ESTIMATING CONSERVABLE WATER IN THE KLAMATH IRRIGATION PROJECT

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ABSTRACT

In 2001, irrigation water was withheld from the majority of farms in the U.S. Bureau of Reclamation Klamath Project to provide in-stream flows for fish species listed as "endangered" or "threatened" under the Endangered Species Act (ESA). The subsequent controversy and pleas for emergency action highlighted a wide gulf in the technical understanding of the actual hydrologic and hydraulic processes that occur in the Klamath Basin.

A multi-year hydrologic assessment was performed to determine the precise destination, volume, and timing of surface and subsurface water flows throughout the Klamath Project. Confidence intervals were assigned to each water origin or destination component based on a systematic field examination of the physical processes used to measure or estimate various hydrologic values. The primary conclusion of the investigation was that significant amounts of irrigation water cannot be made available to the Klamath River by traditional water conservation activities.

The irrigation community in the Klamath Project faces critical future challenges, which the existing internal processes and physical infrastructure are incapable of dealing with successfully. This will require significant irrigation modernization to improve the precise control and monitoring of flows at different levels of the system, especially on a real-time basis, and thus provide excellent water delivery service to individual irrigation districts and water users.

INTRODUCTION

Background

The Klamath Project is one of the earliest federal reclamation projects developed and operated by the U.S. Department of the Interior's Bureau of Reclamation (authorized in 1905). The Klamath Project is located in southern Oregon and northern California and provides irrigation water to over 200,000 acres of

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farmland, as well as water supplies for important national wildlife refuges and wetlands.

The issues in the Klamath River Basin are extremely complex with many different interests being represented, many of which have conflicting views over the desirable outcomes. In part this is a result of different philosophical opinions on various issues (endangered species, tribal responsibilities, economic feasibility of certain types of agricultural production, habitat restoration, etc.). Arguments over the reasonableness of particular claims to the Basin's water resources will eventually be settled in courts or through legislative actions.

This apparent complexity and controversy increases the need for pursuing practical solutions based on information that is sound from scientific, economic, and engineering perspectives. However, the authors' initial impression was that in addition to the desire for different outcomes, there existed a wide gulf in the technical understanding of the actual hydrologic and hydraulic processes that occur at various locations over time in the Basin.

This can be considered a crisis of information. Although the Klamath Project itself, the wildlife refuges, various aspects of the ecosystem, etc., had been studied for many years, there apparently was no clear(er) picture of issues such as the realistic potential for water conservation (either on-farm or at the district level), or the actual irrigation efficiency of the Klamath Project as a whole, as well as the efficiency of individual irrigation districts within the Project.

Study Features

To address the need for accurate and reliable information, a comprehensive hydrologic assessment was undertaken in the Klamath Project. The results were intended to provide decision makers and stakeholders with a scientific framework for understanding the realistic potential for water conservation from agricultural land and wildlife refuges, as well as for management of the water resources for other purposes such as improving water quality.

The investigation was comprised of three components:

1. Multi-year water balances at different hydrologic levels in the Klamath Project with specific estimates of the uncertainty associated with each measurement
2. An examination of the physical infrastructure design, internal operations rules, communication systems, water measurement, and management practices of the Klamath Project
3. An assessment of specific modernization recommendations focused on irrigation water management

The hydrologic assessment incorporated:

- Monthly water balances of the volumes and destinations of irrigation water and precipitation
- 30 separate surface water and groundwater flow components
- A study period of 1999 to 2001
- A division of the Upper Klamath Basin into five hydrologic subregions to facilitate a more accurate assessment of the historic records and internal water control processes
- A systematic field examination of the physical processes used to measure or estimate various hydrologic values that appear in various reports
- Assignment of appropriate confidence intervals (estimate of uncertainty) to each water origin or destination component
- A ranking of the water balance components as a measure of their relative contribution to the accuracy of the final values.

