1976

Water Reuse Practices, Prospects and Problems.

Duane D. Baumann
Butler University

Daniel M. Dworkin
Butler University

WATER REUSE
PRACTICES, PROSPECTS AND PROBLEMS

A Report of the Proceedings
of a Seminar held in Indianapolis, July 20-25, 1975

Duane D. Baumann
Daniel M. Dworkin
editors

Holcomb Research Institute
Butler University
Indianapolis, Indiana

Under
Contracts No. DACW31-75-M-1344
and No. DACW31-75-C-0199

January, 1976

TABLE OF CONTENTS

PREFACE

During the early 1960's, there was a prolonged drought in Northeastern United States. Public response to the imminent crisis was to initiate long-range plans for increases in water supply, while, in the short run, a few emergency measures were employed, such as restrictions on water use, emergency transfers and experimentation with weather modification. While not seriously considered, recycling of renovated wastewater was a viable alternative which nearly a decade later has been only gradually gaining acceptance.

Research on the practicability of water reuse has continually increased during the past decade. By 1973, the United States Offices of Water Resources Research (presently the Office of Water Resources and Technology) published a two-volume bibliography on water reuse. Recognizing that the gap between research findings and practice had widened, the U. S. Army Corps of Engineers sponsored a seminar concerning issues involved in planning for water reuse. Professionals from the federal, state and local level were invited to Holcomb Research Institute, Butler University, in Indianapolis for one week in July, 1975. The seminar was organized around three salient issues:

(1) Economic evaluation of recycled, renovated wastewater, among other alternatives of water supply provision;
(2) Assessment of risk to public health; and
(3) The question of public and professional acceptance.

Each of the papers that appears in this volume was presented at the seminar. The contributors represented several disciplines that relate to the decision to reuse water -- economics, engineering, geography, planning, psychology, and public health. In an effort to encourage serious consideration of water reuse in planning for future water supply needs, this volume of papers focuses on examples of current practices of water reuse, directs attention to the major problems of adoption and appraises the future prospects.

ACKNOWLEDGMENTS

We would like to make special mention of Daniel M. Dworkin of the Holcomb Research Institute and Duane D. Baumann, Consultant to the Holcomb Research Institute who were the moving forces behind the conception, and organization of the seminar reported in this proceedings. Without their diligent effort and experience with the consideration of the planned reuse of water for municipal systems, the present report would not have been possible.

We are also appreciative of the contributions of the speakers to the seminar. Their presentations provided up-to-date information on the practicability of planned water reuse for municipal systems. Acknowledgment of contributions of the seminar participants must also be made. The discussion they initiated was useful in exploring issues of common concern.

We also wish to express our gratitude to the following individuals for their constructive criticisms of earlier drafts of this report: Nancy Baumann, David Christensen, George Griebenow, David Holtz, Robert W. Kates, Jerome Milliman, Clifford Russell, and Gilbert F. White. Special gratitude is due Nancy Baumann for the copy editing of this report.

Finally, we are indebted to the U.S. Army Corps of Engineers Institute for Water Resources for partial financial support of the seminar reported in these proceedings. We are especially grateful to Robert Harrison, James Tang, and Howard Olsen of the Institute for Water Resources for their continual encouragement from the incipient stages of the project.

Thomas F. Malone
Director, Holcomb Research Institute

CHAPTER I

PLANNING FOR WATER REUSE

Duane D. Baumann and Daniel Dworkin

The concept of water reuse is seldom, if at all, seriously considered in the process of planning for future urban water demands. The exclusion of planned water reuse, and virtual reliance upon traditional engineering works, is remarkable in light of the potential savings and the substantial amount of reused water that millions of Americans inadvertently ingest each day. The goal of this report is threefold:

1) an assessment of the potential of water reuse for our cities now and in the future;

2) an appraisal of the factors that may have accounted for the low rate of adoption of planned reuse; and,

3) a description of a simulation model designed to evaluate water reuse relative to other alternatives of municipal water supply provision.

DEMAND FOR WATER: PRESENT AND FUTURE

One prediction is certain: the future demand for water in the United States will continue to increase while the supply will remain relatively fixed. In 1970, the United States withdrew 365 bgd (billion gallons per day) of which 87 bg were for consumptive uses.[1] The estimated average annual streamflow in the conterminous United States is approximately 1,200 bgd[2] and, it is doubtful that this amount will be greatly changed in our near future of 10, 20, or 50 years.[3] Hence, the rate of change in demand will determine the nature of our water resource management problems.

However, the exact rate of increase and nature of demand for water in the future is highly uncertain. As the National Water Commission aptly recognized there are pitfalls and problems in basing planning decisions on a single projection:

"How much water will be used, where, and for what purposes will depend on the policies that are adopted. A range of 'alternative futures' is possible, depending upon population levels and distribution, per capita energy consumption, rate of national income growth, technological development, water pricing policies, consumer habits and lifestyles, various governmental policies, and other variables."[4] For example, research has demonstrated that increases in the price of water would lower demand, for domestic use primarily because of a decline in lawn sprinkling,[5] while increases in the generation of thermal-electric and nuclear power will raise substantially the demand for water.[6]

The National Water Commission analyzed a range of possible outcomes, alternative futures, to assess the consequences of different combinations of the factors affecting demand, such as the interaction of variable levels of population, constraints regarding waste-heat disposal, amounts of dissolved oxygen required in fresh waters, and types of sewage treatment. Depending upon the combination of these factors, the projected demand for withdrawal use in the year 2020 may be as low as 570 bgd or as high as 2,280 bgd--nearly twice the average annual streamflow.[7] Consumptive use of water is expected to increase from 87 bgd in 1970 to 150 to 250 bgd by 2020.[8]

In shifting our focus from a national stance, we find that several regions of the country are already faced with an imminent threat of shortage, especially in the Rio Grande, Lower Colorado and Great Basin regions where withdrawals exceed mean annual streamflow (Table 1). In addition, the Lower Colorado has a consumptive use of 5 bgd which is twice the mean annual streamflow, the deficiency being made up by ground water and water transfers. Moreover, increasing population has accelerated demand for municipal water supply.

As the process of urbanization continues, a large demand

TABLE 1

Streamflow Compared with Current Withdrawals and Consumption
(Billion Gallons Per Day)

Region	Annual Flow Available[2]: Mean Annual[2] Run-off	50% of the Years	90% of the Years	95% of the Years	Fresh Water Consumptive Use 1970	Withdrawals 1970[1]
North Atlantic	163	163	123	112	1.8	55
South Atlantic-Gulf	197	188	131	116	3.3	35
Great Lakes	63.2	61.4	46.3	42.4	1.2	39
Ohio	125	125	80	67.5	.9	36
Tennessee	41.5	41.5	28.2	24.4	.24	7.9
Upper Mississippi	64.6	64.6	36.4	28.5	.8	16
Lower Mississippi	48.4	48.4	29.7	24.6	3.6	13
Souris-Red Rainy	6.17	5.95	2.6	1.91	.07	.3
Missouri	54.1	53.7	29.9	23.9	12.0	24
Arkansas-White-Red	95.8	93.4	44.3	33.4	6.8	12
Texas-Gulf	39.1	37.5	15.8	11.4	6.2	21
Rio Grande	4.9	4.9	2.6	2.1	3.3	6.3
Upper Colorado	13.45	13.45	8.82	7.50	4.1	8.1
Lower Colorado	3.19	2.51	1.07	0.85	5.0	7.2
Great Basin	5.89	5.82	3.12	2.46	3.2	6.7
Columbia-North Pacific	210	210	154	138	11.0	30
California	65.1	64.1	33.8	25.6	22.0	48
Conterminous United States	1,201				87	365
Total United States	1,794				88	371

[1]MURRAY, C Richard & REEVES, E Bodette (1972). Estimated Use of Water in the United States in 1970, Geological Survey Circular 676. U.S. Geological Survey, Washington, D.C. P. 17.

[2]U.S. WATER RESOURCES COUNCIL (1968). The Nation's Water Resources. U.S. Government Printing Office, Washington, D.C. p. 3-2-6.

Source: Modified from National Water Commission, Water Policies for the Future, p. 9.

for water within a relatively small area will add to the pressure for greater efficiency in the present use as well as create intense competition for the presently available supply, e.g., water for our urban population versus the demands for irrigation. Based upon one set of projections,[9] the relative importance of consumptive, municipal use is expected to increase while withdrawal uses will remain approximately the same. In 1965, our urban areas consumed 5.2 bgd representing 7 percent of the total consumptive use: by 2020, consumptive use in urban areas is expected to rise to 24.6 bgd, accounting for 16 percent of all consumptive use (Table 2). Whereas withdrawal use for cities is projected to rise from 27 bgd in 1970 to 74.3 bgd in 2020, the proportion it represents of all withdrawal-uses is seen as remaining approximately the same (7 percent) or even possibly declining (5 percent)--primarily because of expected efficiency in water use and a threefold increase in demand for water for cooling in electric power generation.

connect pgs 4&6

TABLE 2

Estimated Water Use and Projected Requirements, by Purpose

United States

(Billion gallons daily)

Type of use	Used	Projected requirements			Used	Projected Requirements		
	1965	1980	2000	2020	1965	1980	2000	2020
	Withdrawals				Consumptive use			
Rural domestic.............	2.4	2.5	2.8	3.3	1.6	1.8	2.1	2.5
Municipal (public-supplied)...............	23.7	33.6	50.7	74.3	5.2	10.6	16.5	24.6
Industrial (self-supplied).	46.4	75.	127.4	210.8	3.8	6.1	10.	15.6
Steam-electric power:								
Fresh..................	62.7	134.	259.3	410.6	.7	1.7	4.6	8.
Saline.................	21.8	59.3	211.2	503.5	.2	.5	2.	5.2
Agriculture:								
Irrigation.............	110.9	135.9	148.8	161.	64.7	81.6	90.	96.9
Livestock..............	1.7	2.4	3.4	4.7	1.6	2.2	3.1	4.2
Total..................	269.6	442.7	804.5	1368.2	77.8	104.4	128.2	157.1

Source: Modified from Federal Water Resources Council, The Nation's Water Resources, p. 1-8

As demand for water increases, shortages will be most acute in our urban areas. Cities are faced with the prospect of having to import water from distant sites. As sites for new reservoir construction become increasingly scarce and resistance to inter-basin transfers grow, new policies will necessarily be formulated and implemented. Again, we rely upon the final report of the National Water Commission:

> To increase efficiency in water and use and to protect and improve its quality, and to do these things at least cost and with equity to all parts of our country...require major changes in present water policies and programs.[10]

However, in response to the increase in demand, cities have traditionally chosen to increase the available supply Except under emergency conditions, such as drought, alternatives that would lower demand have been ignored. For example, the most common response of 48 Massachusetts communities during the drought of the early 1960's, aside from the unenforced pleas for restrictions on water use, was to plan for increases in supply, new sources, improvements in present supply, emergency sources, and a cloud seeding experiment.[11] Those adjustments directed toward a reduction of demand were rarely considered or adopted (Fig. 1).

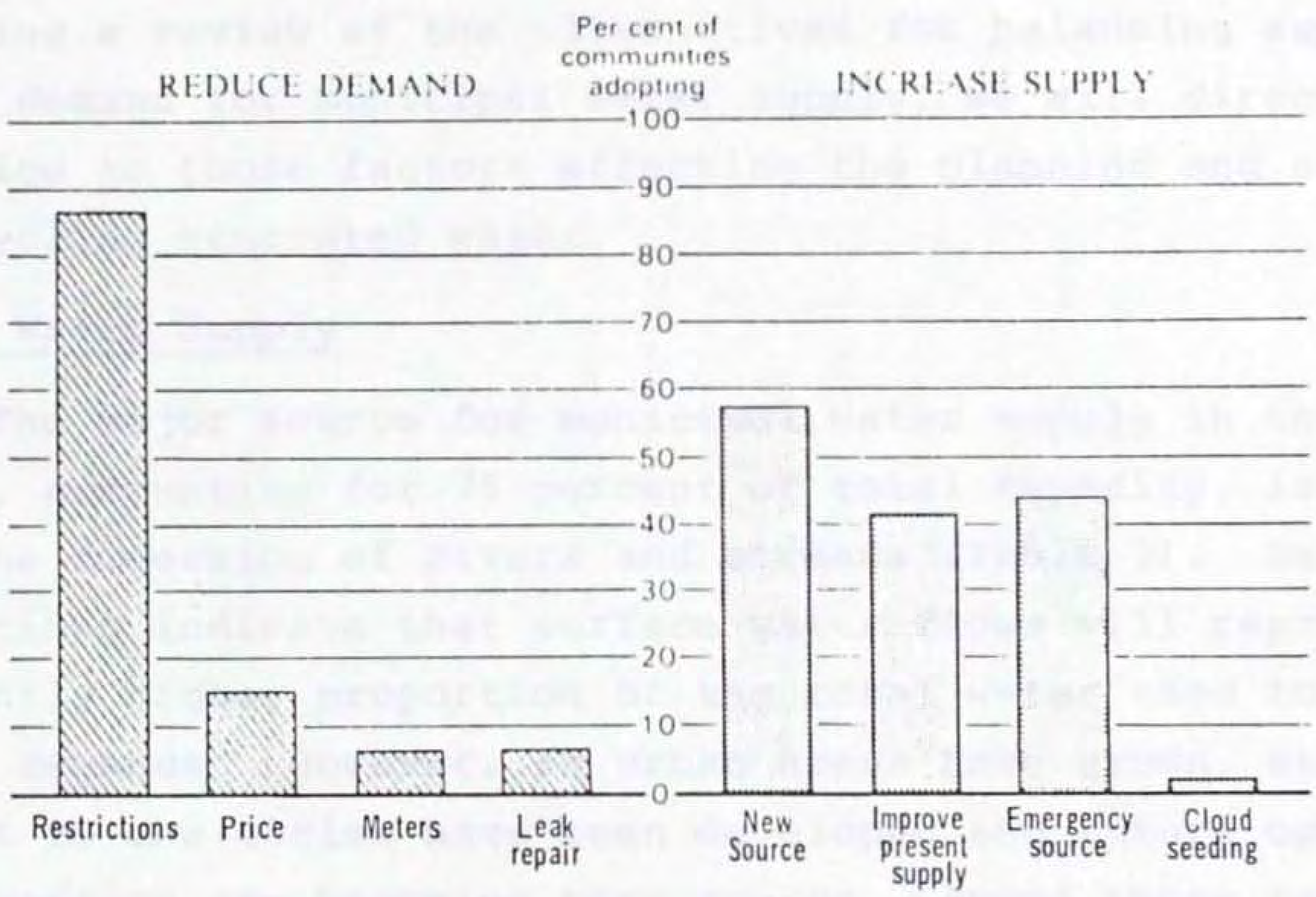
This traditional reliance upon technology designed to modify the environment, instead of policies directed toward changing our schedule of demand, has been equally pronounced in another water resource problem. White has succinctly noted that "...For a long time it was out of the question for a planning officer to study any way of dealing with flood losses other than by constructing engineering works or by providing relief."[12]

THE CHOICE OF ALTERNATIVES

Among the range of alternatives available for coping with urban water resource problems, the reuse of renovated wastewater is a potentially attractive choice. However, it

Figure 1

Nature of Adjustments Made by 39 Massachusetts Communities During 1963–66 Drought.



