encountered. The priority among purposes can be changed to some extent by input specifications. The simulation can be performed in various time intervals such as an hour, day, week, or month. The basic input requirement consists of three types of data. i) physical data including storage-discharge capacity curves and linkages defining the system structures. ii) operational data including allocation of reservoir storage for various purposes, maximum and minimum channel capacities and, iii) hydrologic and time series data consisting of flow values.

### **Model Application**

The HEC1 and HEC5 models developed for Bhakra Beas system could be used for real time integrated operation, by integrating the models through HECDSS and by continuous application of one model after another. For providing real time data inputs to the models, a network of wireless stations are presently available in the system. This system is transmitting rainfall and discharge data from various locations to the Headquarters at Nangal. However, for effective, quick and reliable real time data acquisition, it is essential that suitable DCPs be installed for automatic data collection at these stations. Transmission of data also needs to be made reliable and fast by adopting a suitable transmission media. For management of the real time data, PCs could be utilised



## CONCLUSIONS AND RECOMMENDATIONS

Though India is bestowed with abundant water resources and ranks 5th in the world in water availability, it faces water scarcity during lean periods and floods & wastage of water to the sea during monsoon months. Storage of excess water during monsoon, and inter-basin transfer of water from surplus river basins to water deficient basins are therefore, of paramount importance in meeting the ever increasing demands and multipurpose benefits.

The Bhakra-Beas system of projects has helped to a great extent in the conservation and transfer of excess water from one basin to the other, in addition to deriving multi-purpose benefits. The projects have brought an era of overall development in the area and to the people, who were subjected to floods or droughts year after year. With the availability of assured irrigation, agricultural development has taken place and the whole area transformed into the granary of India. A lot of hydel power is being generated, which has helped in the industrial development. Per capita income, rate of literacy, & the standard of living have improved.

Since these projects are the lifeline of the region and constructed with huge investment, they must be managed and operated in the best possible way. For deriving optimum multi-purpose benefits, the advancements in the field of system engineering and the modern computer facilities available now, could be effectively utilised for integrated planing and management of the various river basins.

In view of the above, the following recommendations are made:

- i) That computer models be used to help in making appropriate decisions for integrated operation of the various reservoirs.
- ii) The present study has been carried out using the water control soft-wares developed by HEC. A number of models developed by other agencies are also available for implementing the procedure. It would be desirable to implement appropriate model after modifications to suit Indian conditions.
- iii) The effectiveness of real time operation of a reservoir system mainly depends upon the data observation & transmission network in the basin. As far as possible, efforts are being made to install automatic data collection and transmission systems.
- iv) In India, the technology of automatic observation & transmission of data is still in a primitive stage. There is an urgent need to assess the state of art available & train field officers on the subject.

## ACKNOWLEDGMENTS

The authors wish to express their gratitude to USAID for funding the scheme for developing the techniques for Real Time Operation of Reservoirs.

Thanks are due to Mr. Richard Hayes, HEC and David Ford consultants, USA for providing training and guidance in installation and making operational various soft-wares. The authors are grateful to Bhakra-Beas Management Board for providing the required data for the study. The opinions expressed in the paper are of the authors and not necessarily of the Central Water Commission or Ministry of Water Resources.

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## MICHIGAN DITCH—PARADIGM FOR TRANS-BASIN DIVERSIONS?

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### INTRODUCTION

The recent population expansion along the Front Range of Colorado has significantly raised the ante in bidding wars for pieces of the finite water resource. Satisfaction of municipal water demands has come at the expense of irrigated agriculture, with transfer of in-basin (native) water being made even more costly—by legal requirements for transfers of use, point of use, and point of diversion—through Colorado's labyrinthine water law system. Waters from out-of-basin sources (imports) are attractive in the water market because they are not encumbered by requirements for extensive legal proceedings, including historic consumptive use studies to establish transferable volumes of water. Import water projects have typically been built in high-elevation watersheds, where annual yields have been generally more consistent than lower-altitude catchments, and possibilities for diversion and conveyance to alternative points of use are greater. Trans-basin diversions have therefore become attractive targets in the quest for additional municipal water supplies.

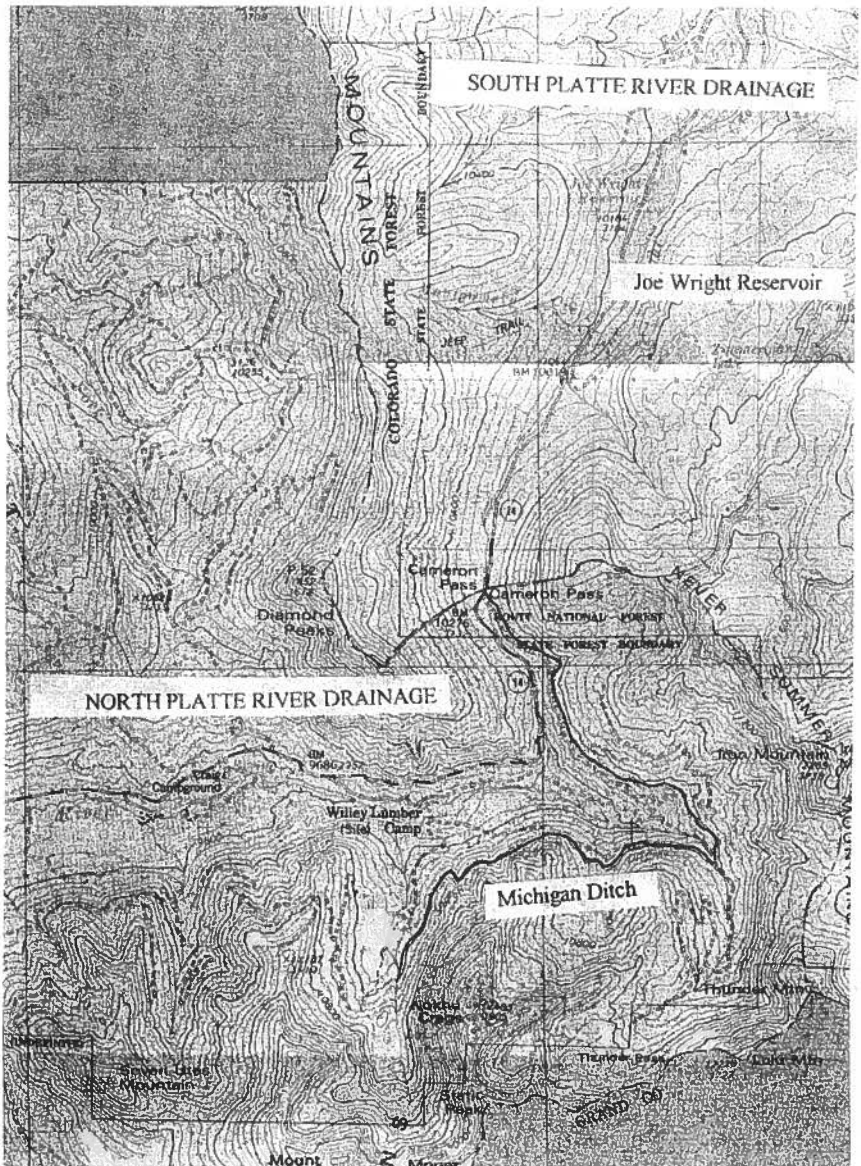
### IRRIGATION HISTORY

From its location on the southern tip of the Medicine Bow mountain chain (see Figure 1), the Michigan Ditch diverts water from the North Platte drainage into the Cache la Poudre River, via Cameron Pass and Joe Wright Creek (and Reservoir). The ditch follows an upward gradient southward from the Pass, intercepting flows from the upper Michigan River and numerous local tributaries. The Ditch and the original Joe Wright Reservoir were constructed by John McNab and William Rist. Construction was done in three stages between 1901 and 1913, to augment water supplies of the Mountain Supply Ditch Company. Following a series of (bankrupted) ownerships, the Ditch became part of the North Poudre Irrigation Company, which owned and operated the ditch until it was acquired by the City of Fort Collins in the early 1970s.

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**Figure 1** Michigan Ditch Area

The initial water control structures were built of timber; for reasons of available construction season, access, and material availability. The first stage of construction, with a decree date of July 10, 1902, included the three-mile long

reach from Cameron Pass to the middle fork of the Michigan River. The open channel in that reach traversed at least one unstable earthslide area and three areas with steep side slopes that presented continual stabilization difficulties. Under the decree of July 9, 1904, the ditch was extended another mile upstream to intercept left-side tributaries. That reach traversed a quarter-mile long area of bare, steep, unstable slope that provided continual challenges for operation and maintenance—especially when summer thunderstorms would result in debris flows into the channel. The on-going quest for trans-basin water resulted in the (conditional) decree of September 9, 1910, which involved extension of the ditch for another two miles to intercept Agnes Creek, directly below Lake Agnes. Unstable hillslopes on that upper two-mile reach resulted in the installation of a two-foot diameter wood stave pipeline in the ditch on the upper half. Parts of that original pipeline remain in service. Over time, most of the original timber structures were replaced with concrete structures made from local aggregate materials. However, the original timber diversion structure at Agnes Creek was replaced only after the ditch came under ownership of the City of Fort Collins.