The area of investigation was geographically restricted to the Upper Klamath River Basin, particularly the area defined by the Klamath Project. While it was recognized that the quantity and quality of available water in the Klamath Project is influenced to a great extent by the hydrology and water operations in the other sub-basins upstream of the selected area of investigation, this study was limited to the region shown in Figure 1.

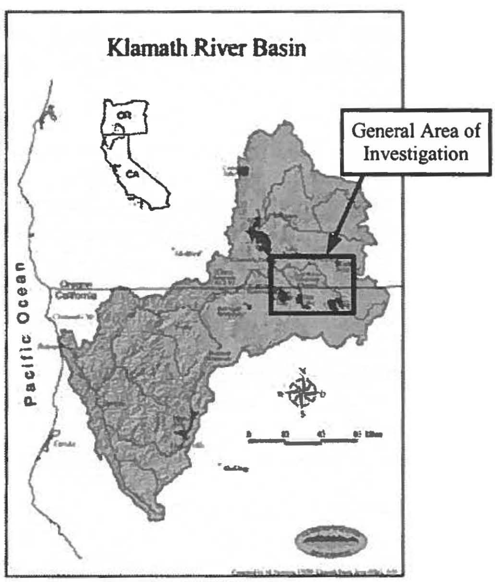


Figure 1. Area of investigation in the Upper Klamath River Basin

CONCEPTUAL APPROACH

The Klamath Project presents some unique challenges in terms of assessing project performance. A necessary prerequisite for examining a project with such extensive geography and operational complexity is a set of standardized investigative procedures. The conceptual approach used in this investigation was intended to gain a better understanding of the precise destination, volume, and timing of surface and subsurface water flows that occur throughout the Klamath Project (i.e., water balance).

A related topic is an assessment of the operational processes that are used in conveying and delivering irrigation water throughout the Klamath Project, consisting of activities such as the manipulation of hydraulic control structures, decision-making procedures, monitoring techniques, record keeping practices, and communication systems. These are broadly described as the "internal processes" of the Klamath Project.

A synthesis of the water balance accounting, recognizing uncertainties, with an understanding of the internal processes allows one to quantify the realistic potential for meeting objectives, in addition to prioritizing investments at different levels in the system, including project facilities and on-farm programs. This allows one to identify specific actions that can be taken while taking into consideration the resulting effects to the rest of the system.

Our conceptual approach has three components, which are interrelated and follow a logical order. In simple terms, this investigation attempted to answer the following set of questions:

- ***What water is potentially available to meet a quantifiable objective?*** What are the water quantities, and timing of surface and subsurface flow paths at different hydrologic levels in the Klamath Project?
- ***Can the available water be manipulated and how?*** What are the most feasible and cost effective options for changing the current physical control and management systems that control the water as it moves through the Klamath Project in order to meet a selected quantifiable objective?
- ***What will be the impact of making "x" change at "y" location at "z" time?*** What is the potential impact of a particular water conservation activity or change in operations, in terms of the relative water quantity, quality, and timing of the various flow paths in the Klamath Project?

This investigative methodology is different from past studies in the Klamath Basin, with important implications. Figure 2 summarizes aspects of our approach of determining the appropriate area and level for targeted investments.

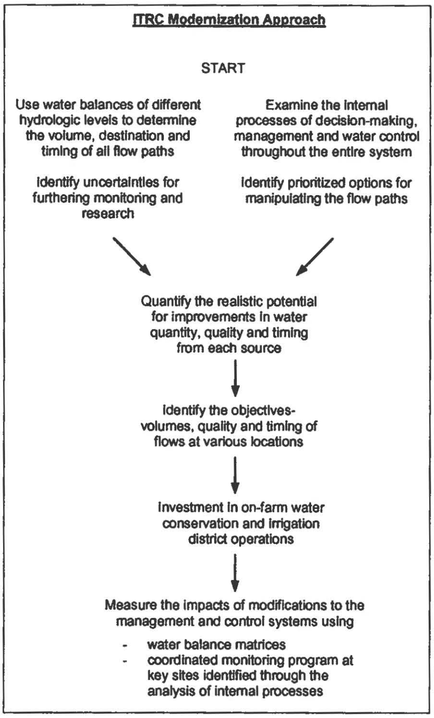


Figure 2. Recommended approach to addressing Klamath Project water-related issues