Source: Russell, Arey, Kates *Drought and Urban Water Supply*, p. 71.

is not to be considered the panacea for all future urban water resource planning problems; instead, water reuse should be considered as one alternative in combination with other adjustments in balancing the supply of and demand for water for our ever-increasing urban areas. Although the implications and potential of reuse is the substantive focus of this report, we reiterate the need in municipal water resource planning for a thorough consideration of each available alternative. Following a review of the alternatives for balancing supply of and demand for municipal water supply, we will direct our attention to those factors affecting the planning and adoption of recycling renovated water.

Modify Water Supply

The major source for municipal water supply in the United States, accounting for 75 percent of total capacity, is water from the diversion of rivers and streams (Table 3). Recent projections indicate that surface water flows will represent a slightly higher proportion of the total water used to satisfy future demands. However, as urban areas have grown, streams nearest to the cities have been developed and future opportunities for diversion are becoming more scarce. Among those regions in the United States that are more suspectible to a shortage of water, interbasin transfers are required.[13]

Transfer of water can be expensive. The economic, political, environmental and technological difficulties increase with the length of transfer required. The area in which the water originates, the donor region, is usually rural and often with a higher incidence of individual well users. There is a tendency to regard the water as belonging to the region and to view its transfer as necessary only because of unreasonable use by profligate urban water users.[14]

Groundwater, which currently represents 25 percent of total municipal supply, is expected to decrease slightly in proportion to the use of surface water.[15] Sources capable of sustaining

TABLE 3

ALTERNATIVES FOR BALANCING SUPPLY AND DEMAND FOR MUNICIPAL WATER SUPPLY

Do Nothing	Modify Supply	Modify Demand
1) Accept Shortage Unplanned rationing	1) Increase Supply Divert New Streams Provide Increased Storage Use Ground Water	1) Restrictions
	2) Increase Efficiency Reduce Reservoir Evaporation Eliminate Leaks Increase Runoff Reduce Evaporation	2) Price Elasticity Peak Pricing, i.e. Peak Summer Pricing Marginal Cost Pricing
	3) Weather Modification	3) Meters
	4) Desalinization	4) Educational Campaign Emphasizing Water Use Conservation
	5) Renovated Wastewater Non-potable Uses Potable Uses	5) Technological Innovations and Application, e.g. Changes from Water Cooling to Air Cooling

Position Table

high withdrawal rates are limited in distribution, and while groundwater is the predominant source of self-supplied individual users, most major cities using groundwater do so as a supplement rather than as a sole source of supply.

Desalinization and weather modification are other potential sources which may, in selected circumstances, serve to augment conventional supplies. Although highly variable, weather modification in some instances has considerable potential, such as increasing snow pack, and subsequently, spring runoff during years when winter reservoir storage is low. Desalinization, on the other hand, is comparatively expensive, requires large amounts of energy, and is most promising on a small scale in unique situations.[16]

Although efforts to reduce seepage and evaporation have had little success, reduction of water loss by identifying undetected leaks can be substantial: in some cases as much as 15 percent of the water withdrawn may be unaccounted for because of leakage.[17]

Modify Demand

Although other alternatives are available and practicable, planners traditionally have seen supply as the variable in the supply-demand equation. Whereas price has been shown to be a significant variable, it is usually disregarded as a method of controlling demand.[18] Marginal efficiency theory in Welfare Economics suggests that marginal costs should equal price; however, the decreasing block-rate pricing system, which is common to most cities, encourages high water-use and prices the last gallon of flow, which has most often been the most costly, at the lowest price. Increasing block rates, peak-summer pricing, and yearly-rate changes based on the supply in storage have all been proposed as methods of reflecting marginal cost in the pricing of water.

Rationing and restricting uses have been used as a management tool predominately during crises--periods of drought.

However, while the cost to consumers during periods of water restriction have been low, it is usually not regarded as a method of planning for water supply.[19] In one city, the prohibition of using once-through cooling water was an economic benefit to industries which installed cooling towers and consequently saved in water bills more than the costs of the investment in recirculating equipment even when a discount rate of 20 percent was used.[20]

Little evidence is available to evaluate the effects of encouraging the public to reduce the amount of water consumed. The available evidence suggests, however, that such pleas were largely ineffective during the drought of the early sixties in the Northeast.[21]

PLANNING FOR REUSE

Renovation and reuse of municipal water is neither a new concept, nor is it an inherently efficient method which should be employed to supply water. It can be inadvertent and unplanned as the withdrawal and use of water from a river with upstream users. For example, on the average, approximately one-third of the population in the United States rely upon municipal withdrawals from streams containing one gallon of previously used water for every 30 gallons withdrawn; and, in some instances, the ratio of previously used water is as high as one-fifth.[22] Likewise, Koenig suggests that of the water withdrawn for municipal supply, up to 18 percent was effluent.[23] Or, water reuse can be direct and planned, as in a factory where water from one process is directed with or without treatment to a second in a series of cascading uses. In the municipal system, planned reuse involves the collection and treatment of sewage and the use of the effluent for irrigation, recreation, industry, or for return directly through an intervening body of water or aquifer for general municipal use.[24]

At the Federal level, the potential for water reuse has long been recognized by such groups as the Senate Select

Committee on National Water Resources in the early 1960's.[25] In 1965, the Water Resource Planning Act required that reuse be considered one of the alternative methods of meeting future demand for water.[26] In the National Water Commission Act of 1968, the Commission was required to:

> review present and anticipated national water resource problems, making such projections of water requirements as may be necessary and identifying alternative ways of meeting these requirements--giving consideration, among other things, to conservation and more efficient use of existing supplies, increased usability by reduction of pollution, innovations to encourage the highest economic use of water, interbasin transfers, and technological advances including, but not limited to desalting, weather modification, and wastewater purification and reuse...[27]

Likewise, the Federal Water Resources Council recognized the potential value of reuse:

> The large withdrawals estimated for 2020 in relation to run-off indicate that even with increased in-plant recycling a large increase in reuse would be required.[28]

In the final report, the National Water Commission recommended that the reuse of renovated wastewater "...should occupy a prominent spot in future planning for overall water resources utilization".[29] In addition, the Commission made the following specific recommendations:[30]

> The Commission believes that direct reuse of water for industrial purposes and that indirect reuse for purposes of human consumption will increase. Where feasible, such indirect reuse should be minimized by limiting wastewater reuse to processes that do not involve human consumption. This will have the effect of releasing for human consumption potable water now being used by industry. However, previously demonstrated successes in protection of public health in instances where municipal water supplies are derived from indirect reuse suggest that increases in such indirect reuse for human consumption should not be discouraged.

In regions where a high-quality source of water is used for irrigation of cropped fields of recreation turf areas such as golf courses and a source of treated municipal waste-water is available, arrangements for water exchange should be considered. Nutrient-rich municipal waste-water could be used for irrigation and exchanged for high-quality water which could be used for domestic and industrial use.

Direct reuse of water for human consumption should be deferred until it is demonstrated that virological and other possible contamination does not present a significant health hazard. Further knowledge on this subject is necessary, and the Commission endorses the research program recommended by the American Water Works Association, as follows:

1. Identify the full range of contaminants possibly present in treated wastewaters, which might affect the safety of public health, the palatability of the water, and the range of concentrations.

2. Determine the degree to which these contaminants are removed by the various types and levels of treatment.

3. Determine the long-range physiological effect of continued use of reclaimed wastewaters, with various levels of treatment, as the partial or sole source of drinking water.

4. Define the parameters, testing procedures, analytical methodology, allowable limits, and monitoring systems that should be employed with respect to the use of reclaimed wastewaters for public water-supply purposes.

5. Develop greater capability and reliability of treatment processes and equipment to produce reclaimed water of reasonably uniform quality, in view of the extreme variability in the characteristics of untreated waste waters.

6. Improve the capabilities of operational personnel.*

*AMERICAN WATER WORKS ASSOCIATION (October, 1971). "On the Use of Reclaimed Wastewater as a Public Water-Supply Source, AWWA policy statement. Journal American Water Works Association, 63 (10): 609.

> The Commission also recommends that research focus on advanced treatment processes that incorporate or replace secondary treatment, on other methods of reducing the amount of advanced treatment, and on the practicability of installing and operating dual water supply systems---one for human consumption and the other for manufacturing purposes.
>
> The net cost of treatment of water for reuse should be compared with the costs of such alternative sources of water as desalting and interbasin transfers before any such alternative is adopted.

DEFINITION OF WATER REUSE

The term reuse as applied to water is universally understood as using water again. However, confusion abounds concerning the exact nature of the type of reuse implied, that is, whether it is planned, or unplanned and inadvertent, whether it is direct or indirect, or whether it is for potable or non-potable uses. The terms describing the treatment, if any, of the water, and the method or manner in which water once used reaches the next user, are used so interchangeably that any work on reuse of water will profit from an operational definition.

Combine 14 & 15 & 16

We use the term planned reuse to refer to wastewater that is collected and purposefully provided for additional use. Inadvertent or unplanned reuse results when water is withdrawn and used from a stream with an upstream discharger. This designation is different from that of the National Water Commission which equates planned as direct reuse and unplanned as indirect reuse and defines these as:

> Direct reuse... is made by the first user who recycles the water through the same system after suitable treatment. Indirect reuse occurs when effluent is discharged into a water body by the 'first user, diluted by natural forces and then withdrawn, treated (if necessary), and used by others.[31]

The National Water Commission definitions are confusing in the case of Windhoek, South West Africa, where effluent is treated, discharged into a water body, diluted and withdrawn and used again.

In this report, terms direct and indirect reuse are used to designate two types of planned reuse. Direct reuse is the transmission of water collected as waste either with or without treatment to an additional use. Direct reuse is provided in the United States for irrigation of agriculture and parklands, lawns and for the grasslands associated with highways; for processing and cooling water in industry, and to form man-made water bodies for fishing and boating and for scenic enhancement. Indirect reuse is the use of wastewater to recharge aquifers or to build up ground water supplies which will be later used as a source of supply. These definitions have also been used by Symons,[32] and others.

Reuse of renovated effluent can serve as a source of potable and non-potable water, and it can be furnished directly to the user or be used indirectly to recharge an aquifer which then serves as a source of supply. The end use, potable or non-potable, and the method of distribution, direct or indirect, each impose different requirements on the physical design of the system and the safeguards to protect human health and well being.

Potable Reuse

DIRECT. While there are, at present, no municipal systems utilizing direct potable use of renovated water in the United States, it has been used in the past in Chanute, Kansas, and is now being used in Windhoek, South West Africa. In Chanute, Kansas, the effluent was processed and returned directly to the distribution system. Such direct return, with external sources used only to supply losses, is designated a closed circuit or a pipe to pipe system. Denver, Colorado, is presently planning a system of this type, investigating "potable reuse with the eventual goal of a nearly closed-loop system in the late 1990's."[33]

In Windhoek effluent is stored in reservoirs and later mixed with water from conventional sources to provide for municipal supply. The important distinction between the two systems is the delay between when effluent is collected and its later reuse, allowing in the interim an extended exposure of the effluent to the natural elements.

INDIRECT. In the United States the most extensive indirect reuse of water for potable supply is in Whittier

Narrows in the Los Angeles metropolitan area. Here fifty million gallons of treated effluent are collected daily and applied to gravel beds, charging the aquifer in the area. The effluent stored as ground water is pumped up and used for both irrigation and general municipal use.

Non-Potable Reuse

DIRECT. Most planned reuse of water is for non-potable purposes, supplied directly from the treatment plant to the user. This category includes most of the present uses for irrigation, industry, and recreation. Some of the proposed innovative uses include dual distribution systems for cities in which separate supply lines would furnish the highest quality potable water for drinking, cooking, bathing, and laundry, while lower quality reused water would be furnished for toilet flushing and for irrigation of lawns and gardens.

INDIRECT. Non-potable reuse of water does not usually require the extra treatment obtained from allowing the effluent to pass through layers of earth. There are, however, some places which reuse non-potable water indirectly. One previously mentioned is Whittier Narrows which uses the water for both potable and non-potable uses. An innovative plan for non-potable reuse has been prepared for Lubbock, Texas, where wastewater, previously applied directly to the land for irrigation, will be obtained by pumping the underlying watertable. It will then be used to fill a series of recreational lakes which will also serve as reservoirs for industrial use. The project has been funded in part by the Bureau of Outdoor Recreation and the Department of Health, Education, and Welfare and is presently under construction.