As uses for its water resource have changed, the mode of operation of the ditch and reservoir system has changed as well. When the ditch provided an irrigation supply, the operation was seasonal and (with respect to rates of diversion) sometimes risky. The operational season started with snow clearing in late March to early May; then continued into October. Operations were sometimes pretty wild, with bankfull discharges screaming through the channel. A number of deep erosion scars attest to occasions when flows exceeded ditch capacity and eroded through the bank. Operational problems notwithstanding, the average annual contribution from the Michigan Ditch to North Poudre Irrigation flows was 3,267 acre-feet in the period from the mid-'20s to the mid-50s. Annual diversions through the Michigan Ditch into the Cache la Poudre River over the period of ownership by the North Poudre Irrigation Company are summarized in Table 1 at the end of this paper, and shown graphically on Figure 2.

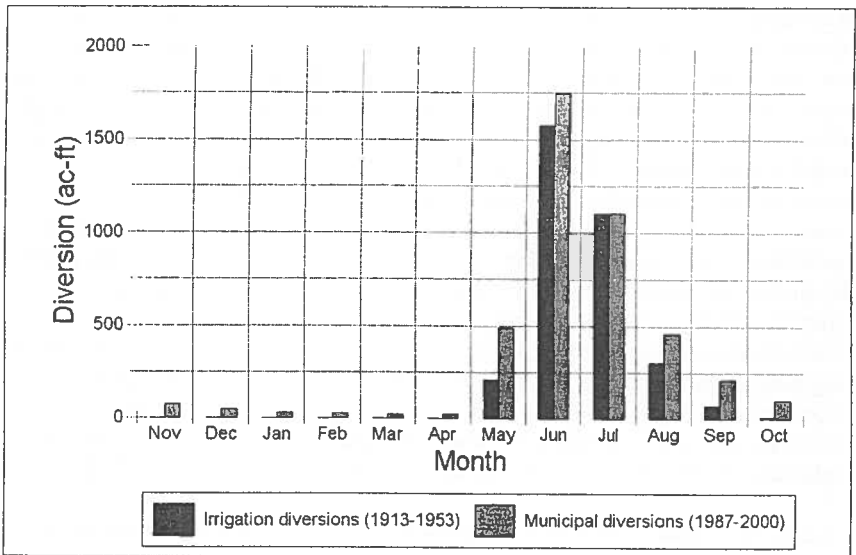


Figure 2 Michigan Ditch Average Monthly Diversions

### MUNICIPAL HISTORY

The availability of reliable supplemental irrigation water from the Colorado-Big Thompson Project, starting in the mid-50s, led to a case of somewhat studied neglect of the physical facilities on the Ditch. The combination of an alternative source of reliable water, operation & maintenance expense, and falling agricultural commodity prices led to the sale of the ditch and reservoir system to the City of Fort Collins in 1972. After the transfer of ownership, the physical condition of facilities prevented full operation of the system until after extensive improvements were made—but the ditch system continued to operate. Figure 3, below, shows the remarkable results of this neglect on water yield following the introduction of Colorado-Big Thompson water into the region.

Since acquiring the ditch and reservoir system, the City of Fort Collins has invested heavily in system improvements. Along with increasing the storage capacity of Joe Wright Reservoir, ditch improvements to insure long-term system integrity have been made. Reservoir capacity has been increased from 700 acre-feet to 11,000 acre-feet. The upper half of the ditch system has been changed over to closed conduit, which has allowed for substantial alterations to the mode of operation. The ditch is now operated year-round, with the reservoir both maintaining minimum stream flows and supplying a continuing base flow to meet municipal needs. Since rehabilitation, completed in 1987, the average annual contribution from the Michigan Ditch to municipal flows has been 4,318 acre-

feet. Annual diversions through the Michigan Ditch into the Cache la Poudre River through the current period of ownership by the City of Fort Collins are also summarized on Table 1 above, and shown graphically on Figure 2 above.

### OPERATIONAL COMPARISON

As shown in the following Figure 3, the average annual diversion under municipal ownership and maintenance has been higher than was previously experienced when operated for irrigation supplies only. This has resulted from both year-round operation of the facility, a closer degree of water control due to diversion structure configuration, and from the improved maintenance afforded to the ditch. The effect of this improved operation & maintenance can also be seen in the reduced range of annual diversion extremes.

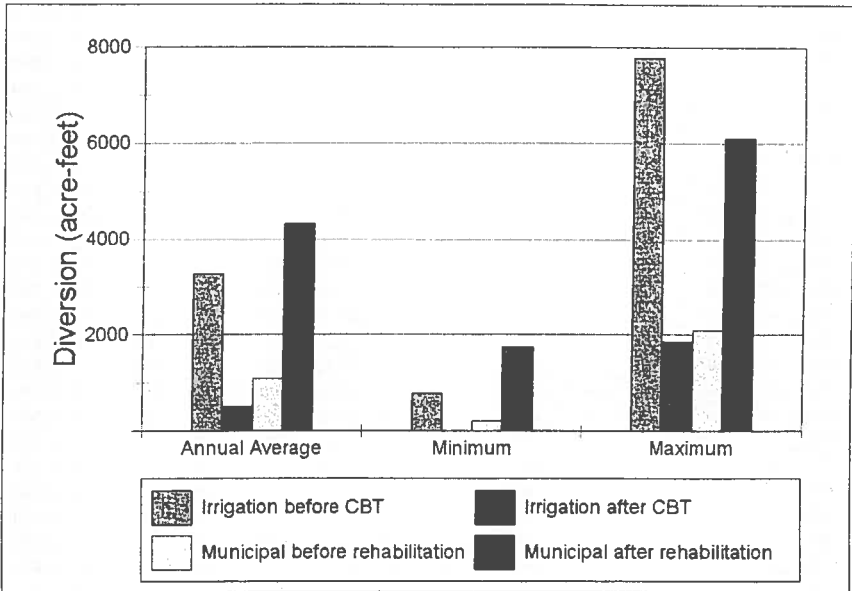


Figure 3 Michigan Ditch Annual Diversion Statistics

### CONCLUSIONS

- The range of ditch annual operating extremes has been reduced under municipal operation.
- Closer control of ditch operation and maintenance by municipal staff has increased average annual yield by 132 percent.

Transbasin Water Transfers

- Operation of the ditch/reservoir delivery system has benefitted the low-flow regime of the Cache la Poudre River from Joe Wright Creek to the Fort Collins diversion.
- The supply system component of the Michigan Ditch and Joe Wright Reservoir have increased drought reliability of City water supplies.
- The evolution of the Michigan Ditch indicates a possible trend in ownership and operation of some of the localized trans-basin diversions, toward municipalities. An advantage which accrues from the nature of imported waters is that, once used for municipal demands, all return flows (with re-regulation) are still available for irrigation.

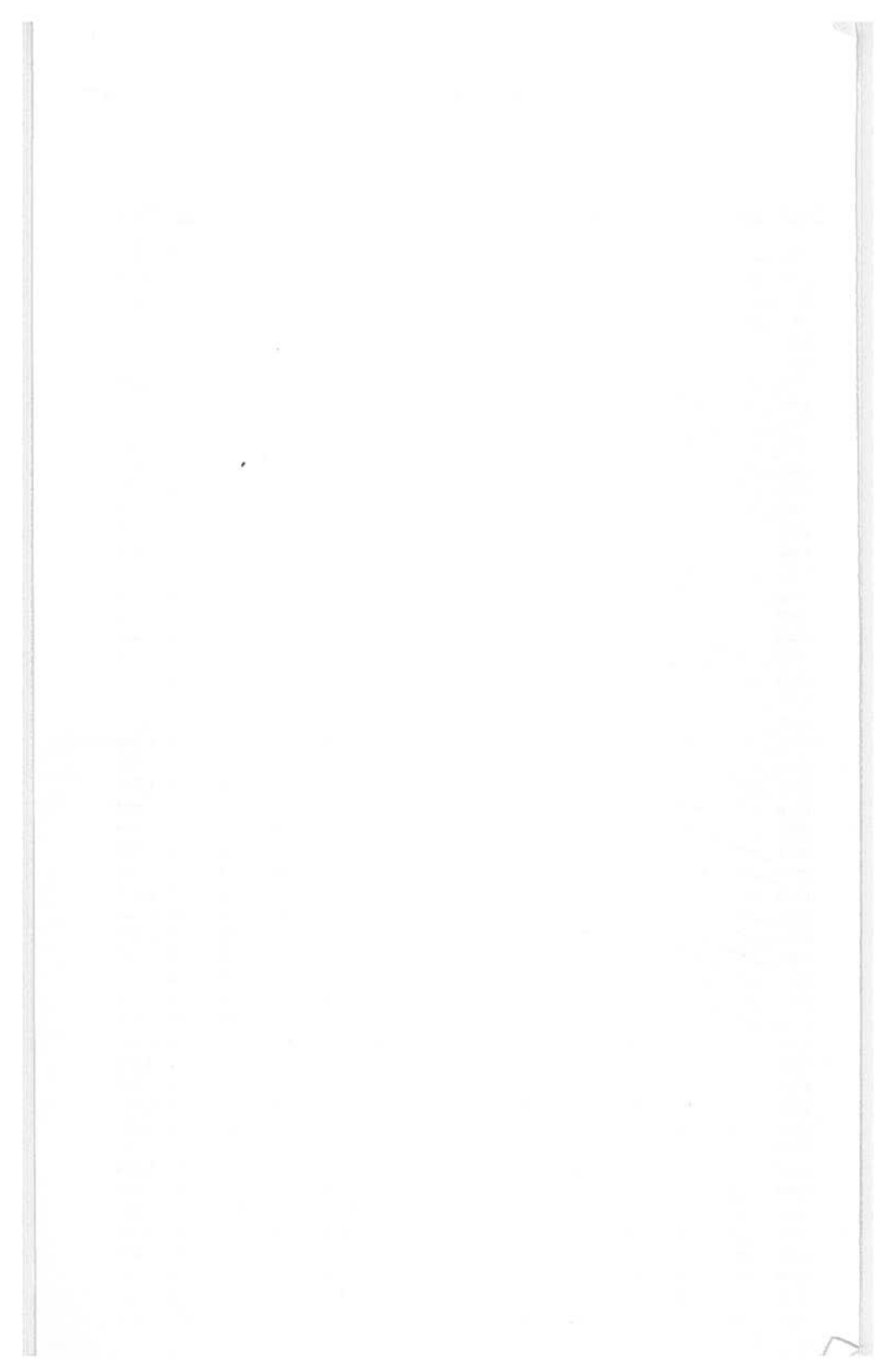
Table 1: Annual Michigan Ditch Diversions