KLAMATH PROJECT WATER BALANCE 1999-2001

A water balance was computed for the Klamath Project for the years 1999 to 2001. The water balance provides an accounting of all surface and groundwater water volumes that entered or left the boundaries of the irrigation districts and wildlife refuges on an annual basis (Burt 1999). The quantitative assessment incorporated detailed information on the hydrology, climate, irrigation district operations, water measurement, hydrogeology, and farming practices of the Upper Klamath Basin. The final hydrologic quantification is composed of over 30 separate flow components, each with an assigned confidence interval to reflect the estimated accuracy of the reported value.

The fundamental hydrologic relationship of water balances is that the volume of water entering the defined 3-dimensional boundaries is equal to the volume of water leaving the same boundaries, plus any change in storage. Thus, the water balance for the Klamath Project was computed using the following methodology:

Inflows = Outflows + Change in Storage

Inflows

+ Surface water diversions

+ River and tributary flows

+ Precipitation and snowfall

+ Groundwater inflow discharged at Bonanza Springs

Outflows

- Total consumptive use

- Surface water discharge

Change in Storage

- Change in surface water storage

- Change in root zone storage

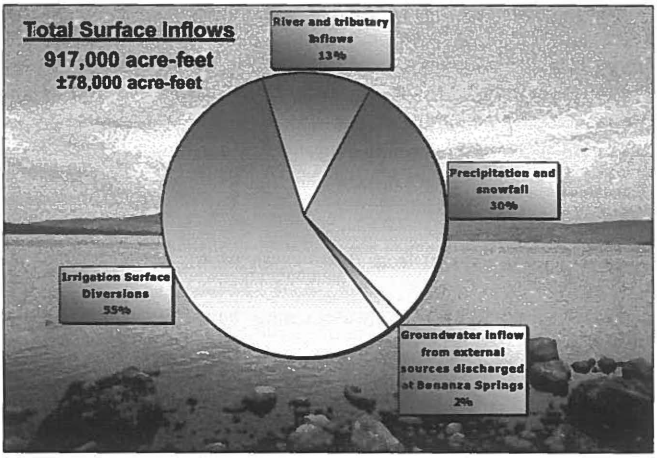
- Change in groundwater storage

= **Net lateral groundwater inflow/outflow** (closure term)

Each of the major flow paths is comprised of individual flow components. For example, the consumptive use term is the sum of:

- Agricultural fields evapotranspiration
- Refuge wetlands evapotranspiration
- Evapotranspiration from canals
- Evapotranspiration from drains
- Evaporation from reservoirs, lakes, streams, and creeks
- Evapotranspiration from urban areas
- Evapotranspiration from undeveloped land

Total average (1999-2000) inflow to the boundaries was approximately 917,000 acre-feet while total outflow was approximately 1,001,000 acre-feet as shown by the simple illustration in Figure 3. Surface water diversions and evapotranspiration from agricultural fields are the largest single inflow and outflow components, respectively. Confidence intervals were assigned primarily on the basis of field visits to each of the surface monitoring stations. The inflow confidence intervals ranged from 7 to 9%, which is equivalent to a margin of error of about ±78,000 acre-feet in 1999 and 2000. The outflow confidence intervals ranged from 12 to 18%, which is equivalent to a margin of error of about ±125,000 acre-feet in 1999 and 2000.