In the future, if land treatment of sewage, a method which has been investigated by the Corps of Engineers as an alternative to more conventional methods of treatment, is adopted, extensive opportunities for indirect non-potable reuse will be provided. In this method of treatment, settled sewage is applied to farmland area. The land then can be under-drained and the water would be available for reuse.

THE FUTURE OF REUSE

If reuse is not at present a least-cost method of supplementing the capacity of municipal systems, its economic attractiveness will increase in the future. The reasons for the increasing economic efficiency of reuse compared to conventional stream flow and storage fall into two major categories: (1) the growing cost of providing conventional flows; and, (2) the decreasing cost of providing renovated water.

The Increasing Costs Of Water Supply

WATER AS AN ECONOMIC GOOD. In most analyses of the cost of water supply, the water itself is considered a free good, the cost results from diversion, regulation, and transmission. By definition, a free good is one available to all users without scarcity, a situation which would result in zero price.[34] As water becomes less available, the concept of water as an economic good is emerging. Since the late 19th century, western courts have regarded water as personal property once it has been lawfully diverted,[35] and a number of institutions have been formed to provide an orderly market in the sale and transfer of water rights.[36]

The increasing value of water can be shown in a number of instances. The North Poudre Irrigation Company issued 10,000 shares of stock, each share representing a right to receive water as an owner of the company. In five years (1960-65), the value of the shares increased from $200 to $600 a share. The owners were assessed $89 a share over the period for which they received 31.2 acre-feet of water, an average cost of $2.85 per acre-foot.[37] The price of the stock represents the value of anticipated benefits the stockholder assumes will be generated. As this changes, it indicates the change in the assessment of the future worth of receiving 5.2 acre-feet of water a year. In 1965, the investors valued the discounted benefits of receiving this water for less then $3 an acre-foot at three times the 1960 rate.

INCREASING COSTS OF STORAGE. The costs of providing storage are increasing because of: (1) increasing cost of sites; (2) decreasing storage potential of sites available; and (3) increased opportunity costs of flooding the land. Wollman and Bonen[38] found a probable rise in the cost of land and relocation costs, although the data collected over the past 50 years were somewhat contradictory. Since 1955, the cost of undeveloped land, farm land, and recreational land has been rising. There are no markets in dam sites, but land along rivers should share in the continued rise of the price of land.

The average potential of storage can be expected to fall since those sites which have the greatest potential for storage and therefore, lower costs per unit of storage are utilized first. Size is critical in cost calculations: dams impounding 10 million acre-feet or more cost on the average $26 per acre-foot of storage, while those storing less than 20 thousand acre-feet cost an average of $186 for each acre-foot of storage.[39]

Major conflicts arise over competing uses of some areas, e.g., a scenic valley which is considered for a dam site. The first historical battle was over the Hetch Hetchy Valley, an area which was flooded to provide municipal water for San Francisco. In many other areas now flooded, little weight was given to the costs of the loss of unique landscapes.[40] Action by environmental groups has focused attention on this problem, thereby further affecting the supply and the cost of available dam sites.

DECREASING RETURNS FROM STORAGE. As the amount of storage increases for any stream, there is a decreasing yield available from any further increase in storage.[41] As a result of providing increasing levels of yield in critical water areas of the country, many streams are approaching maximum levels of storage (defined as the point at which any increase in storage would reduce net flow due to evaporation). The Colorado River, the Rio Grande, the Upper Missouri have all exceeded the point of maximum useful development.[42] If the costs of providing storage are constant, the decreasing yield for each new unit of storage causes the resulting flows to be more costly.

INCREASING COSTS OF TRANSMISSION. The increase in distance between the source of supply and the point of use is raising the cost of water transmission. Those areas of the country which have captured the total available local supply are dependent upon interbasin transfers for more water. If transmountain diversions are planned, expensive tunnels and high energy inputs may be required. While most transmountain developments are only partially for municipal use, some cities, e.g., Colorado Springs and Aurora, Colorado have built and now operate such diversion projects solely for municipal use.

As part of the increasing costs of diversion, transmission losses can become a major factor in rising costs. The Fryingpan-Arkansas Project calculates a 7 percent loss for every hundred miles of transmission.[43]

Decreasing Costs of Effluent

While the costs associated with water supply are rising, the costs for providing water for reuse are declining primarily because of the upgrading of effluent discharged by municipal systems. If the full cost of treating sewage to the level of completely renovated water is divided into primary, secondary, and advanced waste treatment components, slightly more than half (in South Lake Tahoe 56 percent) should be ascribed to advanced waste treatment.[44]

Under the 1972 Federal Water Pollution Control Act,[45] the Federal Government established standards that require secondary treatment of all municipal sewage and additional treatment in some areas of special need. Whatever the pollution control requirements, whether for secondary or advanced treatment, the substantially treated water produced will be available for distribution and reuse.

Thus, the new federal legislation will provide water for reuse at decreasing costs for residual treatment. However, though substantial research efforts have been completed,[46] water reuse still remains only a potential source of water available to municipalities.

THE PRACTICABILITY OF REUSE

Any consideration of the practicability of recycling renovated waste water for municipal supply will necessarily require answers to three equally-important questions. First, what are the risks to health for each specific water reuse project, especially if human consumption of the renovated wastewater would occur? Secondly, to what extent would a proposed water reuse project be socially acceptable: Would the consumers accept reused water and would the politicians, public health officials and engineers provide their endorsement? Third, under what conditions is water reuse an economically efficient alternative for municipal water supply?

<u>Public Health</u>

Public health concerns are, for the most part, restricted to those uses in which drinking or bodily-contact is planned. There are at present, no cities in the United States processing effluent for direct potable reuse. Windhoek, South West Africa, has provided the only long-term example of direct introduction of effluent into the municipal supply. The sewage is treated to a tertiary level and includes a final filtration through activated-carbon before being mixed with the conventional surface flow. Up to one-third of the effluent in Windhoek is recycled for potable supply during periods when chlorine demand of the wastewaters is not excessive.[47] The water produced meets all of the standards set by the World Health Organization.[48]

From October, 1956, to March, 1957, Chanute, Kansas treated and reused water as a direct augmentation to the municipal supply. While the quality of the renovated water met the standards established by the U.S. Public Health Service,[49] the chemical composition deteriorated markedly, and the water had a pale-yellow color, an unpleasant taste and odor, and foamed when it was agitated.[50] During the same period of drought another community, Ottumwa, Iowa, also recycled renovated wastewater and no health problems were observed.[51]

In Denver, Colorado, plans are being implemented to recycle renovated waste water for all uses including water for drinking. Currently a small demonstration plant (1 mgd) is under construction and a substantial research effort concerning water quality and health has been launched. Within ten years Denver may be recycling renovated waste water at the rate of 100 mgd.

In another experiment, Santee, California, developed recreational lakes from treated effluent with a particular focus upon the occurrence of viruses and bacteria. Lakes containing the treated effluent served as a scenic background for picknicking; boating, fishing, and swimming activities were added later in successive stages. The swimming experiment was closely investigated and even though viruses were commonly isolated from raw sewage, none were ever measured in the input to a final contact chlorination process.[52]

Although promising, the conclusions reached from these experiments should not lead to confidence concerning the relationship of health and the quality of renovated waste water. Bacteria and viruses appear to be controlled under proper filtration and chlorination, but little is known concerning the occurrence and distribution of heavy metals, such as chromium, mercury and lead, and organochlorine compounds, such as carbon tetrachloride, DDT, aldrin, dieldrin, and chlordane. Moreover, there is evidence which suggests that at least some organochlorine compounds are carcinogenic. The recently published study on the New Orleans, Louisiana water supply noted heavy concentrations of chloroform and carbon tetrachloride, both possible carcinogens.[53]

The lack of definitive information on water quality and health should not preclude serious consideration of water reuse as a possible alternative in planning for municipal water supply. The same problems exist for nearly all other alternative sources of municipal water supply; and by not considering planned water reuse we are not increasing the assurance of the production of safe, potable water since most surface water sources contain substantial quantities of effluent and organic agricultural wastes. In nearly all communities in the United States, there are no routine tests for viruses; in fact, the U.S. Public Health Service's Drinking Water Standards have not yet established virus standards. The point is simply stated: the questions about health and water quality are unknown for both water reuse techniques as well as the currently operating conventional treatment technologies. Communities continue to focus upon bacteriological standards, tastes, and odors, while the effects of organics, heavy metals, and viruses are not measured and remain unknown.

However, conventional wisdom assumes that most water produced in the United States is safe to drink, and the implementation of water reuse would necessarily raise the risks to health. Harris and Brecher,[54] when discussing conventional water supply systems, succinctly noted:

> Almost everyone supposes that such systems are under continuous surveillance by competent state and local health officials, that water samples are scrupulously tested at frequent intervals, that any flaws in a water system will be soon discovered and corrected--and that the water we drink therefore must be safe. Unfortunately, almost everyone supposes wrong.

In a U.S. Public Health Service survey of 969 communities, "only 10 percent (of the communities) had bacteriological surveillance programs that met the 'criteria', while 90 percent either did not collect sufficient samples, or collected samples that showed poor bacterial quality, or both."[55] And, 61 percent of the operators of the 969 communities"...had not received any water treatment training at a short-school level or higher."[56] Finally, in the same survey, only 59 percent of the communities produced drinking water that was acceptable under the recommended standards of the U.S. Public Health Service, standards that are considered by many to be lax when compared to those established by the World Health Organization. Similar results were observed in a more recent study of 446 United States' communities by the Comptroller General of the United States: 18 percent of the communities did not meet the standards, as measured by coliform, in two or more months during the preceeding 12 months.[57]

With the passage and implementation of the 1974 Safe Drinking Water Act,[58] enormous progress should be made towards improving the quality of our drinking water. With respect to the potential of water reuse, we would argue for a relativist perspective, rather than an unattainable absolutist stance. With the completion of the Denver, Colorado water reuse project, the quality of the finished product will undoubtedly be significantly higher than the tap water presently available in most communities in the United States. This conclusion is not new. For example, Dean noted as early as 1965:

> That we can make a better quality of water by treating sewage than is available in many of our cities. Controlled treatment of a known hazardous raw material can produce a safer product than routine treatment of a deteriorating source. Viruses can be removed from heavily polluted water by suitable treatment and the cost is not unreasonable.[59]

Finally, the entire question of health is circumvented in those situations where water can be reused for purposes other than ingestion, e.g., industrial cooling, irrigation, and recreation. Indeed, it is these non-ingestive uses where reuse will most likely be adopted, but savings to the community might be foregone if water reuse is not also considered as a potential source for potable use.

Public Acceptance

Although renovated wastewater may be relatively safe to drink, a second and equally-important question concerns public acceptance, not only the consumers, but the politicians, management personnel, public health officials, and consulting engineers. In essence, no program utilizing renovated waste water can be implemented without their acceptance.

Recalling the flouridation debates and aware of the heightened public participation of the present day, water resource managers are particularly concerned about public acceptance of recycled waste water. From an unpublished survey by Baumann of 300 municipal water managers in the United States in 1969, the most common reason cited by the 50 percent who opposed waste water reuse was an anticipated rejection by the public. Similarly, Johnson found that "It would appear that water managers know very little of consumer responses concerning renovated waste water, but generally consider the public would not accept it."[60]

On the other hand, in a recent review of the literature, Baumann and Kasperson concluded that "there is little evidence to support the wide-spread conviction among those charged with proposing solutions to the nation's water supply problems that public opposition constitutes the most important obstacle to the adoption of waste water reuse systems."[61] Moreover, there is evidence that the public will accept renovated waste water for potable use provided they are aware of the technological characteristics of water treatment. Based upon survey data in five communities, Sims and Baumann suggest that what the consumers know and feel about drinking renovated waste water is related to the individual's general level of education and his knowledge about water treatment and is not related to unconscious threats of specific concerns such as fear of contamination or beliefs concerning nature, technology, aesthetics, authority, progress, or destiny.[62]

The recent experience in Denver, Colorado, supports these findings. In a survey of 500 people, the initial response to the concept of recycling renovated waste water was primarily negative. However, as the respondents were provided additional information concerning the implications of water reuse planning, the rate of public acceptance increased until 85 percent of the respondents expressed a willingness to drink renovated waste water.[63]

In Windhoek, South West Africa, "...public acceptance has been very good."[64] And although sales of bottled water increased in the Chanute, Kansas experience, the majority of the consumers drank the renovated waste water.[65]

The central question, then, is why do the managers and engineers perceive the public as unwilling to aceept recycled, renovated waste water when the available evidence suggests that the consumers would not be, in fact, an obstacle in community adoption of such a program. Could it be that a result of the process of professional socialization, the engineers, water managers, and public health officials are reluctant to innovate or change the established procedures of municipal water supply provision? Hence, the public becomes a scapegoat for their reluctance to consider and/or recommend a program of reuse? If so, a key obstacle in the consideration and adoption of alternative strategies of recycling renovated waste water in municipal water supply planning may lie not so much in the minds of the consumer, as in the perceptions of consulting engineers and public health officials--two influential groups in community decision making in planning for municipal water supply. In another study by Sims and Baumann,[66] 98 consulting engineers (33 firms) and 22 state public health officials (from 9 states) were interviewed concerning the practicability of a community program using renovated waste water. It is public health officials who "...hold the more negative position--they begin by not liking the idea, then raise many and major objections to it, and in the end, find their reflection has strengthened their antagonism. Consulting engineers...begin with a far more favorable attitude, raise fewer objections and conclude with a perfectly even-split between endorsement and rejection."[67]

Economic Efficiency

HOW IS REUSE PRESENTLY CONSIDERED AND UTILIZED? Reuse of water is an especially attractive concept for those cities which are in water-short areas and have no alternative sources of supply, cities which have provided water by expensive transmountain transfers, particularly those in which reuse is restricted by the law of prior appropriation of imported water, cities which have innovative, aggressive water programs, and finally, cities which can experiment with water reuse through federal funding. Each of these cities has reasons to be interested in reuse as a supplementary source of municipal supply.