<u>YEAR</u>	<u>Nov</u>	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>TOTA</u>
													<u>L</u>
1913	/	/	/	/	/	/	0	0	1,540	617	220	227	83 2,687
1914	/	/	/	/	/	/	0	0	427	1,290	391	165	0 2,273
1915	/	/	/	/	/	/	0	0	647	1,240	229	0	0 2,116
1916	/	/	/	/	/	/	0	0	1,990	2,160	1,130	537	81 5,898
1917	/	/	/	/	/	/	0	0	0	954	306	34	0 1,294
1918	/	/	/	/	/	/	0	77	1,360	825	121	0	0 2,383
1919	/	/	/	/	/	/	0	625	1,220	468	83	0	0 2,396
1920	/	/	/	/	/	/	0	0	1,640	1,810	331	0	0 3,781
1921	/	/	/	/	/	/	0	198	1,120	1,270	427	101	0 3,116
1922	/	/	/	/	/	/	0	198	2,280	595	218	69	0 3,360
1923	/	/	/	/	/	/	0	115	1,520	3,070	664	98	0 5,467
1924	/	/	/	/	/	/	0	439	750	931	292	0	0 2,412
1925	/	/	/	/	/	/	0	903	3,600	1,810	778	596	95 7,782
1926	/	/	/	/	/	/	0	317	2,670	1,840	702	375	0 5,904
1927	/	/	/	/	/	/	0	299	2,420	1,530	500	62	0 4,811
1928	/	/	/	/	/	/	0	0	1,510	2,210	552	168	0 4,440
1929	/	/	/	/	/	/	0	0	2,310	2,000	770	416	0 5,496
1930	/	/	/	/	/	/	0	308	1,880	665	689	63	0 3,605
1931	/	/	/	/	/	/	0	625	2,630	789	372	0	0 4,416
1932	/	/	/	/	/	/	0	275	2,320	1,530	394	17	0 4,536
1933	/	/	/	/	/	/	0	52	3,360	1,240	228	0	0 4,880
1934	/	/	/	/	/	/	0	581	405	28	0	0	0 1,014
1935	/	/	/	/	/	/	0	0	1,840	1,650	394	0	0 3,884
1936	/	/	/	/	/	/	0	746	2,490	759	488	0	0 4,483
1937	/	/	/	/	/	/	0	283	1,360	693	87	0	0 2,423
1938	/	/	/	/	/	/	0	141	3,040	1,530	217	0	0 4,928
1939	/	/	/	/	/	/	0	656	1,520	30	78	0	0 2,284
1940	/	/	/	/	/	/	0	332	1,240	182	25	0	0 1,779
1941	/	/	/	/	/	/	0	612	2,130	566	91	0	0 3,399
1942	/	/	/	/	/	/	0	0	56	728	2	0	0 786
1943	/	/	/	/	/	/	0	0	655	839	43	0	0 1,537
1944	/	/	/	/	/	/	0	0	1,070	706	31	0	0 1,807
1945	/	/	/	/	/	/	0	0	834	1,660	596	0	0 3,090
1946	/	/	/	/	/	/	0	0	1,880	122	18	0	0 2,020
1947	/	/	/	/	/	/	0	0	815	2,040	406	0	0 3,261
1948	/	/	/	/	/	/	0	586	1,240	23	64	0	0 1,913
1949	/	/	/	/	/	/	0	0	691	1,600	72	0	0 2,363



# Michigan Ditch

YEAR	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	TOTA
													L
1950							0	21	1,810	240	0	0	2,071
1951							0	127	1,800	2,080	301	0	4,308
1952							0	0	1,080	916	82	0	2,078
1953							0	0	1,450	0	0	0	1,450
1954							0	0	0	0	0	0	0
1955							0	0	0	0	0	0	0
1956							0	249	1,610	0	0	0	1,859
1957							0	0	0	1,010	165	0	1,175
1958							0	0	0	0	0	0	0
1959							0	0	1,080	462	0	0	1,542
1960							0	0	1,440	26	0	0	1,466
1961							0	0	127	0	0	0	127
1962							0	0	0	0	0	0	0
1963							0	0	0	0	0	0	0
1964							484	0	0	0	0	0	484
1965							0	0	63	1,012	9	0	1,084
1966							0	0	0	0	0	0	0
1967							0	0	0	0	0	0	0
1968							0	0	748	688	0	0	1,436
1969							0	0	0	0	0	0	0
1970							0	0	0	0	0	0	0
1971							0	0	0	0	0	0	0
1972							0	399	1,282	83	0	0	1,764
1973							0	0	451	1,190	235	14	1,890
1974							0	521	795	368	94	6	1,784
1975							0	104	359	1,158	90	0	1,711
1976							0	253	1,241	67	133	0	1,694
1977							0	0	333	61	59	0	453
1978							0	0	77	228	0	0	305
1979							0	0	0	407	309	33	749
1980							0	0	479	446	150	12	1,087
1981							0	96	446	409	102	64	1,183
1982							0	2	841	951	269	36	2,099
1983							0	0	0	0	182	121	322
1984							0	0	0	200	0	0	200
1985							0	144	0	178	0	0	322
1986							0	0	0	353	195	159	860
1987	123	55	49	44	0	0	702	849	587	377	21	6	2,813
1988	0	0	0	9	0	0	355	3,104	855	249	113	45	4,730
1989	0	0	0	1	5	6	611	524	131	342	75	58	1,753
1990	41	36	42	14	15	15	31	1,911	0	309	175	85	2,674
1991	67	26	13	6	7	9	476	2,208	1,079	404	211	93	4,600
1992	9	20	0	4	8	10	1,193	1,759	1,011	366	217	123	4,720
1993	2	0	0	0	0	0	545	2,244	2,166	610	219	103	5,889
1994	120	85	48	42	42	53	1,011	1,648	536	234	136	87	4,043
1995	47	31	21	16	26	25	28	1,649	2,777	897	231	179	5,927
1996	156	106	76	72	65	51	654	1,117	656	267	201	127	3,549
1997	113	68	44	28	15	19	468	1,980	1,601	873	697	191	6,098
1998	237	107	65	46	44	42	126	1,936	1,700	631	231	125	5,291
1999	96	52	40	42	47	54	353	1,124	1,502	406	0	0	3,715
2000	46	49	31	21	16	11	319	2,390	846	418	370	133	4,651



## **A HISTORICAL VIEW: TRANSMOUNTAIN DIVERSION DEVELOPMENT IN COLORADO**

John N. Winchester, P.E.<sup>1</sup>

### **ABSTRACT**

As the headwaters for seven major rivers, water resources in Colorado have been diverted for use for over 150 years. Transbasin diversions have been developed to move water from one river basin to another, including transmountain diversions, which move water over the continental divide. Transmountain diversions have historically been developed to provide water for irrigated agriculture and municipal purposes. This paper briefly discusses the development of each of Colorado's 30 transmountain diversions between the Colorado, South Platte, Arkansas and Rio Grande river basins, and provides a summary of diversions for recent years.

### **INTRODUCTION**

Many people in the Colorado water community have traditionally divided transbasin diversions into two categories: transmountain diversions, which move water from one side of the continental divide to the other, and transbasin, where water is moved between basins that ultimately drain to the same ocean. In addition to surface water diversions, there are also geological formations that allow wells located in one basin to pump water native to another.

### **BACKGROUND**

Based on the 2000 Census and the Colorado State Engineer's records, the front range of Colorado (the east slope, excluding the North Platte and Rio Grande basins) has 89% of the state's population but only 16% of the state's water (USCB, 2000; SEO, 2000). Because the front range and the eastern plains of Colorado are in a semi-arid environment, transmountain diversions, diversions from one side of the continental divide to the other, have been constructed to move water to the eastern slope to help satisfy the region's demand for water.