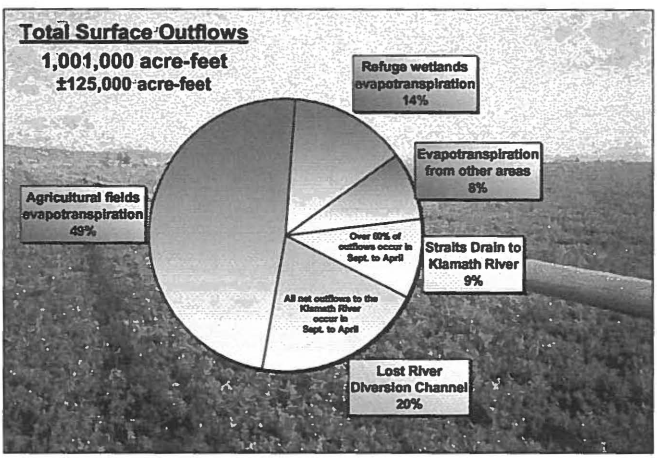


Figure 3. Surface water balance of the Klamath Project (avg. of 1999-2000)

In 2001, surface diversions to the Klamath Project were curtailed by over 60%, while irrigated agricultural acreage in the Klamath Project was reduced by about 27% based on remote image processing. The corresponding reduction in the evapotranspiration from agricultural fields was about one-third, compared to an average of the two previous years.

The water balance closure term was the net lateral groundwater inflow/outflow to the boundaries. Taking into account the annual change in surface water storage and the change in groundwater storage, both in the root zone and the aquifer system, the apparent 3-year average net lateral groundwater inflow to the area was about 31,000 acre-feet. However, there is more than 100% uncertainty in the closure term of net lateral groundwater inflow/outflow, as evidenced by the closure confidence intervals of 1.0 or greater. Thus, the magnitudes of the confidence intervals of the annual closure terms mean that the actual net recharge or discharge contribution of lateral groundwater flow is uncertain.

Key Conclusions

There are three key conclusions from this investigation.

1. Significant amounts of irrigation water cannot be made available to the Klamath River by traditional water conservation activities such as canal lining and improved field irrigation efficiencies.

   Almost all on-farm and district conveyance inefficiencies are recycled internally within the project, or returned back to the Klamath River. Figure 4 shows the volume of surface irrigation water diverted into the Klamath Project versus the evapotranspiration of irrigation water from agricultural fields and refuge wetlands.

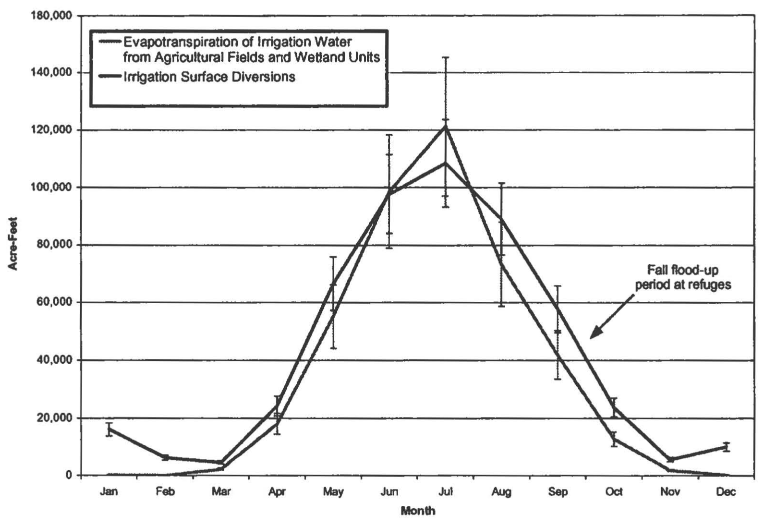


Figure 4. Irrigation surface diversions and the evapotranspiration of irrigation water from agricultural fields and refuge wetlands in the Klamath Project area of investigation (avg. of 1999-2000). [Vertical bars indicate confidence intervals of data.]