How is reuse judged in economic terms? Colorado Springs, Colorado sees reuse as a low-cost source of supply costing approximately one-third as much as deriving its potable water supply from extensive transmountain diversions of water from the western slope to the eastern slope of the Rockies.[68] As a result, it is actively pursuing a program of water reuse.

Whittier Narrows, California buys potable water from the Los Angeles Metropolitan Water District (MWD). It has calculated the cost of providing secondary treated effluent as approximately equal to the cost of water from MWD. Because treating and reusing water at Whittier Narrows will provide needed capacity in the downstream sewer lines, it is using the treated sewage to recharge an aquifer.

In both Colorado Springs and Whittier Narrows, only 3 factors were utilized to determine the efficiency of reuse: (1) the cost of an alternative source of water; (2) the necessary treatment to provide an effluent of suitable quality; and (3) the cost of providing and operating a plant to produce the effluent. Once these costs were determined, the analysis consisted of a comparison of the costs of reuse and the costs of the alternative source.

To provide these comparisons, extensive data have been provided on the effectiveness and cost of all sewage treatment processes. The Taft Water Center of the Environmental Protection Agency has developed data on the cost and effectiveness of processes for treating waste water for flow rates from 1 to 100 mgd. For most analysis only a comparison with the costs of providing water from conventional sources provides a measure of the efficiency of reuse.

James Johnson provided the first challenge to this method of calculating the costs of reuse. His study points out that some of the necessary treatment costs would be required for pollution control whether or not water was re-used.[69] The National Water Commission[70] in its final report used this modification in setting out the methods for calculating the true cost of reuse which it expressed as follows:

1) The cost of advanced treatment to make waste water suitable for reuse;
2) minus the cost of pollution control treatment measures otherwise necessary to achieve water quality standards;
3) minus the cost of water treatment of the supply being considered as an alternative to reuse; and,
4) plus or minus the difference in conveyance costs between the reusable supply and its alternative, including allowance for the cost of separate supply lines if reuse is contemplated for industrial water supply only.

Other cities are reusing water for different reasons. Santee, California has provided reused water to fill lakes which are used for boating, fishing, and as a focus for a park area for family gatherings. The reuse project was started by an innovative water manager who attracted federal funding to investigate the potential of reused water for recreation. South Lake Tahoe, California is treating sewage to produce a high quality effluent which is then pumped out of the Tahoe watershed because of an agreement by the state of California and Nevada to export all wastes from the Tahoe basin. The water is collected in a lake in the adjoining basin which is used for recreation and irrigation.

Although there are other examples of reuse, these were selected because they illustrate problems with the present conception and practice of the reuse of waste water. In Santee and Whittier Narrows in Southern California reuse is being provided when there is extensive unused capacity to furnish water because of the California Water Plan. In Colorado Springs, water is being reused during years when non-reused water is spilling from over supplied storage reservoirs. South Lake Tahoe is pumping effluent of potable quality across a mountain range because of an agreement limiting discharge within the basin.

HOW SHOULD REUSE BE UTILIZED? Any consideration of utilizing reuse more efficiently must start with the concept of an integrated system, integrated both in management and in the distribution of water, so that either treated effluent or potable water could be furnished to non-potable users. With this control, the managers could make a decision based on his judgment of the state of the system, to produce and distribute treated effluent or to use only the potable supply for all users. This would eliminate the unnecessary costs in production and distribution of effluent during periods when unused capacity exists in the potable water supply.

In general, there is a relationship between reuse and storage of flows which provides a guide to using treated effluent: reuse systems cost less to build, but are more expensive to operate than systems designed to divert and store flows. On the other hand, reservoir systems are expensive, but have low operating costs which suggests that reuse systems should be used only when water from storage is unavailable to meet the demands. In this way, reuse would function as a source of peak supply while storage with its low operating costs would provide the necessary continual capacity. However, there are limitations. Treated effluent is not usually considered to be acceptable as a source for potable supply and would be restricted to those uses previously identified and furnished with a separate distribution system for non-potable effluent. These limitations, however, only serve as constraints on the realization of the full potential of the system.

Reuse, no matter how it is used, provides a source of water which can delay or obviate the need for conventional additions to supply. In addition to supplying water, the presence of reuse as a standby source, not affected by periods of low-flow, can increase system yield and provide planning flexibility by serving: (1) as a substitute for the high levels of assurance required in municipal systems; (2) as a means of mobilizing any over supply in the system; and, (3) as a means of shortening the planning cycle which would allow pragmatic evaluation of change in demand to replace present long-term projections.

Reuse to Supply Assurance. The yield of a water supply system based on storage of flows is usually expressed as a quantity of water available or assured ninety-five percent (or more) of the time. To achieve this level of assurance, some storage must be provided which will be required less than 5 percent of the time. There is an inverse relationship between assurance and yield; yield increasing as assurance declines.[1] By allowing the levels of assurance in a system to be relaxed, the yields withdrawn from the system could be increased, and reuse could furnish the additional water necessary to maintain the desired levels of assurance.

Mobilizing Excess Supply. While the yield of municipal systems is always calculated to provide high assurance levels, there is indication from cities, which have been forced to restrict water because of drought, that rationing or restriction of water causes little damage. There is, however, an indication that even a shortage less than 5 percent of the time is not acceptable to engineers. Engineering and reference handbooks urge conservative calculations. Social scientists, on the other hand, claim that yields are often if not always, understated. As an alternative to this sometime academic debate, renovation and reuse can provide a standby source which will allow the use of thepresent facilities until pragmatic evaluations of the response of the physical system to the demands placed on it can replace the engineering estimates of yield.

Shortening the Planning Cycle. The long time required for the development of new water sources requires long-term estimations of the future demand for water. In the past, there was little concern if the future demand had been overstated and if subsequent projects based on this inflated demand had resulted in temporary oversupply. The rapid growth in the use of water utilized any excess capacity. There are indications that the rapid growth in demand has slowed. Some factors, such as the low rate of births and the replacement of the single family house with apartments and cluster homes, indicate that the present slowdown will continue. Excess capacity added now under lower rates of growth will be utilized more slowly with a consequent investment in idle-capacity for a longer period.

Factors Affecting Economic Feasibility. The present method of evaluating the economic efficiency of reuse by comparing the costs of both reuse and an alternative supply is misleading. The important consideration in any economic analysis is the cost at the margin. If two systems of supplying water have the same average costs and reuse is considered as a supplement to both, an average cost analysis of the operations of both systems would result in the same findings. If, however, one system were dependent on storage of flows and had excess capacity, employing reuse would be an unnecessary expense since demand could be supplied from existing storage. If, however, there was no excess capacity and the alternative was the addition of storage, providing reuse might be a more efficient economic solution. Calculation of the costs of the final unit of water delivered in a system with and without reuse should be the criterion of any evaluation of the system.

Evaluation of reuse should not stop, however, with considering the two alternatives: reuse and conventional supply. The analysis should be extended to include the method of operating the reuse facility to provide more optimal long-term solutions to meeting the demands for water. In such an analysis, reuse should be considered as one of the methods of supply along with surface and ground water. Such an analysis should also consider the demands for water. The manager should be encouraged to manipulate any one of the four components, ground water, surface water, reuse, and demand to achieve the most efficient system for the specific year and for the entire planning period.

THE SIMULATION MODEL

Evaluating alternative proposals for municipal supply planning is a complex problem. The number of variables is large and calculating solutions for a number of possible streamflows which might occur during the planning period is beyond the possibility of a deterministic analysis.

Even if such an analysis could be done, it would represent a unique solution--an assumed set of population growth and stream flows. What is more helpful is a range of solutions representing some distribution of probabilities that any individual set of conditions might occur.

Simulation models provide this capability. Using a simulation model, it is possible to investigate a series of alternate futures--varying the timing and durations of droughts, changes of populations, and other factors causing an increase or decrease in supply and demand. The cost of simulation in time and money is small. A typical plan for a 50-year simulation of a municipal water supply system requires a period measured in minutes of computer time and costs only a few dollars.

What can such a simulation reveal? If the elements of the system have been selected appropriately and the interrelationships reflected accurately, the model will provide insights into the effect of different planning strategies. Those models which represent strictly engineering considerations, such as pipeline flows, can retain high levels of accuracy, that is, for a given set of input conditions the outputs can be predicted with a high degree of confidence. Those which attempt to predict rainfall, runoff, population growth, and/or subsequent demands for water over an extended period, cannot retain the same degree of accuracy because the underlying processes of some systems are unknown, poorly understood, or random.

The value of a simulation model under these circumstances is that the planner can generate a series of possible outcomes based on a statistical analysis of the probabilities inherent in the range of inputs. For example, while an individual population projection over long periods of time may not reflect conditions which might develop, a range of populations can be selected that will represent the extremes which might be reasonably expected to occur. Using these extremes together with the variance of other inputs, a set of solutions and their costs can be generated which should produce guidelines to planners.

The model can provide a holistic approach to the operation of the system which is not considered under the usual compartmentalized decision-making structure in which separate individuals plan only for their areas of expertise. Even if a planner would attempt an holistic approach, there is evidence to indicate that modeling can provide better solutions. Simon argues that man's capacity for solving complex problems is relatively small compared to the size and complexity of the problems encountered.[72] In part, simulation provides a medium of exchange where experts in specific fields of knowledge can assemble the fragments of information to provide a series of decisions for a complex problem.

In order to evaluate the use of municipal wastewater, a computer model was developed to simulate the supply and storage of surface and ground water, the demands by a number of water-using sectors and the treatment of sewage by secondary and advanced waste treatment processes (Fig 2).* For a detailed description of the model, see Appendix A.

To test the model, the water supply system of Colorado Springs, Colorado was simulated. Streamflows and rainfall were generated using the program HEC-4 provided by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers.[73] Water demand models were based on multiple regressions of 12 years of monthly demand for 5 sectors of use: residential, commercial, industrial, military, and municipal.

Application of the Model: Colorado Springs, Colorado

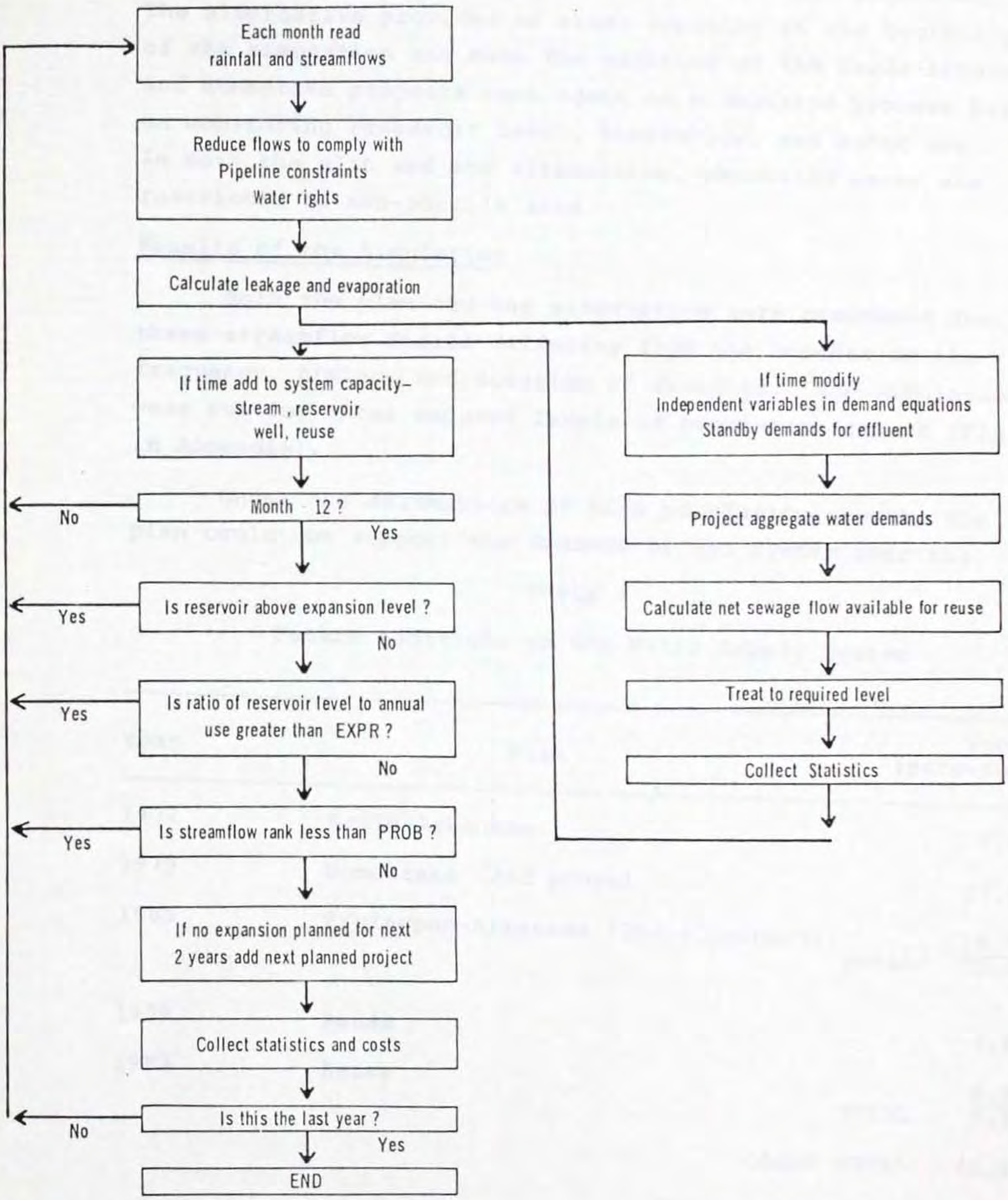
The water supply system of Colorado Springs is a complex network utilizing ground water, surface water, and renovated water from returned sewage. Twenty reservoirs, some for the non-potable system, provide for the storage and release of water. The doctrine of prior appropriations governs the amount and timing of diversions from streams and the storage and reuse of water.