As a prior appropriation state, water users who first put water to a beneficial use and obtained a water right have the right to do so over users who started using water later in time. The right to divert water from one basin to another is administered under the prior-appropriation system, like other water rights. The oldest surface water diversion in continuous use in Colorado is the San Luis Peoples Ditch in the San Luis Valley, with a priority date of April 1852. The first transmountain diversion recorded in Colorado was constructed 8 years later in 1860, to provide water for

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mining near the town of Fairplay. The East and West Hoosier ditches diverted water from the headwaters of the Blue River into the Middle Fork of the South Platte River. Since 1860, 30 ditches and tunnels have been constructed to move water over the continental divide for irrigation, domestic, commercial and industrial uses.

**TRANSMOUNTAIN DIVERSION PROJECTS**

Broadly speaking, the development of transmountain diversions in Colorado has occurred in two waves, with a group of projects developed around the 1930's to provide supplemental water for irrigation, and another set of projects constructed in the 1960's and 1970's to provide water for municipal purposes. Many projects originally built to provide irrigation water have been changed, at least in part, to municipal and other non-agricultural uses.

Figure 1 shows the location of the active transmountain diversions in Colorado. Table 1 shows the 1990-1999 10-year average diversion, and the year 2000 diversion for each of the projects. Following these are descriptions of Colorado's transmountain projects, arranged by basin, and listed in order, from north to south.

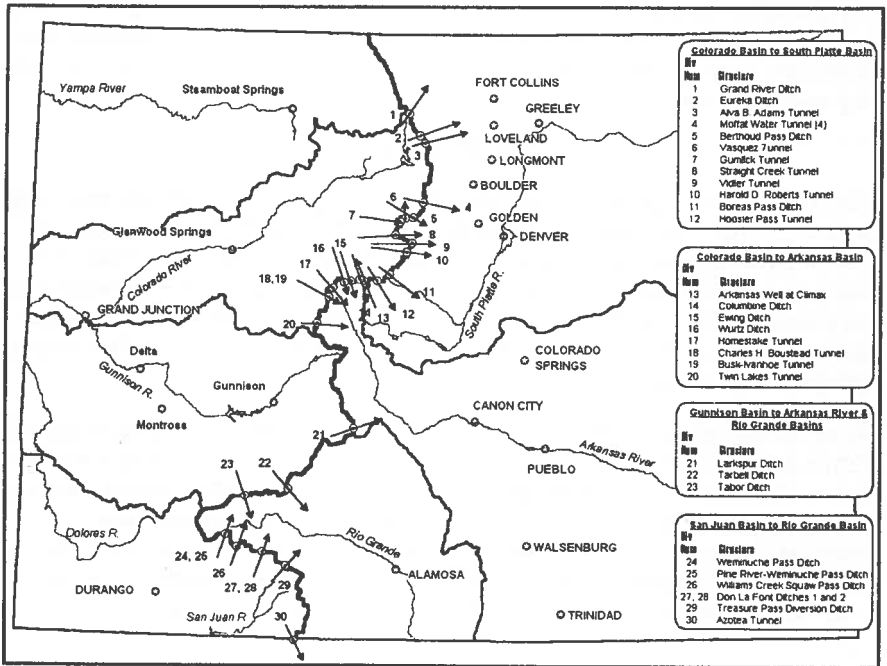


Figure 1. Transmountain Diversions in Colorado.

Table 1. Summary of Transmountain Diversions.

Diversions Number	Structure	Quantity Diverted Water Year (Oct 1 - Sep 30)			Principal Owner / Contact
		1985 (1) (AF)	1990-1999 10-year mean (AF)	2000 (3) (AF)	
1	Grand River Ditch	20,831	20,460	18,559	Water Supply and Storage Co.
2	Eureka Ditch	0	128	0	City of Loveland
3	Alva B. Adams Tunnel	285,200	205,718	247,735	Northern Colorado Water Conservancy District
4	Moffat Water Tunnel (4)	77,545	44,318	51,726	City of Denver
6	Gumlick Tunnel		2,340	2,781	City of Denver
7	Berthoud Pass Ditch	567	950	0	City of Northglenn
8	Straight Creek Tunnel	409	323	370	Adolph Coors Company
9	Vidler Tunnel	369	643	332	Vidler Water Company
10	Harold D. Roberts Tunnel	299	61,789	93,645	City of Denver
11	Boreas Pass Ditch	40	139	111	City of Englewood
12	Hoosier Pass Tunnel	7,400	9,939	10,770	City of Colorado Springs
13	Arkansas Well at Climax	0	230	0	Vall Associates
14	Columbine Ditch	1,809	1,773	1,720	Pueblo Board of Water Works
15	Ewing Ditch	1,359	1,057	1,030	Pueblo Board of Water Works
16	Wurtz Ditch	3,832	2,762	2,080	Pueblo Board of Water Works
17	Charles H. Boustead Tunnel	71,797	59,740	44,830	US Bureau of Reclamation
18	Homestake Tunnel		23,048	26,914	Cities of Aurora / Colorado Springs
19	Busk-Ivanhoe Tunnel	8,268	4,740	5,210	Pueblo Board of Water Works, Aurora
20	Twin Lakes Tunnel	8,016	38,452	42,117	Twin Lakes Reservoir and Canal Co.
21	Larkspur Ditch	329	31	0	Callin Canal Company
22	Tarbell Ditch	172	419	630	Private Individuals (3)
23	Tabor Ditch	1,435	495	485	Colorado Division of Wildlife
24	Weminuche Pass Ditch	2,088	1,099	0	Colorado Division of Wildlife
25	Pine River-Weminuche Pass Ditch	873	491	203	San Luis Valley Conservation District
26	Williams Creek Squaw Pass Ditch	253	359	230	Navajo Development Company
27, 28	Don La Font Ditches 1 and 2	447	201	10	Colorado Division of Wildlife
29	Treasure Pass Diversion Ditch	613	123	70	Private Individual
30	Azotea Tunnel	91,790	96,189	40,506	US Bureau of Reclamation
TOTAL		751,279	577,954	592,074	

## Notes:

1. U.S. Geological Survey. Estimated Use of Water in Colorado, 1985, Water-Resources Investigation Report 88-4101. 1985.
2. Based on Irrigation year, Nov 1 - Oct 31
3. All year 2000 data should be considered preliminary.
4. Does not include Gumlick / Vasquez diversions.

**Colorado Basin into the South Platte Basin**

**Grand River Ditch:** The Grand River Ditch diverts from numerous streams tributary to the North Fork of the Colorado River and delivers the water over La Poudre Pass into Long Draw Creek, a tributary of the Cache la Poudre River. The ditch is 14.2 miles long and is located entirely within Rocky Mountain National Park. The ditch is owned by the Water Supply and Storage Co. and the water is used as a supplemental irrigation supply. The ditch has an appropriation date of September 1, 1890, and a decreed capacity of 524.6 cubic feet per second. The Grand River Ditch generally diverts from late May or early June until late September. Flows are measured through a 10-foot Parshall Flume, equipped with telemetry.

Long term average diversions are about 18,530 acre-feet per year. The water year 1990-1999 average annual diversions were 20,460 acre-feet. The year 2000 diversion was 18,559 acre-feet (CDSS, 2000, Seivers, 2000).

**Eureka Ditch:** The Eureka Ditch was a small ditch which diverted water from the headwaters of Tonahutu Creek, tributary of the North Fork of the Colorado River

approximately one mile north of Grand Lake, owned by the City of Loveland. The 0.8 mile long ditch had an estimated capacity of 0.85 cubic feet per second. The ditch collected surface runoff from the southwest side of Sprague Pass and conveyed it over into the headwaters of Spruce Creek, tributary of the Big Thompson River. The ditch was located entirely within Rocky Mountain National Park. Because the 11,700 foot elevation of the ditch made it difficult to maintain, the City exchanged the ditch for shares of the Colorado-Big Thompson project owned by the U.S. Park Service in 1995. The Park Service removed the diversion and backfilled the ditch. Water previously captured by the ditch now continues to flow westward and is used for instream flow purposes.

The annual diversion has ranged between 0 and 260 acre-feet per year, with an average annual diversion of 34 acre-feet. The 1990-1992 average annual yield was 128 acre-feet, with no diversions since 1992 (CDSS, 2000; Howard, 2000).

Alva B. Adams Tunnel: The 13.1-mile Alva B. Adams Tunnel transports water west to east 3,800 feet beneath the Continental Divide, a tunnel second in length only to the Roberts Tunnel. The Adams Tunnel is part of the Colorado - Big Thompson (CBT) project, which is owned by the U.S. Bureau of Reclamation and managed by the Northern Colorado Water Conservancy District. The project furnishes supplemental irrigation water to approximately 720,000 acres, domestic water to more than 400,000 people in the South Platte River Basin, and generates hydroelectric power. The project also conveys water from the Windy Gap Project from the west to east slope.

The tunnel passes under Rocky Mountain National Park, which receives both electricity and water from the project. The west portal is at an elevation of 8340 feet, the east portal is at an elevation of 8240 feet, and the tunnel passes under Andrews Pass nearly 3700 feet below the ground surface. Excavation from the east portal lasted 37½ months and averaged 1,146 feet per month, while west portal contractors worked 31 months and averaged 833 feet per month. The tunnel holed through on June 10, 1944, with a difference in alignment of less than one inch.