2. Because almost all of the diverted surface irrigation water is consumed as evapotranspiration, increasing the flows to the Klamath River during critical late summer months can only be accomplished by actions such as one or more of the following:

   - Decreasing evapotranspiration through a reduction in irrigated agricultural acreage or irrigated wetlands acreage
   - Replacing surface irrigation water with groundwater
   - Increasing surface storage of irrigation water

3. While a primary issue at the moment is restoring endangered fish populations and habitats in the Upper Klamath Basin, the irrigation community in the Klamath Project faces critical future challenges that the existing internal processes and physical infrastructure are incapable of dealing with successfully. Example future issues that have already arisen in other irrigation projects, and that can have profound impacts in the Klamath Basin include:

   - Total Maximum Daily Loads (TMDLs) in rivers, streams, and drainage canals
   - Proposed electricity rate hikes in 2006. Current electricity rates in the Klamath Project are among the lowest in the U.S.
   - The ability to increase crop yields and crop qualities
   - Efficiency of farm fertilizer practices
   - Possible changes in water law that would require verified deliveries of specified volumes of water per acre, equitably distributed to turnouts within irrigation districts
   - Possible changes in water law and rights that would allocate specific volumes and flows to each irrigation district, with penalties for excess diversions. Although this may make no sense from a project-wide water conservation standpoint, it would have an impact on in-stream flows downstream of diversion points.

Priorities for Improving Future Water Balances

The relative importance of the accuracy of each water balance component was ranked to determine priorities for improving future water balances and hydrologic investigations of the Klamath Project. A variance analysis of the water balance volumes provides a general indication of the influence of the accuracy of each component on the accuracy of the overall water balance.

Table 1 shows the Klamath Project water balance components with a relative importance of uncertainty of more than 0.5%. The combination of the evapotranspiration volumes from agricultural fields and refuge wetlands together accounted for about 60% of the total variance.

Table 1. Ranking of the relative importance of the uncertainty of various overall water balance components (above 0.5%)

Water Balance Component	Relative Importance[1]
Agricultural fields evapotranspiration	55%
Ady Canal	16%
Lost River Diversion Channel (inflow/outflow)	15%
Refuge wetlands evapotranspiration	5%
North Canal	3%
Straits Drain	3%
Precipitation	2%
A Canal	0.6%
Evapotranspiration from undeveloped land	0.5%

[1] Based on 1999 and 2000 variance analysis

The relative importance gives an indication where further investment is required to improve the accuracy of a water balance. One cannot evaluate the significance of the known accuracy of a single water balance component based solely on the assigned confidence interval. Take, for example, the estimate of the annual change in groundwater storage in Table 1. This component had an assigned confidence interval of 0.25, meaning that the change in groundwater storage was only known within ±25%. However, the change in groundwater storage only had a 0.0001% impact on the accuracy of the final values in the water balance. This may be considered negligible when compared to the overall accuracy of the water balance. This further indicates that additional investment would be more beneficial directed towards improving the accuracy of other water balance components with a higher relative importance (e.g., better evapotranspiration estimates from upgraded/expanded weather station networks and more accurate information on irrigation practices and crop related factors).

SUMMARY

The water balance results indicate that on-farm modernization efforts will have minimal impact upon Klamath River flow quantities or timing of those flows, because of the vast system of reuse and re-circulation that exists within and between irrigation districts in the Klamath Basin. There also appears to be only a small lag time between application of irrigation water at one location and the reappearance of excess application (in the form of return flows) elsewhere.

Even though the primary focus at the present time is on restoring endangered fish populations and habitats in the Upper Klamath Basin, the irrigation community in the Klamath Project faces critical future challenges that the existing internal processes and physical infrastructure are incapable of dealing with successfully. This will require significant irrigation modernization to improve the precise control and monitoring of flows at different levels of the system, especially on a real-time basis, and thus provide excellent water delivery service to individual irrigation districts and water users.

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REFERENCES

Burt, C.M. 1999. Irrigation Water Balance Fundamentals. Proceedings of the USCID Conference on Benchmarking Irrigation System Performance using Water Measurement and Water Balances. March 10, 1999. San Luis Obispo, CA.