The areas served by the water system have been growing rapidly both by natural population increases and by the annexation of the surrounding water systems. In the decade from 1960 to 1970, the population of the SMSA, which includes Colorado Springs, increased 64 percent. To meet the demand, the water system has expanded rapidly from less than 10,000 acre-feet in 1960 to over 50,000 acre-feet in 1973, including the capacity to provide 3,600 acre-feet of renovated effluent. Secondary effluent is further treated either by filtration to produce irrigation water or by coagulation, sedimentation, and carbon filtration to produce water for industrial use. Present plans are for additions which will bring the total yield from all sources up to 97,700 acre-feet (Table 4).

*For a complete description of the model, see An Evaluation of Water Reuse for Municipal Supply, D. Dworkin and D. Baumann, U.S. Army Engineer Institute for Water Resources, 1974.

Figure 2

FLOW DIAGRAM OF THE MODEL



This plan for increasing the capacity at fixed times was simulated.

An alternative to the above plan was also simulated. The alternative provided no reuse capacity at the beginning of the simulation and made the addition of the Eagle-Arkansas and Homestake projects contingent on a decision process based on monitoring reservoir level, streamflow, and water use. In both the plan and the alternative, renovated water was restricted to non-potable uses.

Results of the Simulation

Both the plan and the alternative were simulated for three streamflow series differing from one another in the frequency, timing, and duration of droughts. The simulations were run for three assumed levels of population growth (Fig.8 in Appendix).

Under the assumptions of high population growth, the plan could not support the demands of the system over the

TABLE 4

Future Additions to the Water Supply System

Year	Plan	Yield (acre-feet)
1977	Eagle-Arkansas	5,000
1979	Homestake (2nd phase)	17,000
1985	Fryingpan-Arkansas (2nd allotment)	10,000
	TOTAL	32,000
1979	Reuse	4,000
1983	Reuse	5,500
	TOTAL	9,500
	GRAND TOTAL	41,500
	Present capacity	56,200
	Present and future total	97,700

Source: Colorado Springs, Colorado Water Division records.

50-year planning period. Using three different sequences of streamflows, the plan failed after 33, 34, and 36 years. The alternative, however, supported demands for the full 50 year period. Moreover, the addition of two water supply projects was delayed an average of 16 years. The necessary capacity of the reuse plant was nearly three times as large as required for operating the plan but was not required until later. The amount of water reused was higher than scheduled in the plan only during the fourth decade. The present value of operating the plan (using a 6.875 rate of discount) averaged $21 million, compared with $12 million as the average cost of the alternative.

The medium and low population growth cases resulted in lower costs for the alternative, but the plan, depending on a fixed schedule of investments and requiring a predetermined quality of reuse, was isolated from the lowered demands of the system and required the same $21 million investment (Table 5).

For every assumed population and streamflow simulated, the alternative was a less costly method of supply than the plan. Of the two modes of providing water for Colorado Springs, the plan is least desirable under conditions of low population growth.

The alternative is economically a more efficient method of providing water supply for Colorado Springs. The additional expense of the plan arises from the cost of treating effluent when it is not required and from premature investment in both conventional and reuse facilities.

SUMMARY AND CONCLUSIONS

Water reuse is a viable and attractive alternative for the provision of municipal water supply. While the demand for water continues to increase in the United States, particularly in our burgeoning urban areas, the traditional

TABLE 5

Summary of Simulations: High, Medium, and Low Population Assumptions; Streamflow Series 1

	PLAN*	ALTERNATIVE High Population	ALTERNATIVE Medium Population	ALTERNATIVE Low Population
Years of Projection	50	36	50	50
Capacity of Reuse Plant (Maximum)				
Decade 1	12	0	0	0
2	12	26.4	0	0
3	12	27.4	11.9	9.7
4	12	32.0	11.9	12.8
5	12		11.9	16.8
Reuse Water Processed (acre-feet)				
Decade 1	19,000	0	0	0
2	40,000	7,000	0	0
3	40,000	10,644	1,400	700
4	40,000	40,107	0	1,500
5	40,000		0	2,100
Additions to Capacity (Year)				
Fryingpan, Arkansas	1985	1985	1985	1985
Eagle, Arkansas	1977	1993	1998	2013
Homestake	1979	1998	2000	never required
Present value of investments (millions of dollars at 6.875 percent)				
Reuse Capacity	2.20	1.91	0.7	0.6
Reuse operations and maintenance	4.44	1.69	0.4	0.8
Conventional Capacity	14.50	7.17	6.5	4.6
	21.50	10.77	7.6	6.0

*These figures are for 50 years of operation of the PLAN. There is little difference, less than a million dollars, in operation of the PLAN for less than 50 years.

alternatives for municipal water supply planning may be less appropriate or no longer practicable.

From the perspective of public health, the growing evidence suggests that while new criteria may be necessarily formulated and applied to determining whether our water is safe to drink, and although new problems may emerge, for example, contamination by carcinogenic chemicals, these problems are not unique to the planned reuse of water. In fact, because of more sophisticated treatment techniques and monitoring of water quality, recycled renovated wastewater is probably less of an insult to public health than the water currently produced by most municipal systems in the United States.

If recycled renovated wastewater can be safe to drink, and under specific qualifications the concept is a socially acceptable and economically efficient alternative for municipal water supply planning, then why has the rate of adoption been so low? The answer may be related to the existence of two problems: the unavailability of a methodology to assess the relative value of reuse, and the professional biases of consulting engineers, public health officials, and municipal water managers. An effort has been made to correct the first defínciency: a simulation model has been developed to evaluate the relative merits of specific water reuse systems. The second problem has been only defined and awaits additional research.

Water reuse should be integrated in the planning for municipal water supply. The thrust is no longer whether reuse is possible; instead, our attention should be directed toward programs and research on the diversity of opportunities for efficient implementations.

Delete

ACKNOWLEDGEMENTS

We are indebted to the Institute for Water Resources for their support in the preparation of this report. Moreover, we are grateful to Robert Harrison for his continual encouragement from the incipient stages of this project.

We also wish to express our gratitude to the following individuals for their constructive criticisms of earlier drafts of this report: Nancy Baumann, David Christensen, George Grebnow, David Holtz, Robert W. Kates, Jerome Milliman, Clifford Russell, and Gilbert F. White.

REFERENCES AND NOTES

[1]The distinction between the two uses are as follows: withdrawal water is available for further use, while water consumed is not available for reuse since it is either lost through evapotranspiration or incorporated into the product; See U.S. National Water Commission, Water Policies for the Future. Washington, D.C.: U.S. Government Printing Office, 1973, p.9.

[2]U.S. Water Resources Council, The Nation's Water Resources, Washington, D.C.: U.S. Government Printing Office, 1968, p. 1-22.

[3]We are assuming no significant change in climate, although planned weather modification efforts may be effective in selected local areas under unique atmospheric conditions.

[4]National Water Commission, op. cit., p.3.

[5]Linaweaver, F. Pierce, Jr., Geyer, John C., and Wolff, Jerome B., A Study of Residential Water Uses, Balitmore: The Johns Hopkins Univ., June, 1966, p.78.

[6]David, George and Wook, Leonard, "Water Demands for Expanding Energy Developments," Reston, Virginia: U.S. Geological Survey Circular 703,1974.

[7]National Water Commission, op. cit., p.13.

[8]Ibid.

[9]U.S. Federal Water Resources Council, op. cit., p.8.

[10]National Water Commission, op. cit., p. 1.

[11]Russell, Clifford S., Arey, David G., and Kates, Robert W., Drought and Urban Water Supply, Baltimore: The Johns Hopkins Press, 1970.

[12]White, Gilbert F., in Environmental Quality and Water Development, C. Goldmand, J. McEvoy III, P. Richardson (Eds.), San Francisco: W.H. Freeman & Co., 1973, p. 161.

[13]Wollman, Nathaniel and Bonem, Gilbert W., The Outlook for Water, Balitmore: The Johns Hopkins Press, 1971, p. 18.

[14]This is an attitude expressed commonly by groups such as S.O.S. (Save our Streams) in Western Massachusetts fighting the diversion to the Quabbin System; also, see: Marion Clawson, Suburban Land Conversion in the United States, Balitmore: The Johns Hopkins Press for Resources for the Future, 1973, p. 130.

[15]U.S. Bureau of the Census, Statistical Abstract of the United States, Washington, D.C., 93d edition, 1972, p.173.

[16]National Water Commission, op. cit., p. 345.

[17]Simmons, John, "Economic Significance of Unaccounted for Water," Journal of the American Water Works Association, LVIII, pp. 639-641. (1966)

[18]The literature is extensive. See Charles W. Howe, "Municipal Water Demand," in Forecasting the Demands for Water, ed., by W. R. Derrick Sewell, et al, Ottawa: Dept. of Energy, Mines, and Resources, 1968, p.48.

[19]Russell, Clifford S., Arey, David G., and Kates, Robert W., Drought and Water Supply.

[20]Ibid.

[21]Ibid

[22]National Water Commission, op. cit., p. 306.

[23]Koenig, Louis, Studies Relating to Market Projections for Advanced Waste Treatment, Washington, D.C.: U.S. Dept. of Interior Publication WP-20-AWTR-17, 1966.

[24]Examples of reuse applications are: Irrigation, Lubbock and San Angelo, Texas; recreation, Santee and South Lake Tahoe, California; aquifer recharge, Whittier Narrows, California; direct reuse, Windhoek, S.W. Africa.

[25]U.S. Senate Select Committee on National Water Resources, Water Resources Activities in the United States, Washington, D.C.: U.S. Government Printing Office, 1960.

[26]Water Resources Planning Act of 1965 (P.L. 85-90). Sec. 102; also Water Resources Council "Principles and Standards for Planning Water and Related Land Resources," Federal Register, XXXVIII, No. 175, Sept. 10, 1973, 24778-24869.

[28]U.S. Federal Water Resources Council, op. cit., p. 1-23.

[29]National Water Commission, op. cit., p.314.

[30]Ibid.,pp.314-315.

[31]Ibid., p.306.

[32]Symons, George E., "Water Reuse-What Do We Mean?" Water and Wastes Engineering, June, 1968.

[33]Heaton, R. D., Linstedt, K. D., Lennett, E. R., and Suhr, L. G., "Progress Toward Successive Water Use in Denver," Mimeo, October, 1974.

[34]Samuelson, Paul., Economics, New York: McGraw-Hill, 1970.

[35]Hutchins, W. A. Water Law in the Nineteen Western States, Washington, D. C.: U.S. Dept. of Agriculture, 1971, p.27.

[36]Hartman, L. M. and Seastone, D., Water Transfers, Baltimore: Johns Hopkins Press, 1970, p.4.

[37]Ibid.

[38]Wollman, and Bonen, G.W., The Outlook for Water, Baltimore: The Johns Hopkins Press, 1971, P. 25.

[39]Ibid.

[40]Krutilla, J.V. and Cicchette, C.J., "Evaluating Benefits of Environmental Resources with Special Application to the Hells Canyon," Natural Resources Journal, 12 (January, 1972), pp. 1-29.

[41]Lof, G. O. G. and Hardison, C.H., "Storage Requirements for Water in the United States," Water Resources Research, 2, (Autumn, 1966), pp. 323-354.

[42]Wollman and Bonen, G.W., op. cit.

[43]Brochure 6, Southern Water Conservancy District.n.d.

[44]Culp, R.L. and Culp, G.L. Advanced Wastewater Treatment, N.Y.: Van Nostrand Rheinhold Co., 1971.

[45]The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, 92nd Congress, S. 2770, Oct. 18, 1972.

[46]The U.S. Office of Water Resources and Technology has published two volumes of an annotated Bibliography concerning research related to water reuse: U.S. Office of Water Resources Technology (formerly the U.S. Office of Water Resources Research) Water Reuse--a Bibliography. Washington, D.C.: Water Resources Scientific Information Center, 1973.

[47]National Water Commission, op. cit., p. 313.

[48]G. C. Cillie, et al., "The Reclamation of Sewage Effluents to Domestic Use," Third International Conference on Water Pollution Research , Washington, D.C.: WPFC, 1966, also G. J. Stander, "Water Reclamation in Windhoek," Scientiae, X, January, 1969, pp. 3-14.

[49]U.S. Public Health Service, Drinking Water Standards, Washington, D.C.: Government Printing Office, 1962.

[50]Metzler, Dwight, et al., "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas." Journal of the American Water Works Association, 50, 1958, pp. 1021-1057.

[51]U.S. Senate Select Committee on National Water Resources, Water Resource Activities in the United States: Present and Prospective Means for Improved Reuse of Water, 86th Congress, 2nd Sess., Print No. 30. Washington D.C. Government Printing Office, 1960. p.3.

[52]Merrill, John C., et al., The Santee Recreation Project, Cincinnati, Ohio: Federal Water Pollution Control Agency, 1967, pp. 108-116.

[53]Marx, Jean, "Drinking Water: Another Source of Carcinogens," Science, 186 (Nov. 20, 1974), pp. 809-811.

[54]Harris, Robert H. and Edward M. Brecher, "Is the Water Safe to Drink," Consumer Reports, 39, (June, 1974), p. 437.

[55]U.S. Public Health Service, Community Water Supply Study, Washington, D.C.: U.S. Public Health Service, 1970, p. vi.