The 9-foot, 9-inch tunnel was lined with a one-foot thick concrete ring. A 69-Kilovolt transmission line, encased in a pipe running along the roof of the tunnel, connects east and west slope power facilities. The tunnel has a capacity of 550 cubic feet per second. The 1990-1999 average annual delivery was 205,718 acre-feet, with a 2000 delivery of 247,735 acre-feet (U.S.B.R., 2000).

Moffat Water Tunnel: The Moffat Tunnel is owned by the Denver Water Board and delivers water from the Williams Fork and Moffat collection systems in the Colorado River basin, under the Continental Divide into South Boulder Creek to Gross Reservoir. The tunnel was originally the pilot bore for the Moffat Railroad Tunnel, and is located 75 feet south of, and parallel to, the railroad tunnel. The west portal is near the Winter Park Ski Area at an elevation of 9,091 feet.

The circular tunnel is fully lined, 10.5 feet in diameter, 6.1 miles long, and designed

to operate under pressure. The tunnel has a capacity of 1,280 cubic feet per second. The pioneer bore was completed in 1927. The tunnel was enlarged and partially lined in 1935-36. The first western slope water flowed east on June 10, 1936. Lining the tunnel was completed 1958.

Deliveries through the Moffat Tunnel include water from the Williams Fork collection system, which has already flowed through the Gumlick and Vasquez tunnels. The tunnel also conveys an average of 2300 acre-feet of water from the City of Englewood's Ranch Creek and Meadow Creek collection systems, which was completed in the 1940's.

The 1990-1999 mean annual diversion through the Moffat Tunnel (excluding water from the Gumlick/Vasquez tunnels) was 44,318 acre-feet. The year 2000 diversion was 51,726 acre-feet (DWB, 2000; Lewellen, 2001; Wood, 2001).

Berthoud Pass Ditch: The Berthoud Pass Ditch is owned by the Cities of Northglenn and Golden, which each receive approximately half its yield. The ditch diverts water from the headwaters of the Fraser River and delivers it into the headwaters of the West Fork of Clear Creek. The diversion includes a ditch that collects surface runoff, and a short tunnel that carries the water under the parking lot for the Berthoud Pass Ski Area. The ditch is 3.5 miles long and diverts water from the northwest side of Berthoud Pass above 11,300 feet in elevation.

The ditch has an appropriation date of June 30, 1902, a decreed capacity of 53.4 cubic feet per second, and was originally used for irrigation. Northglenn and Golden purchased the ditch from FRICO in the mid-1980's, and the water is now used for municipal purposes. The Berthoud Pass Ditch typically diverts during June and July.

The 1990-1999 average annual yield was 950 acre-feet, though the ditch did not divert in 1999 or 2000 due to a collapse in the tunnel. With repairs to the tunnel complete, the ditch is expected to divert water in 2001 (CDSS, 2000; Moore, 2000).

Vasquez Tunnel: The Vasquez Tunnel was constructed by Denver to convey water from the east portal of the Gumlick Tunnel in Clear Creek, north under the continental divide to the Fraser River basin. The Gumlick and Vasquez tunnels are connected by a short conduit. The Vasquez Tunnel conveys water from the Williams Fork collection system to the Moffat Tunnel, thence to South Boulder Creek.

The southern, or east slope, portal is located at an elevation of 10,310 feet, and the north, or west slope, portal is located at 10,210 feet. The tunnel is 3.4 miles long, with a 7 foot, horseshoe cross section. The tunnel has a capacity of 550 cubic feet per second and was completed in 1958.

The 1990-1999 mean annual diversions through the Vasquez Tunnel were 2070 acre-feet, with the diversions being equal to those of the Gumlick Tunnel in 7 of the last 10 years. The 2000 diversion was 2781 acre-feet, the same as the Gumlick Tunnel.

Gumlick Tunnel: The Gumlick Tunnel (a.k.a. the Jones Pass Tunnel) is owned by the Denver Water Board. It carries water diverted by the Williams Fork collection system on the west slope to the West Fork of Clear Creek, which is tributary to the South Platte. The tunnel was originally completed in 1940, with lining and other improvements undertaken in 1957-1958. The tunnel is 2.9 miles long, fully lined, with a 7-foot horseshoe shaped cross-section. Water is diverted at the west portal at an elevation of 10,313 feet, to the east portal at 10,000 feet, 11 miles west of the town of Empire. The tunnel has a capacity of 550 cubic feet per second.

The Williams Fork collection system diverts water from Steelman Creek at an elevation of 10,480 feet and Bobtail Creek at 10,313 feet. Originally, water carried through the Gumlick Tunnel was delivered to Clear Creek. After the completion of the Vasquez Tunnel in 1958, water has typically been re-diverted from Clear Creek back to the west slope to the Fraser River basin, though in 3 years of the last 11 water delivered through the Gumlick was allowed to flow down Clear Creek.

The water year 1990-1999 annual average diversion through the tunnel was 2340 acre-feet, with a year 2000 diversion of 2781 acre-feet.

Straight Creek Tunnel: The Straight Creek Tunnel is located approximately 60 miles west of Denver, and carries west-bound Interstate 70 under the continental divide. The tunnel was renamed the Dwight D. Eisenhower Memorial Bore in 1972. The tunnel is the highest vehicular tunnel in the world, with an elevation of 11,013 feet at the East Portal and 11,158 feet at the West Portal. The tunnel is operated by the Colorado Department of Transportation. Construction on Straight Creek Tunnel took 5 years, with the tunnel opening to traffic on March 8, 1973.

Water from the Straight Creek Tunnel comes from two sources; a transmountain diversion that is piped under the continental divide for industrial use at the tunnel, and tunnel seepage. Water from both sources is discharged into Clear Creek, and the Adolph Coors Company holds a decree for the right to use the water discharged from the tunnel. The decree was filed by Coors while the tunnel was under construction.

Water used at the tunnel is diverted from Straight Creek via an infiltration gallery and stored in an underground reservoir near the west portal of the tunnel. The water is then piped through the tunnel, with taps for fire fighting and other non-potable uses. A water treatment plant located at the east portal treats the water to potable standards. Drainage for tunnel seepage is provided beneath the roadway. Wastewater from the potable system, drainage from non-potable uses and tunnel seepage all flow to the east portal, where it is treated and then discharged into Clear Creek.

The 1990-1999 annual average delivery to Clear Creek was 316 acre-feet, with a 2000 yield of 370 acre feet. Water from the Straight Creek Tunnel diversion is used for augmentation purposes by the Adolph Coors Company or others to which it leases the water. (CDOT, 2000; Vaught, 2000).

Vidler Tunnel: The Vidler Tunnel is owned by the City of Golden. The water is used



primarily for augmentation and municipal purposes in the Clear Creek basin, though some of the water has been purchased for augmentation purposes in Summit County. The Vidler Tunnel diverts water from the headwaters of Peru Creek, a tributary of the Blue River, under Argentine Pass and into the headwaters of Leavenworth Creek, a tributary of Clear Creek. The water used in Summit County stays in the Blue River basin and so is not transbasin in nature. The majority of the diversions occur during the months of June, July and August.

Rees Vidler bought the Horseshoe Tunnel (a.k.a. Good Luck Tunnel) in 1902, intending to extend the tunnel under the continental divide to connect the railroads at Silver Plume and Keystone. Financing to complete the tunnel was never found, and the mining claims overlaying the Vidler tunnel reverted to Clear Creek and Summit counties due to unpaid taxes. In 1952, Herbert Young began buying the claims in the Vidler Claims Group, all but one of which were purchased for back taxes. In 1956 the Vidler Tunnel was presented as an alternative for a highway tunnel under the continental divide, but was rejected because the grade was too great for automobile traffic. Young then purchased an option on water rights located above the confluence of Soda Creek and the Snake River. In 1967 financing was found and in 1968 the 1.4 mile long tunnel was completed. The first water flowed through the tunnel in 1969, and the collection system, which diverts water above an elevation of 11,000 feet, was completed in 1970. The tunnel is decreed for 31.5 cubic feet per second.

The 1990-1999 water year average annual diversion was 643 acre-feet, and the 2000 water year diversion was 332 acre-feet (Vidler, 2000; CDSS, 2000; Hydrosphere, 1999; Young, 1991; Burcher, 2001).

Harold D. Roberts Tunnel: At 23.3 miles, the Roberts Tunnel is the longest major tunnel water delivery tunnel in the world, approximately as long as the tunnel under the English Channel. Construction on the pilot bore began on September 17, 1942, and was completed in 1962. The west portal lies opposite Dillon Dam on the bottom of Dillon Reservoir. The east portal is near the town of Grant. The bore has two horizontal bends and a maximum overburden of 4465 feet.

The fully lined tunnel is 10.25 feet in diameter, designed to operate under pressure, and has a capacity of 1020 cubic feet per second. The tunnel flows by gravity, with the west portal at an elevation of 8,845 feet, 174 feet higher than the eastern portal. The first water flowed through the tunnel on July 17, 1964. The tunnel cost an average \$25 per inch to construct. The tunnel has an outside diameter of sixteen feet, with a quarter-inch steel plate lining that was inserted in two, 30-foot long pieces. Grout was pumped in to fill the space between the rock walls and liner.

Diversions through the Roberts Tunnel can occur year-round, with the highest deliveries typically occurring in July and August. The 1990-1999 average annual delivery was 61,789 acre-feet, and the 2000 diversion was 93,645 acre-feet (DWB, 2000; USNet1b, 2000; Lewellen, 2000).

Boreas Pass Ditch: The Boreas Pass Ditch diverts water from the headwaters of

Indiana Creek, a tributary of the Blue River, and delivers it into the headwaters of North Tarryall Creek, a tributary of the South Platte River. The ditch is owned by the City of Englewood, which uses the water for municipal purposes.

The 0.8 mile long ditch diverts water from the northwest side of the summit of Boreas Pass, at approximately 11,500 feet above sea level. The ditch has a total decreed right to 16 cubic feet per second, with an appropriation date of January 1, 1910, and was originally appropriated to irrigate land in South Park. The ditch generally diverts during the months of June and July. In 1990 Englewood rehabilitated the ditch, which included putting the ditch in pipe where it crosses a talus slope to eliminate high seepage losses.

The 1990-1999 annual diversions, including the non-diversion years, averaged 139 acre-feet, with 111 acre-feet diverted in 2000. With a recent annual demand of between 6000 and 7000 acre-feet, the ditch typically provides between 2 and 3 percent of the City's annual supply (CDSS, 2000; McCormick, 2000; Wood, 2000).

East Hoosier and West Hoosier Ditches: The Hoosier Ditches were the first recorded transmountain diversion constructed in Colorado, and were used to provide supplemental water for hydro-mining near Fairplay. The ditches divert water from the headwaters of the Blue River into the Middle Fork of the South Platte River. The east East Hoosier Ditch is 1.8 miles long, while the west East Hoosier Ditch is 1.3 miles long. Hoosier Pass, the lowest point on the diversions, is at an elevation of 11,540 feet. The East Hoosier Ditch is decreed for a total of 60 cubic feet per second, and the West Hoosier Ditch is decreed for 17 cubic feet per second, both with an appropriation date of August 5, 1929. The City of Colorado Springs obtained the rights to the Hoosier ditches and now diverts the water through the Hoosier Pass Tunnel as part of the Continental-Hoosier Diversion System (Radosevich, 1976).

Hoosier Pass Tunnel: The Continental-Hoosier Diversion System (a.k.a. the Blue River Project) is located southwest of Breckenridge, Colorado, and is owned by the City of Colorado Springs which developed the project as a source of municipal water. Water is diverted from the Blue River and its tributaries on the west slope to the Middle Fork of the South Platte River on the east slope. Water taken through the Hoosier Tunnel is delivered to Montgomery Reservoir, which is located in the headwaters of the Middle Fork of the South Platte River above Fairplay.

The Hoosier Pass Tunnel is an unlined tunnel, approximately 10 feet in diameter and 1.5 miles long. The tunnel was completed in 1951 and has a capacity of approximately 500 cubic feet per second. Montgomery Reservoir has a capacity of 4900 acre-feet, a spillway elevation of 10,861 feet and was completed in 1957. The reservoir is also decreed to store water from the South Platte basin.

Water from both the Blue River and the Middle Fork of the South Platte River is conveyed 70 miles across South Park to Colorado Springs via the 30-inch Montgomery Pipeline.

The 1990-1999 average annual yield from the Blue River portion of the project was 9939 acre-feet, while diversions from the South Platte were 1401 acre-feet. The 2000 diversions for the Blue River and South Platte are 1401 and 386 acre-feet respectively (CDSS, 2000; USGS, 1985).

### **Arkansas Basin to the Colorado Basin**

**Arkansas Well:** The Arkansas Well (a portion of the Stevens and Leiter Ditch) is owned by the Climax Molybdenum Mine, and is the only transmountain diversion in Colorado that diverts water from the east slope to the west slope (except for the Vasquez Tunnel, whose water is eventually re-diverted to the east slope). The original 38 cubic feet per second right to the Stevens and Leiter Ditch was used by the Leadville Water Company for municipal use and for the smelters in Leadville. In 1964, 5.4 cubic feet per second was changed to industrial use at the Climax Mine, which diverted the water at the Arkansas Well, a sump located in the headwaters of the Arkansas River. Diversions from the well have been used for domestic, industrial and commercial purposes, and have averaged about 300 acre-feet per year. Diversions occur year-round, and the Arkansas Well has an annual pumping limit of 786 acre-feet per year.

The 1990-1999 average annual diversion by the Arkansas Well was 230 acre-feet, with no delivery in the year 2000 (CDSS, 2000; Gelvin, 2000; Thompson, 2000).

### **Colorado Basin to the Arkansas Basin**

**Columbine Ditch:** The Columbine Ditch diverts water from the headwaters of the East Fork of the Eagle River and delivers it into the headwaters of Chalk Creek. The ditch was built in 1931 as a supplemental source of irrigation water, and purchased by the South Side Water Works of Pueblo (which became part of the Pueblo Board of Water Works) in 1953. In 1993, the Board changed the decreed use of the Columbine Ditch from agricultural to municipal and other beneficial uses. The Pueblo Board of Water Works uses the water for municipal purposes or leases it out to others for use as a supplemental irrigation supply or for augmentation.

The ditch is located 13 miles north of Leadville and diverts water over an unnamed pass approximately 2 miles southwest of the Climax Molybdenum Mine, crossing the continental divide at an elevation of 11,500 feet. The ditch is approximately 2 miles long, 3 to 5 feet deep, and 15 feet wide at the top.

The ditch has an appropriation date of June 21, 1930, for 60 cubic feet per second. The ditch may divert between April 28 and October 21 of each year, and may divert a maximum of 3148 acre-feet in any one year. The majority of the diversions through the Columbine Ditch occur during the months of May through August.

The average annual diversion through the Columbine Ditch for 1990-1999 was 1773 acre-feet, while the 2000 diversion was 1720 acre-feet (CDSS, 2000; Ward, 2000).

**Ewing Ditch:** The Ewing Ditch (a.k.a. the Ewing Placer Ditch) diverts water from

the headwaters of Piney Creek, a tributary of the Eagle River, over Tennessee Pass at an elevation of 10,500 feet, and into the headwaters of Tennessee Creek, a tributary of the Arkansas River. The ditch is approximately 1.5 miles long, and was constructed in 1880, making it the oldest transbasin diversion into the Arkansas basin, and the oldest diversion still in use. Constructed as a source of supplemental irrigation water, the ditch is approximately one mile long and intercepts runoff from a drainage area of 2,400 acres.

The Ewing Ditch, the Clear Creek Dam and Reservoir were purchased by the Pueblo Board of Water Works from the Otero Canal Company in 1955. In 1993, the Board changed the decreed use of the Ewing Ditch from agricultural to municipal and other beneficial uses. The Board uses the water for municipal purposes or leases it to other water users as a supplemental irrigation water supply or for augmentation purposes.

The Ewing Ditch has an appropriation date of June 1, 1906, for 18.5 cubic feet per second, with an estimated capacity of 19.6 cubic feet per second. The ditch may divert water between April 18 and October 28, and may divert a maximum of 2402 acre-feet in any one year. The 1990-1999 average annual diversion through the Ewing Ditch averaged 1057 acre-feet, with a 2000 diversion of 1030 acre-feet. (CDSS, 2000; USGS, 1985).

Wurtz Ditch and Wurtz Extension Ditch: The Warren Wurtz and the Wurtz Extension ditches divert water from approximately 9.2 square miles in the headwaters of the South Fork of the Eagle River and deliver it into the headwaters of Tennessee Creek, a tributary of the Arkansas River. The ditch is 6 to 8 feet deep, 20 feet wide at the top and 6 miles long. The Wurtz Extension Ditch is another 6.5 miles long and empties into the Wurtz ditch at Bennett Creek. The Wurtz Ditch was originally constructed in 1929 to provide "irrigation of land for agricultural purposes in the Valley of the Arkansas River." The North Side Water Works of Pueblo (which became part of the Pueblo Board of Water Works) purchased the Wurtz Ditch in 1938. In 1953, the Board extended the ditch to intercept Rule and Yoder creeks.

In 1993, the Board changed the decreed use of the Wurtz Ditch from agricultural to municipal and other beneficial uses. The Board uses the water for municipal purposes or leases it to other water users as a supplemental irrigation water supply or for augmentation purposes.

The Wurtz Ditch has an appropriation date of June 8, 1929, for 85.0 cubic feet per second; the decree for the Extension is dated 1953 and is for 100 cubic feet per second. The ditch may divert between April 18 and October 28, and may divert up to 4083 acre-feet in any one year. The average annual yield for the 1990-1999 period was 2762 acre-feet, while the 2000 yield was 2080 acre-feet (CDSS, 2000; USGS, 1985; Ward, 2000).

Homestake Tunnel: The Homestake Project diverts water from the headwaters of the Eagle River, northwest of Leadville. The project is a joint venture of the Cities of Colorado Springs and Aurora and was built to provide water for municipal purposes.

Water is diverted from several tributaries of Homestake Creek and routed to Homestake Reservoir. Diversions then pass from the reservoir through the Homestake Tunnel to Lake Fork, above Turquoise Reservoir. Water moves from Turquoise to Twin Lakes Reservoir through the Mt. Elbert conduit and power plant, then through the Otero Pump Station and the Homestake Pipeline to Aurora and Colorado Springs.