[56]Ibid, p.8.

[57]Comptroller General of the United States, Improved Federal and State Programs Needed to Insure the Purity and Safety of Drinking Water in the United States. Washington, D.C.: General Accounting Office, B-166506, 1973.

[58]Safe Drinking Water Act, 93rd Congress, S. 433 and H.R. 1059.

[59]Dean, Robert in Berg, (ed.), Transmission of Viruses by the Water Route, New York: John Wiley and Sons, 1965, p. 470.

[60]Johnson, James F., Renovated Waste Water: An Alternative Supply of Municipal Water Supply in the United States. Chicago: University of Chicago, Dept. of Geography Research Paper No. 135, 1961, p. 92.

[61] Baumann, Duane D., and Kasperson, Roger E., "Public Acceptance of Renovated Waste Water: Myth and Reality," Water Resources Research, 10 (August 1974), p. 673674.

[62] Sims, John H. and Baumann, Duane D., "Renovated Waste Water: The Questions of Public Acceptance," Water Resources Research, 10 (August 1974), pp. 659-665.

[63] Heaton, R. D., Kinstedt, K. D., Bennett, E. R., and Suhr, L. G. "Progress Towards Successive Water Use in Denver," unpublished paper.

[64] National Water Commission, op. cit., p. 313.

[65] Metzler, Dwight et al. "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," Journal of the American Water Works Association, 50 (1958), pp. 1021-1057.

[66] Sims, John H. and Baumann, Duane D., "Professional Bias and Water Reuse," Economic Geography, 1976, (forthcoming).

[67] Ibid.

[68] City of Colorado Springs, Department of Public Utilities. 1970 Annual Report p. 11.

[69] Johnson, James F., op. cit.

[70] National Water Commission, op. cit.

[71] Lof, G.O.G. and Hardison, C. H., op. cit.

[72] Simon, Herbert A., Administrative Behaviour, 2nd ed. New York: The Free Press; 1957 p. 79.

[73] U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-4 Monthly Streamflow Simulation. Davis, California: The Hydrologic Engineering Center, 1971.

[74] Ibid.

APPENDIX

THE MODEL

The model TINKLE simulates a municipal water supply, demand, and waste treatment operation (Fig.2). These three major systems of the model are combined in a simulation consisting of a main routine and thirteen subroutines. The design and testing of the model was carried out over an eight month period. An experienced programmer, Roy A. Wyscarver worked full-time in close collaboration with Dworkin writing and debugging the model. As previously noted, the model required a snythetic record of streamflows and rainfall. The record is simulated by the use of the U.S. Army Hydrologic Engineering Center's program, HEC-4 and stored on tape or disc for use during the simulation.[74] The main program which serves as the executive routine, is designated TINKLE. In running a simulation, TINKLE first obtains data on the system from INPUT and then reads rainfall and streamflows generated by HEC-4 (Fig. 3).

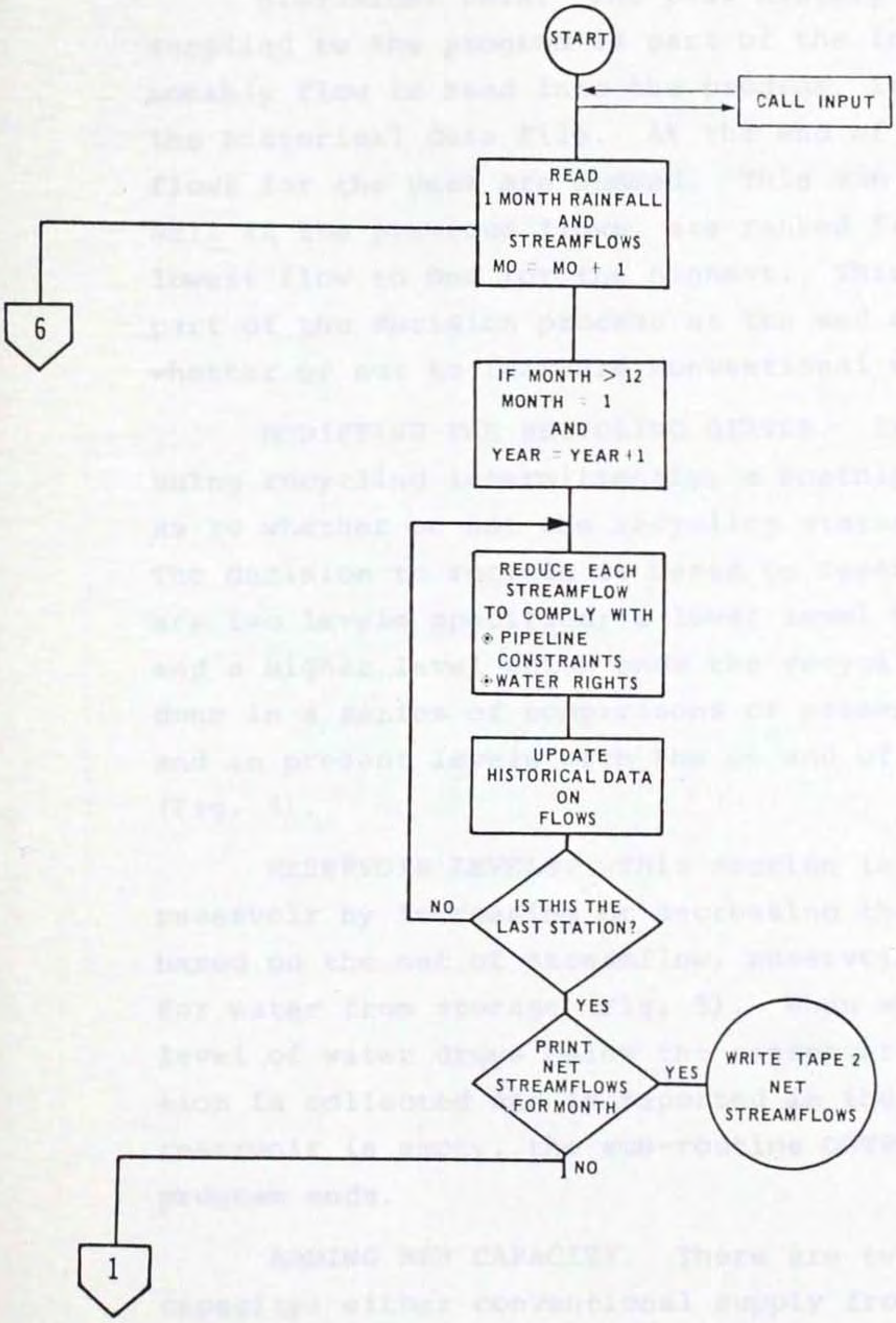
MAIN ROUTINE

LIMITING STREAMFLOWS. The monthly flow of each stream used in the system is decreased under the following circumstances: (1) if the diversion works or pipeline is unable to pass the required flow, (2) if restrictions require a base flow before diversion, and, (3) if senior rights and intervening rights must be satisfied. The limitations can be set for seasonal variations in restrictions. In addition to limiting flows, the water may be designated as local or imported for those areas in which reuse is limited to water originating outside of the basin. The editing parameters of the program can be set to print net streamflows for each year or if only a sampling of flows are desired, the frequency of the net streamflow print-out can be reduced to as little as

Ctr

Figure 3

MAIN ROUTINE TINKLE
Streamflows and Rainfall



once during a 50 year simulation.

HISTORICAL DATA. The past history of monthly flows is supplied to the program as part of the input data. As each monthly flow is read into the program, it is used to update the historical data file. At the end of each year, the total flows for the year are summed. This sum of yearly flows, as well as the previous flows, are ranked from zero for the lowest flow to one for the highest. This ranking is used as part of the decision process at the end of each year as whether or not to increase conventional capacity.

MODIFYING THE RECYCLING STATUS. If the simulation is using recycling intermittently, a monthly check is initiated as to whether or not the recycling status should be changed. The decision to recycle is based on reservoir levels. There are two levels specified; a lower level which starts recycling, and a higher level which ends the recycling process. This is done in a series of comparisons of present and past levels, and in present levels with the on and off levels for recycling. (Fig. 4).

RESERVOIR LEVELS. This section is designed to manage the reservoir by increasing or decreasing the supply in storage based on the net of streamflow, reservoir losses, and demands for water from storage (Fig. 5). When water is spilled or the level of water drops below the conservation pool, the information is collected and is reported in the final output. If the reservoir is empty, the sub-routine OUTPUT is called and the program ends.

ADDING NEW CAPACITY. There are two methods of adding capacity: either conventional supply from streams, reservoirs, wells, or projects, or by increasing the amount of reused water continuously processed and distributed. The first is by scheduling the increase for a specific time during the simulation. The second is a decision which at the end of each year is based

Figure 4

MAIN ROUTINE TINKLE

The Decision to Change the Recycling Status

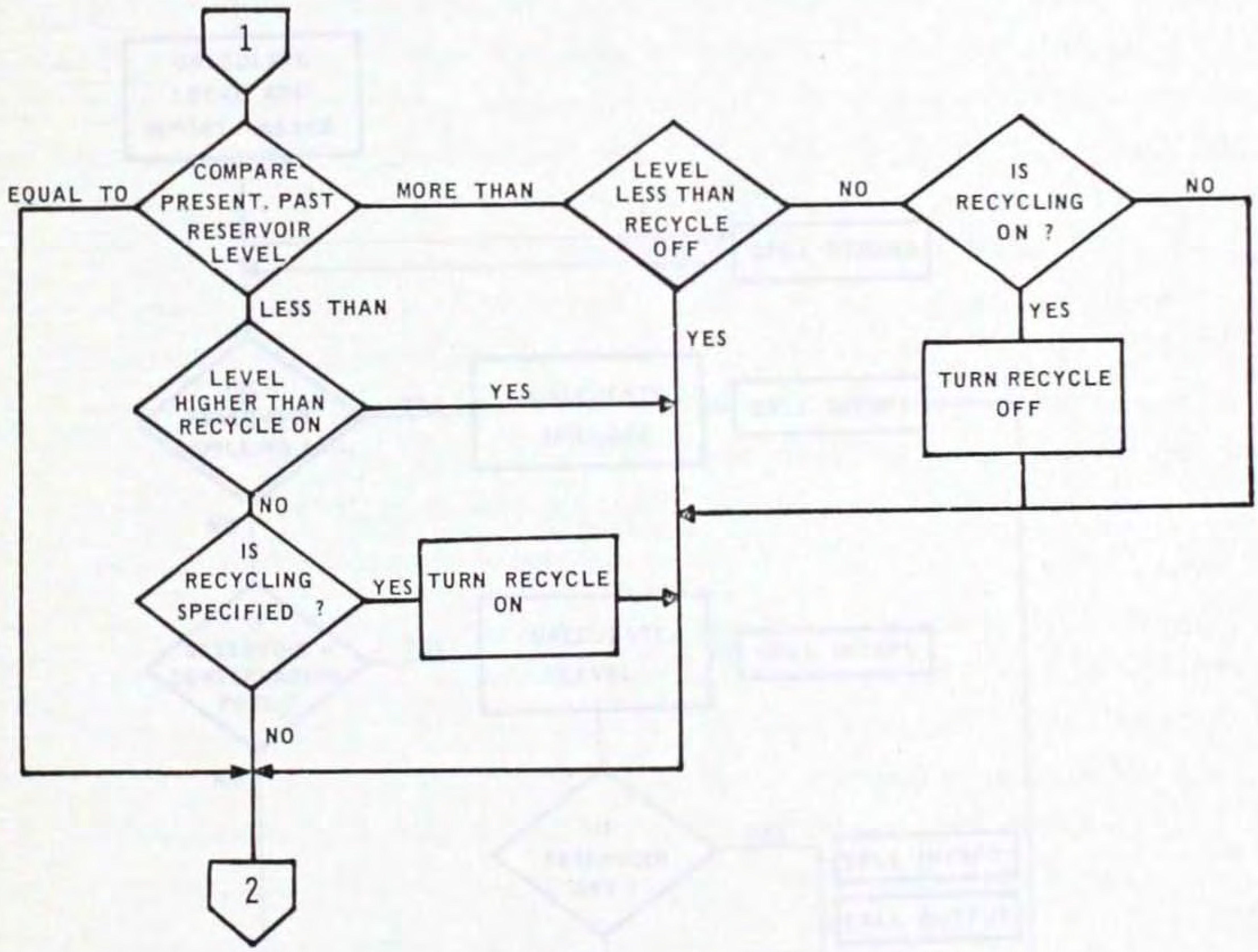
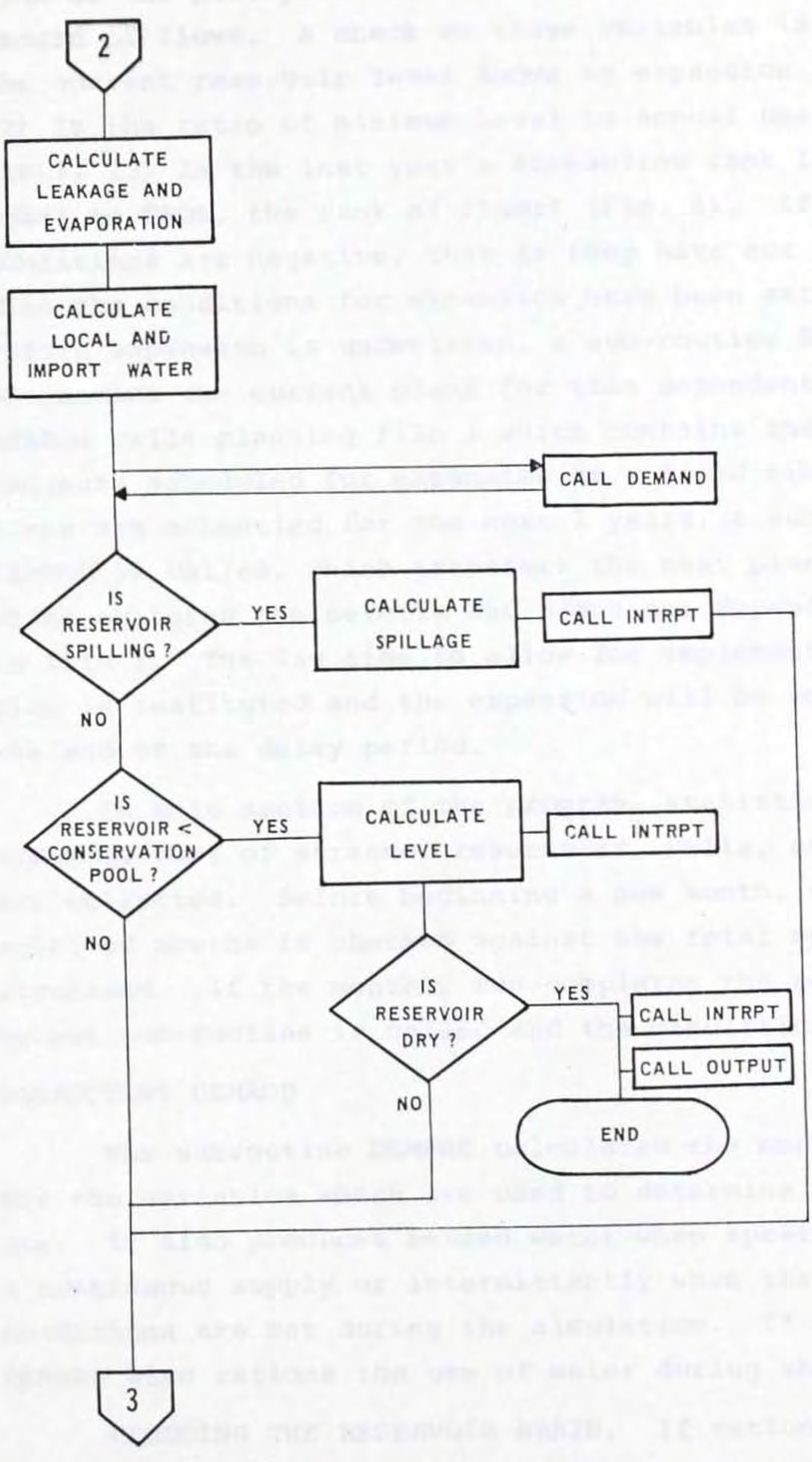