Homestake Reservoir was completed in 1967 and has a total capacity of 43,300 acre-feet, with a spillway elevation of 10,260 feet. The Homestake Tunnel was completed in 1965 and is 5.5 miles long. The west portal is in the bottom of Homestake Reservoir at an elevation of 10,280 feet. The east portal is at an elevation of 9,960 feet, and the tunnel has a maximum cover of 1,600 feet.

The 1990-1999 average annual yield of the project was 23,048 acre-feet, while the 2000 yield was 26,914 acre-feet (USGS, 1985; Colorado Springs Utilities, 1994).

Charles H. Boustead Tunnel: The Charles H. Boustead Tunnel (a.k.a. Divide Tunnel) transports water from the Fryingpan River under the Continental Divide to the head of Turquoise Reservoir in the Arkansas River Basin. The tunnel is part of the Fryingpan-Arkansas Project, a multipurpose water development constructed by the U.S. Bureau of Reclamation. Diversions from the west slope are made from an elevation 10,002 feet.

The Boustead Tunnel is approximately 5.4 miles long, is horseshoe shaped with a diameter of 10.5 feet, has a maximum overburden of approximately 2000 feet, and a decreed capacity of 945 cubic feet per second. Construction on the tunnel began in 1965 and was complete in 1971. The primary purpose of the project is to provide supplemental water for irrigation and municipal use, though the project also generates electrical power. The tunnel can divert an annual average of 69,200 acre-feet, plus up to 3000 acre-feet of water to be exchanged with the Twin Lakes Reservoir and Canal Company.

The 1990-1999 average annual delivery through the tunnel was 59,740 acre-feet. The water year 2000 diversion was 44,830 acre-feet (CDSS, 2000; USGS, 1985, Simpson, 2000).

Busk-Ivanhoe Tunnel: The Busk-Ivanhoe Tunnel (a.k.a. the Carlton Tunnel) was originally built as a railroad tunnel. The tunnel diverts water from the headwaters of Ivanhoe Creek, a tributary of the Fryingpan River and delivers it to Turquoise Reservoir, in the headwaters of the Arkansas River. The 1.3-mile long tunnel delivers the water to Busk Creek, which is tributary to Turquoise Reservoir.

In 1888 surveys were made for a tunnel from Busk to Ivanhoe creeks. Tunneling crews met in October 1893, and the first train passed through the tunnel on December 13, 1893. The Busk-Ivanhoe tunnel was originally 21 feet high, 15 feet wide, and cost \$1.25 million to construct. It took workers, who were paid \$7.00 per day, 236 days to complete. The west portal of the tunnel is at an elevation of 10,280

feet, the east at 10,800 feet, and the tunnel has a maximum overburden of 1220 feet.

By 1900, most of the railroad traffic was from silver mines of the Cripple Creek region and coal mines from Glenwood Springs. Because the price of silver slumped in the early 1900s, the railroad was sold to a group of private investors from Colorado Springs in 1917. The Busk-Ivanhoe Tunnel was renamed Carlton Tunnel and used for automobile traffic. Recognizing the tunnel as a way to convey additional water to the Arkansas basin, a half-pipe was installed on one side of the tunnel. In 1942 use of the tunnel as a roadway ceased when the State discontinued maintenance of the road. In 1945, the tunnel caved in. The tunnel was purchased in 1949 by the Highline Canal Company and restored at the cost of \$50,000. The High Line Canal Company used the tunnel to convey supplemental water for irrigation east of Pueblo.

The Pueblo Board of Water Works purchased half of the Busk-Ivanhoe Water System from the High Line Canal Company in 1971. The High Line Canal Company retained ownership of the remaining half of the Busk-Ivanhoe system until 1988, when it sold 95 percent of its remaining half to the City of Aurora. In 2000 Aurora bought the remaining shares of the company.

The capacity of the Busk-Ivanhoe Tunnel is currently limited to about 60 cfs through a 30-concrete pipe lying on the floor of the tunnel. In order to offset some of the lost capacity, the Pueblo Board of Water Works contracted with the U.S. Bureau of Reclamation to take deliveries of a portion of the yield of the Busk-Ivanhoe System through the Boustead Tunnel.

The tunnel has an appropriation date of June 27, 1921 and may divert between March 24 and November 25. The tunnel and west slope ditches have a total decreed capacity of 180 cubic feet per second and may divert a maximum of 10,082 acre-feet in any one year. The Busk-Ivanhoe Company has a contract for 10,000 acre-feet of storage space in with the U.S.B.R. in Turquoise Reservoir; but because the contract was originally with the Highline Canal Company, the Bureau asserts that the space may only be used to store irrigation water. Because both municipalities have changed the water from agricultural to municipal use, the Bureau has not allowed water from the system to be stored in the account.

The majority of the diversions are made during the snowmelt runoff months, sometimes extending into October. The 1990-1999 average annual yield was 4740 acre-feet, and the 2000 yield was 5210 acre-feet (Abbott, 1985; Colorado Railroad, 2000; CDSS, 2000; Hancock, 1990; Ward, 2000).

**Twin Lakes Tunnel:** The Twin Lakes collection and delivery system was constructed in the 1930's to serve land irrigated by the Colorado Canal in Crowley County in the Arkansas basin. The collection system is located in the headwaters of the Roaring Fork River. Water is diverted into Grizzly Reservoir, which is located in Lincoln Gulch. Grizzly has an active capacity of 570 acre-feet, but normally fluctuates less than 400 acre-feet. From Grizzly Reservoir, the water flows under the

continental divide through the Twin Lakes (a.k.a. Independence Pass) Tunnel into North Fork Lake Creek. The water is stored in 54,452 acre-feet of storage space owned by the Twin Lakes Reservoir and Canal Company in Twin Lakes Reservoir. The Company also holds water rights for water native to the Arkansas river basin. Diversions through the Twin Lakes Tunnel began on May 24, 1935.

Fifty-four percent of the Twin Lakes Reservoir and Canal Company is owned by the City of Colorado Springs, with the remaining shares held by the Pueblo Board of Water Works, Pueblo West, The City of Aurora, and a dozen smaller users.

The Twin Lakes Tunnel is circular, concrete lined and 8.5 feet in diameter. The tunnel is about 4 miles long and has a capacity of 625 cubic feet per second. The western portal of the Twin Lakes tunnel is at an elevation of 10,520 feet, the eastern portal is at 10,460 feet, and the tunnel has a maximum overburden of 2630 feet.

The Twin Lakes Tunnel is "as straight as a rifle barrel," and when the tunnel is shut down you can stand downstream of the gates at the western portal and see the pinprick of light of the eastern portal, 4 miles away. During the winter when snow closes the road between the caretaker's house and the town of Aspen, and the only flow in the tunnel is what leaks past the closed gates, the caretakers can open an access door and drive through the tunnel to get their groceries and mail at Leadville.

Flows through the tunnel are measured in a 12-foot Parshall flume at the tunnel's east portal, which is fitted with satellite telemetry. The 1990-1999 average annual yield of the west slope portion of Twin Lakes project was 38,785 acre-feet, with a yield of 42,117 acre-feet in water year 2000 (Abbott, 1985; Ringle, 2000).

### **Gunnison Basin to the Arkansas Basin**

**Larkspur Ditch:** The Larkspur Ditch was constructed by the Catlin Canal Company to provide supplemental water for irrigation under the Catlin Canal, east of Pueblo. The ditch was built in 1939, and diverts water from Hurry Creek, from the north of the west side of Marshall Pass, approximately 3 miles west of Poncha Pass. The ditch crosses Marshall Pass at an elevation of 10,900 feet, and delivers water to Poncha Creek, a tributary of the South Arkansas River. The ditch is 1.5 miles long, with a conditional right to extend it another 1.5 miles. Diversions are measured in a 4-foot Parshall flume. The ditch generally runs all summer, from June 1 through September. The ditch can divert a maximum of 7 to 8 cubic feet per second, but typically flows at 3 to 4 cubic feet per second.

The canal company anticipates the ditch delivering an average of 200 acre-feet per year. The 1990-1999 average annual water year diversions were 31 acre-feet. There were no diversions in the year 2000 because the ditch was out of priority for all but 3 or 4 days.

### **Gunnison Basin to the Rio Grande Basin**

**Tarbell Ditch:** The Tarbell Ditch (a.k.a. Cochetopa Transmountain Ditch) diverts

water from Lake Fork of Cochetopa Creek in the Gunnison River basin, to Lake Fork Creek, tributary to the Middle Fork of Saguache Creek, in the Rio Grande basin. Flows in the ditch are measured with a 2.5 foot Parshall flume. The ditch is approximately 0.7 miles long and diverts water from Lake Fork at an elevation of 11,190 feet, over an unnamed pass at an elevation of approximately 11,180 feet. The ditch is equipped with satellite telemetry.

The decree was applied for on February 1, 1905, and the first water was delivered in 1917 and was used for supplemental irrigation near Saguache. The ditch typically runs from the third week in June through the end of August. The ditch is decreed for 25 cubic feet per second. The ditch is currently owned by three individuals, with 2/5, 2/5, 1/5 ownership, all of whom use the water for irrigation.