Figure 5

MAIN ROUTINE TINKLE

Reservoir Accounting; Net Demand and Losses



on monitoring reservoir level use for the past year, and the rank of the past years streamflow compared to the historical record of flows. A check on these variables is made: (1) is the current reservoir level above an expansion level EXPR?, (2) Is the ratio of minimum level to annual use larger than EXPL?, (3) Is the last year's streamflow rank less than or equal to PROB, the rank of flows? (Fig. 6). If all these conditions are negative, that is they have not been fulfilled, then the conditions for expansion have been satisfied. Before expansion is undertaken, a sub-routine SEARCH is called to examine the current plans for time dependent expansion. SEARCH calls planning file 1 which contains the data on new projects scheduled for expansion at a fixed time. If no plans are scheduled for the next 2 years, a sub-routine EXPAND is called, which transfers the next plan in file 5, which contains the details and plans not dependent on time to file 1. The lag time to allow for implementation of the plan is instituted and the expansion will be completed at the end of the delay period.

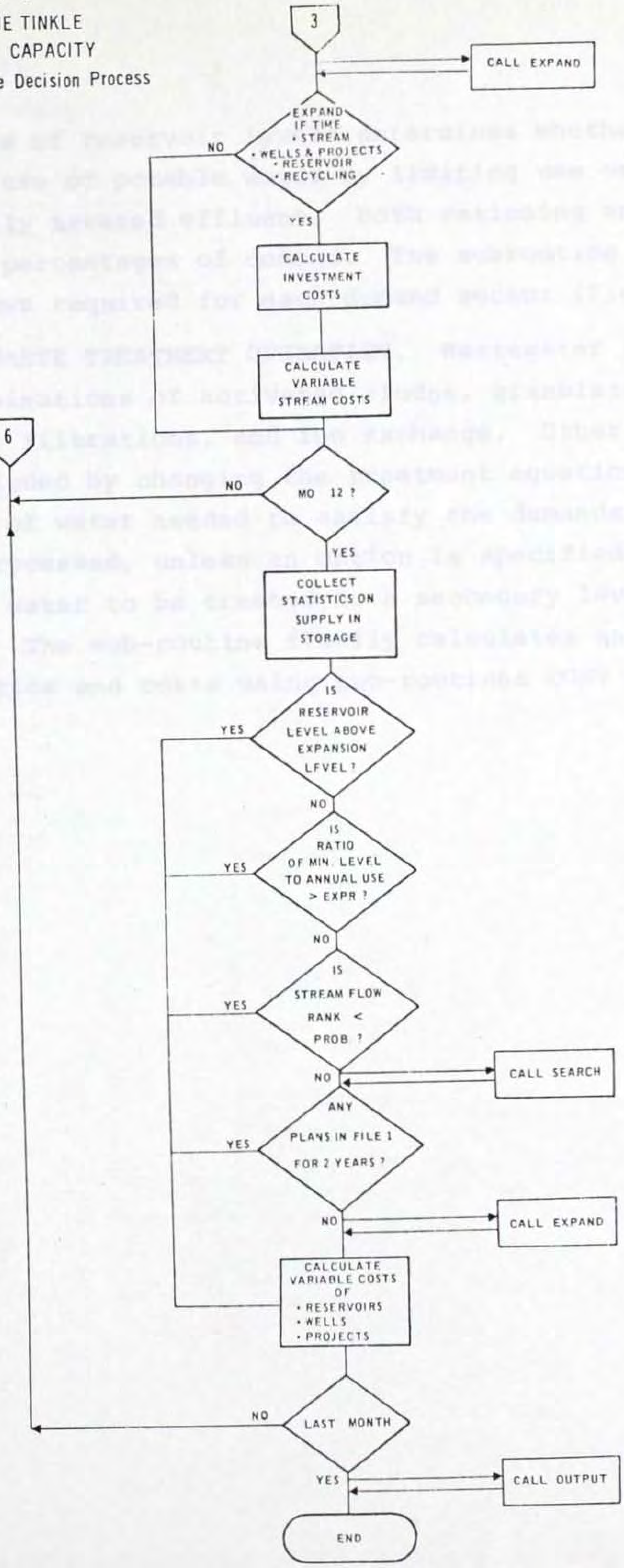
In this section of the program, statistics on the variable cost of streams, reservoirs, wells, and projects are collected. Before beginning a new month, the cumulative total of months is checked against the total month to be simulated. If the monthly run completes the series, the output sub-routine is called and the simulation ends.

SUBROUTINE DEMAND

The subroutine DEMAND calculates the monthly values for the variables which are used to determine monthly water use. It also produces reused water when specified either as a continuous supply or intermittently when the appropriate conditions are met during the simulation. If specified, DEMAND also rations the use of water during shortages.

REDUCING THE RESERVOIR DRAIN. If rationing or reuse are specified in the program input parameter, the subroutine

Figure 6
MAIN ROUTINE TINKLE
ADDING NEW CAPACITY
Time and an Alternate Decision Process



on the basis of reservoir levels determines whether to reduce the use of potable water by limiting use or supplying appropriately treated effluent. Both rationing and reuse are limited to percentages of demand. The subroutine calculates all the flows required for each demand sector (Fig. 7).

THE WASTE TREATMENT OPERATION. Wastewater is treated by any combinations of activated sludge, granulated carbon absorption, filtrations, and ion exchange. Other processes can be included by changing the treatment equations. Only the amount of water needed to satisfy the demands for reused water is processed, unless an option is specified which requires all water to be treated to a secondary level before discharge. The sub-routine finally calculates and collects all statistics and costs using sub-routines COST and CCOST (Fig. 8).

ctr

Figure 7

SUBROUTINE DEMAND

Reducing the Reservoir Drain by Reuse or Rationing

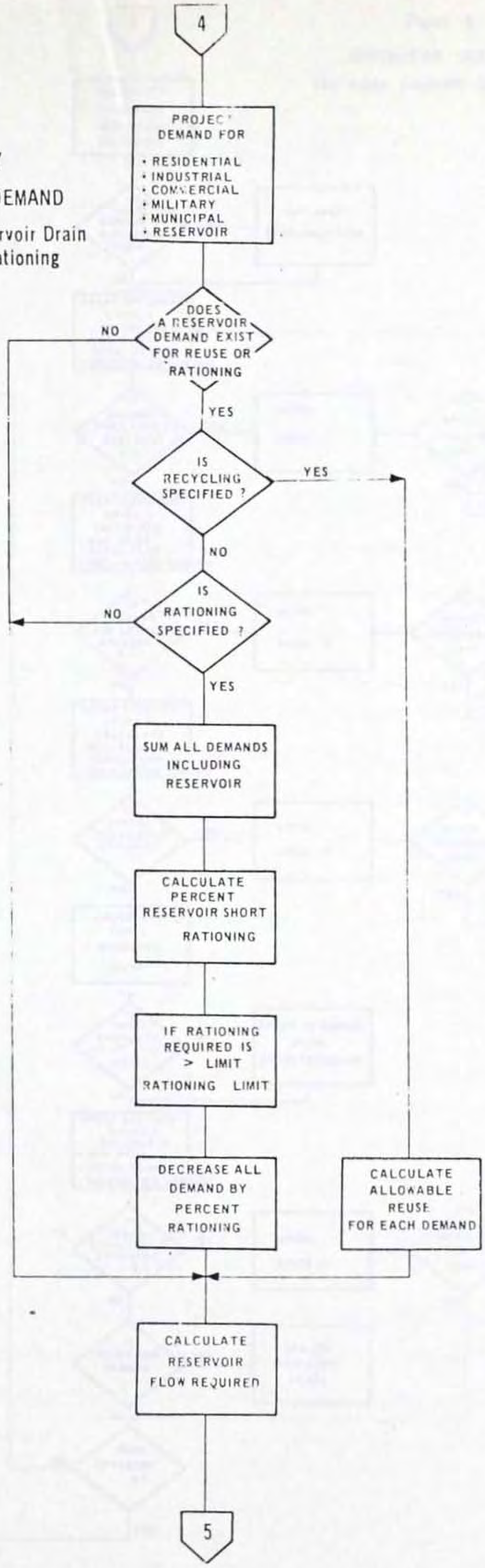
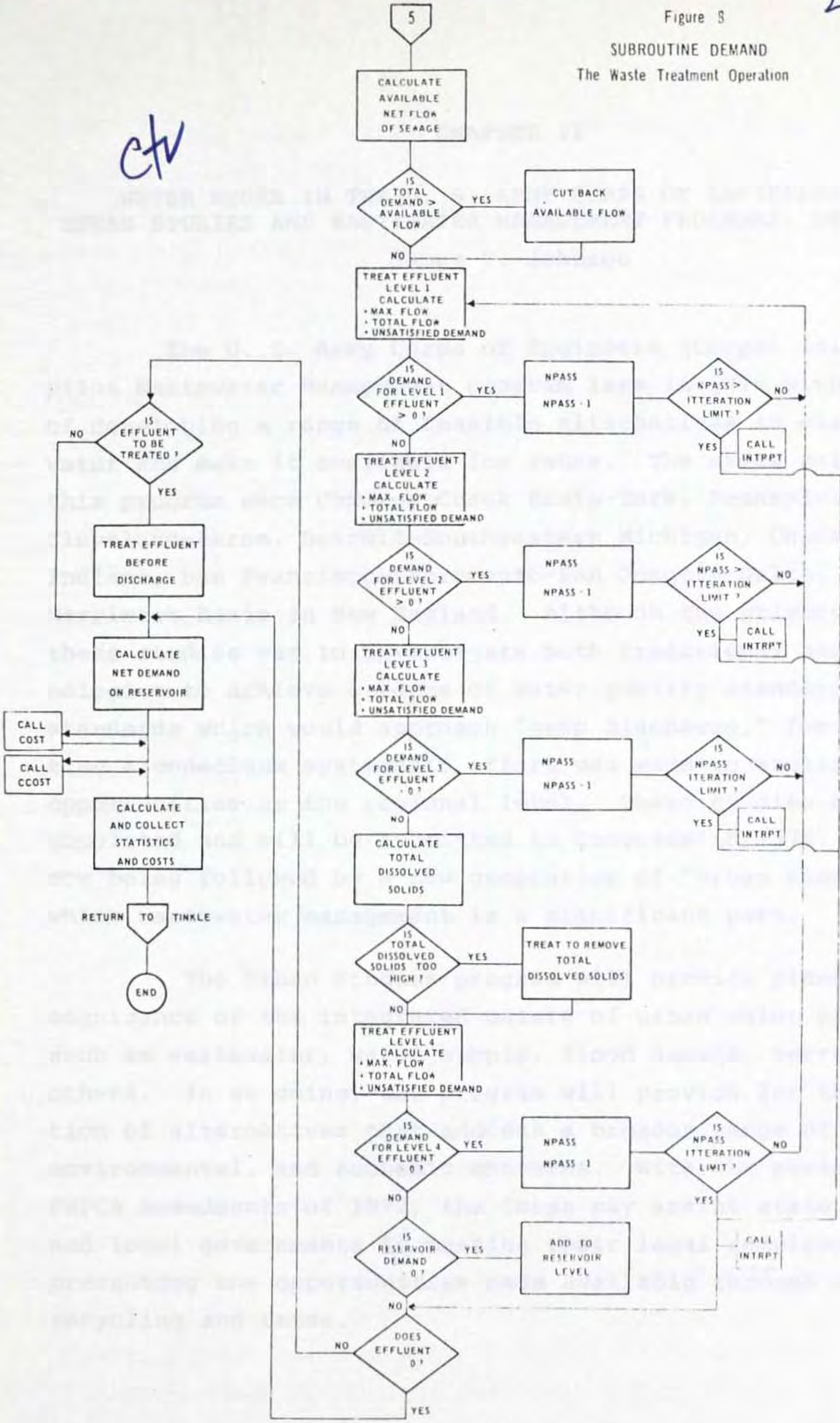


Figure 8

SUBROUTINE DEMAND

The Waste Treatment Operation



CHAPTER II

WATER REUSE IN THE U. S. ARMY CORPS OF ENGINEERS' URBAN STUDIES AND WASTEWATER MANAGEMENT PROGRAMS: AN OVERVIEW

James F. Johnson

The U. S. Army Corps of Engineers (Corps) initiated its pilot Wastewater Management program late in 1970 with the purpose of developing a range of feasible alternatives to cleanse wastewater and make it available for reuse. The areas selected for this program were Codorus Creek Basin-York, Pennsylvania, Cleveland-Akron, Detroit-Southeastern Michigan, Chicago-Northwest Indiana, San Francisco-Sacramento-San Joaquin Delta, and the Merrimack Basin in New England. Although the primary emphasis in these studies was to investigate both traditional and new technologies to achieve a range of water quality standards including standards which would approach "zero discharge," for the first time a conscious systematic effort was made to explore reuse opportunities at the regional level. These studies have been completed and will be submitted to Congress in 1976. They are now being followed by a new generation of "urban studies" in which wastewater management is a significant part.