The water year 1990-1999 average annual diversion was 419 acre-feet, with a year 2000 diversion of 630 acre-feet in 89 days (Lovato, 2000).

**Tabor Ditch:** The Tabor Ditch is owned by the Colorado Division of Wildlife. The ditch diverts water from tributaries of Cebolla Creek, in the headwaters of the Gunnison basin, over Spring Creek Pass into Big Spring Creek, tributary to North Clear Creek. The ditch was originally constructed to provide supplemental irrigation water, but was changed by the Division of Wildlife to include augmentation, wildlife habitat, reservoir conservation pool, and refill rights.

The ditch is open, approximately 0.5 miles long, 5 feet wide at the bottom and 3 feet deep. The ditch has an appropriation date of 1910 for 24.41 cubic feet per second, with a second enlargement right for 15.21 cubic feet per second. The ditch is approximately 3/8 of a mile long, with an estimated capacity of 30 cubic feet per second. Flows are measured in a 3-foot Parshall flume fitted with a data logger and satellite telemetry.

The 1990-1999 average annual yield was 1435 acre-feet, while the diversion for the water year 2000 was 495 acre-feet. Because the ditch is fairly senior, it is typically in priority when there is a demand for water in the Rio Grande basin (Johnson, 2000).

### **San Juan Basin to the Rio Grande Basin**

**Weminuche Pass Ditch:** The Weminuche Pass Ditch (a.k.a. Raber Lohr Ditch) diverts water from the headwaters of the Los Pinos River, a tributary of the San Juan, into Weminuche Creek, a tributary of the Rio Grande. The ditch is owned by the Colorado Division of Wildlife, which uses the water for irrigation in conjunction with various wildlife programs. The ditch, with an appropriation date of 1934, was originally constructed to supply supplemental water for irrigation and was purchased by the Division of Wildlife in the early 1980's. There have been four filings on the ditch, for a total of 40 cubic feet per second. Diversions typically begin around the beginning of June and continue until mid-July. The ditch is approximately 1.5 miles long, open, with a 10-foot wide bottom, and a depth of 3 to 4 feet.



The average annual diversion for water years 1990-1999 was 1088 acre-feet, which included no diversions in 1993-1996, when the ditch was shut down for repairs. There was also no diversion in water year 2000, because the call in the San Juan basin curtailed diversions through the ditch by the time there was demand for the water in the Rio Grande basin (Baer, 2000; Johnson, 2000; Riverside, 2000).

Pine River - Weminuche Pass Ditch: The Pine River - Weminuche Pass Ditch (a.k.a. Fuchs Ditch) diverts from the headwaters of the Los Pinos River into Weminuche Creek, a short distance from the Weminuche Pass Ditch. The ditch was constructed in 1934, is approximately 1.3 miles long, is decreed for 6 cubic feet per second, and has a physical capacity estimated at 25 cubic feet per second. The original decree was to provide supplemental irrigation water for 320 acres in the San Luis Valley.

The ditch is owned one quarter each by two different individuals and half by the San Luis Valley Water Conservancy District. Currently the ditch is used both for irrigation and for augmenting out of priority uses in the San Luis Valley. Flows are measured in a 3-foot Parshall flume fitted with satellite telemetry where the ditch crosses the continental divide.

The ditch begins diverting around the beginning of June and is typically out of priority by mid-July. The highest flows typically occur right after the ditch is turned on, and ditch diversions are administered from the satellite data. Average annual diversions are approximately 450 acre-feet per year. The 1990-1999 average annual yield was 491 acre-feet. The water year 2000 diversion was 203 acre-feet, and was limited because the ditch was called out of priority. (Baer, 2000; Riverside, 2000).

Williams Creek - Squaw Pass Ditch: The Williams Creek - Squaw Pass Diversion diverts water from the headwaters of Williams Creek, a tributary of the Piedra River, and delivers it into the headwaters of Squaw Creek. The ditch has an appropriation date of September 9, 1937, as a supplemental supply of irrigation water for 600 acres in the San Luis Valley.

The ditch was purchased in 1978 by the Navajo Development Company, which has converted part of the right to augmentation uses. While sales of the right for augmentation purposes have resulted in the ditch being owned by numerous individuals, the majority of the water is still used for irrigation purposes by ranchers and farmers in the area around the town of Creede. The majority of the water is diverted during the months of June and July.

The ditch is approximately 0.1 miles long, and flows through the ditch are measured in a 2-foot Parshall flume which is fitted with satellite telemetry. The ditch is decreed for 10 cubic feet per second, with an estimated capacity of 12 cubic feet per second.

The 1990-1999 average annual yield was 359 acre-feet. The water year 2000 yield was 230 acre-feet, when diversions stopped due to a lack of water physically available. Typically 35 to 40 acre-feet per year are used for augmentation purposes, with the remainder being used for irrigation (Baer, 2000; Riverside, 2000).

Don La Font Ditches 1 and 2: The Don Lafont Ditches No. 1 and No. 2 divert from the headwaters of the East Fork of the Piedra River, over Piedra Pass and into tributaries of the Rio Grande. The ditches are owned and operated by the Colorado Division of Wildlife. The majority of the water is diverted during the runoff months, typically from June 1 through mid July. Typically diversions are curtailed because of insufficient stream flow rather than the river call. Both ditches have an appropriation year of 1940. The Don Lafont #1 has a decreed capacity of 4 cubic feet per second with an estimated capacity of 10 cubic feet per second. The Don Lafont #2 has an original filing for 6 cubic feet per second, an enlargement for an additional 6 cubic feet per second, and an estimated capacity of 12 cubic feet per second.

The ditches are decreed for irrigation use. The Division of Wildlife works with irrigators, and delivers water from the ditches to irrigators in exchange for the irrigators leaving water in reservoirs for wildlife purposes.

Both ditches are approximately 0.5 miles long. Because of the high elevation of the ditches, snow and ice accumulation in the ditches delayed the initiation of diversions. To begin diverting earlier in the season, both ditches were put into corrugated pipe in the 1980's. Because the ditches are located inside a wilderness area, a special use permit had to be obtained to use construction equipment to install the pipe, and a helicopter was used to lift a backhoe in and out of the site. Flows from Don La Font No. 1 and No. 2 are measured in 9-inch and 1.5-foot Parshall flumes, respectively, and equipped with satellite telemetry.

The average annual combined diversion has been approximately 225 acre-feet. The water year 1990-1999 average annual yield was 201 acre-feet, with a year 2000 diversion of 10 acre-feet. The 2000 diversion was limited by insufficient flows (Riverside, 2000; Johnson, 2000).

Treasure Pass Diversion Ditch: The Treasure Pass Diversion Ditch diverts water from Treasure Creek, a tributary of Wolf Creek, a tributary of the West Fork of the San Juan River. The ditch crosses the continental divide at Wolf Creek Pass, and delivers water into the South Fork of the Rio Grande. The ditch was built in 1922 to provide supplemental irrigation water for 800 acres in the San Luis Valley. The ditch is decreed for 7 cubic feet per second and has an estimated capacity of 15 cubic feet per second. The headgate is approximately a half mile southwest of the highway at the top of Wolf Creek Pass.

The ditch is owned by a private individual and is used to irrigate approximately 300 acres in the San Luis Valley. The structure typically diverts during the runoff months of June and July. Flows are measured in a 2-foot Parshall flume, and are recorded with a graphical recorder.

The water year 1990-1999 average annual diversion was 123 acre-feet. The water year 2000 diversion was 70 acre-feet. The 2000 diversions were limited in duration because of insufficient flows, and in quantity because ditch maintenance had not been completed (Baer, 2000; Riverside, 2000).

Azotea Tunnel: The San Juan Chama Project was developed by the U.S. Bureau of Reclamation as part of the Colorado River Storage Project. The project diverts water from tributaries of the San Juan River in the Colorado River basin in Colorado for delivery to the Rio Grande basin in New Mexico. The Project provides an average annual diversion of about 110,000 acre-feet of water from tributaries of the San Juan River for municipal, domestic, and industrial uses, as well as supplemental irrigation water and incidental recreation and fish and wildlife benefits.

Surveys for diverting San Juan River Basin waters into the Rio Chama began in 1933. Construction of Azotea Tunnel began on April 22, 1964, and was completed on November 11, 1970. The Azotea Tunnel is 12.8 miles long, has a capacity of 950 cfs, and carries the water from the Navajo River, tributary to the San Juan, to Azotea Creek in the Rio Grande basin.

As the project was a federal undertaking, there are no state water rights associated with the project. The average annual diversion for water years 1990-1999 was 91,790 acre-feet, and the water year 2000 yield was 96,189 acre-feet (USBRb, 2000).

### SUMMARY

Transmountain diversions in Colorado have been developed to divert water from an area with unappropriated water to areas that were deemed to be water short. Generally speaking, water projects built in the first half of the 1900's were developed to provide supplemental water for agricultural purposes, while projects constructed in the second half were wholly or at least in part for municipal purposes. Combined with the fact that several of the projects originally developed for irrigation purposes have been purchased and converted to municipal use, the majority of the water diverted across the continental divide is now used for municipal purposes.

Excluding the Arkansas Well, the total amount of water diverted from the west side of the continental divide to the east averaged 577,724 acre-feet for the 1990-1999 period, and was 591,742 acre-feet in 2000.

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