The Urban Studies program will provide plans that take cognizance of the integrated nature of urban water problems such as wastewater, water supply, flood damage, recreation, and others. In so doing, the program will provide for the formulation of alternatives that address a broader range of social, environmental, and economic concerns. With the passage of the FWPCA Amendments of 1972, the Corps may assist state, regional, and local governments in meeting their legal requirements while presenting the opportunities made available through efficient recycling and reuse.

The Corps' Urban Studies and Wastewater Management programs, viewed broadly, will contribute to national objectives such as those set forth by the Water Resources Council. Specific technical goals also were established to provide a basis for the actual formulation and evaluation of wastewater systems. The technical goals of the pilot wastewater program were (a) to prevent the continued degradation of our water resources by waterborne wastes and (b) to provide for the efficient reuse of treated or renovated wastewater and its separated constituents.

The Corps standard of "no discharge of constituents at critical levels " was designed to reflect the intent of the subsequent Federal Water Pollution Control Act Amendments of 1972.

Achieving the goal of efficient reuse in the pilot program was undertaken through an examination of reuse and multiple use of every component of the wastewater system, including renovated water, sludge, brines, and generated gases; and the physical system components such as storage lagoons, land, rights-of-way, and pipelines. Investigation of water reuse opportunities include agricultural irrigation, turf irrigation, aquifer recharge, stream flow stabilization, recreational lakes, industrial cooling, industrial process water, industrial boiler feed, and municipal use.

Analysis of water reuse potential met with limited success in the pilot wastewater studies. Water reuse opportunities were explored in a general way, but without specific detail for the most part. The Codorus Creek wastewater management study[1] examined reuse in some detail. According to the Final Report, wastewater reuse already exists on a small scale in the study area. A prime example of this is the P.H. Glatfelter Company which recycles a portion of its process water. This study found that, on a large scale, reuse is extremely attractive, especially for industrial process water. The Codorus Creek study area, however, contains only one large user of industrial process water, The P.H. Glatfelter Company at Spring Grove.

All industry in the study area generates a total of 29.1 mgd of wastewater. Of this, P.H. Glatfelter produces 17.2 mgd or 59 percent of the total, and obviously the company is the key to the success of large scale industrial reuse of wastewater.

Potential for reuse in the basin is predominantly associated with the York Urban Area treatment system. Other components of the regional systems are not affected. Instead of providing advanced treatment for all the wastewater generated in the York Urban Area, a portion could be transmitted to the P. H. Glatfelter Company for use as process water, thereby releasing its present water supply sources for other uses. The wastewater, after reuse, would be treated by either advanced water process or land application techniques, a choice P.H. Glatfelter Company has to make under any circumstances.

Chicago, Cleveland, and Detroit shared similar reuse opportunities and characteristics as the metropolitan areas in the Great Lakes Region. Reports on each of these sites detail reuse potential. For purposes of this paper, some examples of reuse are extracted from the Cleveland-Akron report.[2]

EXAMPLES OF REUSE IN THE CLEVELAND-AKRON REPORT

Reuse of Effluent

The reuse of effluent, including the reclaiming and recycling of water, can take many forms with varying degrees in order to create additional urban and rural benefits. The reuse of sewage effluent can range from low flow augmentation of area streams for recreational, environmental and water supply purposes to providing large cooling water lake surfaces for new power plant sites. The type and extent of the reuse would be limited only by need, economics, and imaginative planning.

Low Flow Augmentation

The augmentation of low flow in streams for aesthetic, recreational and water supply purposes falls into two categories:

first, in the Three Rivers Basin where benefits accrue locally; and secondly, in the outlying basins west of Cleveland. The in-basin augmentation applies to both water-based and in-basin land-based treatment, while the western Ohio low flow agumentation is related to the land treatment method in those counties. The value of storage for regulation of streamflow including effects on navigation, recreation, aesthetics, and the fish and wildlife should be accounted for in determining total benefits of multiple-purpose planning.

New Power Plant Sites

The construction of large reservoirs in the land treatment management areas could be designed to provide for power plant sites, perhaps nuclear plants, which would utilize the reservoir water surface as cooling areas. An immediate and large financial benefit to the local counties would be the high capital investment and resulting significant mill levy income to the particular county.

The western land treatment sites would provide the opportunity to create new power plant sites which would be surrounded with a cooling pond and up to one to three miles of buffer zone. These sites would be created in the basic planning and construction for use initially or later. In addition, these large cooling ponds would provide a beneficial use for the waste heat and thermal discharges associated with power plants, especially during winter months when biological activity for effluent stabilization generally proceeds at a slower rate due to lower temperatures.

Approximately 1500 acres of water surface is required per 1000 Megawatts of generation capacity. The plants would be expected to "burn up" some 10,000 to 14,000 acre-feet per year per 100 Megawatts of capacity. Since flow-through plants using Lake Erie water, or plants using cooling towers have the same general consumptive use, this cooling evaporation need not be considered a "waste" of a water resource, but merely a relocation of the point of depletion within the hydrological cycle.

Power Plant Cooling

The existing power plants in the Cleveland area generally utilize Lake Erie water or Cuyahoga River water for flow-through cooling. The trend on newer installations is to cooling towers. The constant and dependable supply of treated sewage effluent makes possible flow-through cooling use in power plants in some cases, though the available sewage effluent flow rate is often limited when compared with the total needs for the larger power plants. Nevertheless, opportunities exist which can be utilized for both land and water-based plans. Makeup water for the power plants can be provided using more highly treated effluent.

Recreational Water Use

The augmentation of low stream flow is oriented towards recreational use and aesthetics in and on the water. Where canoeing, kayaking and rafting is of special significance, the final layout of return flow points and release of water from reservoirs can be timed to accommodate these specific and important water needs. These opportunities apply to both land and water-based plans.

The construction of storage reservoirs for storm runoff detention provides basins throughout the Three Rivers Basin with some environmental benefits which would be tailored to the specific site and area needs. Stormwater detention basins in some cities provide significant additions to parks and open spaces.

In addition to water reuse, the Cleveland-Akron study discussed opportunities for reuse of waste treatment by-products, such as settling basin deposits of sand and silt, and the nutrient value of sewage solids. The Merrimack Basin study, while exhibiting different physical characteristics, examined reuse in much the same manner. The San Francisco-Sacramento-San Joaquin study focused only on land treatment techologies, and reuse opportunities were limited accordingly.

URBAN STUDIES PROGRAM

More than forty urban studies have been initiated by the U. S. Army Corps of Engineers in vastly diverse environmental and demographic settings. These range from metropolitan areas such as Atlanta, New Orleans, and Kansas City, to sparsely populated areas such as Boise, Idaho and Kaneohe Bay, Hawaii. In Fiscal Year 1975, the urban studies planning budget of $10 million comprised about 1/3 of the Corps Civil Works General Investigation Survey Program. Wastewater Management is a key element of the Urban Studies. Under the wastewater management function, the Corps will comply with the U. S. Environmental Protection Agency (EPA) requirements for 201-type facilities plans.

Specifically, reuse will be examined in compliance with the following sections of EPA guidance: Section 4.4.3 states that treatment and reuse must be considered as one alternative to meet the requirements for best practicable waste treatment technology; in addition, Section 4.4.5.3 lists industrial reuse and recycling as a flow and waste reduction measure to be considered in determining system cost-effectiveness.

Although Corps studies are strongly supportive of EPA reuse requirements, there is currently very little in the way of procedural guidance on water reuse from EPA at this time. Until such guidance is provided, the Corps will continue to investigate reuse opportunities in a manner similar to that employed in the pilot wastewater program. We need to examine the option of reuse as we examine other sources of water supply. Water managers in urban areas generally view water reuse in a limited scope as an alternative to fresh water sources of potable water supply. Instead, reuse should be considered in virtually every instance where water is "initially" used; in quantities and qualities dictated by the particular use, and both in isolated delivery via "directed" pipeline or through a centralized municipal system. Water reuse should be considered, depending upon a weighing of its attendant value and associated impacts, for a range of uses such as previously discussed (irrigation, aquifer recharge, stream stabilization, recreational lakes, industrial use, and municipal uses). The quality and quantity requirements and locational specificity of these demands should be reviewed as a basis for examining how water reuse might be adapted to serve these projected uses most efficiently. These considerations are ordered in the following simplified process.

Investigate Potential Range Of Uses

Various uses such as streamflow stabilization, potable municipal supply, and turf irrigation can be met with water of substantially different physical, biological, and chemical characteristics. Reuse opportunities should be investigated by first developing an inventory of desired water characteristics of the specific projected water uses.

Compare Alternative Sources of Supply

Various sources of water with their associated physical, biological, and chemical characteristics should be compared according to their ability to supply the previously projected uses. Locational specificity of these projected "demands" and "supplies" should be matched carefully in order to avoid over-looking costs associated with the delivery of water over short or intermediate distances.

Investigate Alternative Delivery Systems

Particular attention should be given to investigating systems for delivering water other than those traditionally employed in the particular region. Delivery of water for reuse may be accomplished through systems utilizing dual pipelines, single source wastewater pipelines to concentrated users, reservoir and emergency supplements, aquifer recharge, and systems employing cascading reuse to meet descending levels of water quality demands.

Examine Alternative Impacts

The Corps proposes to provide an objective assessment of the full range of alternative water systems, and an evaluation of the economic, environmental, and social effects associated with these systems. Resource requirements, facilities and resource output of these systems are investigated to view their impacts upon such parameters as the regional and national resource base, selected ecological systems, local economies, community cohesion, public health, aesthetic value of the landscape, and regional development. In considering the value of water reuse, particular attention should be given to recognizing that alternatives which result in expanded capacity of the water supply operations also may generate impacts in wastewater treatment and disposal operations. Such related impacts must be reflected in the analysis and comparison of alternatives to reuse.

CONSIDERATIONS ON REUSE

Planners investigating the feasibility of water reuse must take care not to be biased in its consideration. Traditional planning and engineering approaches to water supply problems may inhibit consideration of water reuse options even when they are clearly the most practical choice. The urban studies program has been characterized by its comprehensive, innovative approach to water resources planning. Accordingly, Corps planners are encouraged to reflect the following attributes.

Be Thorough

Avoid simplistic negative responses to reuse opportunities. Reuse may not be of obvious value until one examines the "true" cost of water for certain geographic or functional (e.g., industry) sectors. In particular, avoid the assumption that apparent water "abundant" areas do not need to reuse water.

Be Imaginative

Water plans in these studies are being developed for time frames twenty to fifty years in the future. During this time, significant land use changes may be expected to occur. Planners should recognize that future development and land use decisions can incorporate water reuse as a basis for location and distribution of selected water-consuming activities.

Be Responsive

PL 92-500 requires the consideration of treatment and reuse, as do EPA guidelines for facilities planning. The Urban Studies program intends to meed EPA requirements; plans of study and scopes of work will be reviewed with a focus on such items as reuse in order to assure compliance with EPA requirements.

Combine 66-67 or is this style

REFERENCES

[1]U. S. Army Corps of Engineers, Baltimore District, The Codorus Creek Wastewater Management Study, April 1973.

[2]U. S. Army Corps of Engineers, Buffalo District, Wastewater Management Study for Cleveland-Akron Metropolitan and Three Rivers Watershed Areas, August, 1973.

[3]U. S. Environmental Protection Agency, Office of Water Program Operations, Guidance for Preparing a Facility Plan, May, 1975.

CHAPTER III

THE U. S. ENVIRONMENTAL PROTECTION AGENCY AND WATER REUSE

Paul Durand

BACKGROUND

While indirect and delayed reuse of water has many accepted applications, the direct application of measures to reuse wastewaters for constructive purposes presents both new opportunities and new problems. Direct reuse is currently being conducted in a number of places for specific purposes; in fact, California reported in 1969 over 200 non-potable reuse situations. Reuse is being applied for a number of purposes, including industrial use for cooling purposes, for groundwater recharge to prevent salt water intrusion in coastal areas; as a source for recreational waters; for irrigation and other agricultural uses, not involving direct contact with food surfaces; and for other uses. Appendix A is included for definition of direct and indirect reuse and for discussion of the differences related thereto.

The potential for water reuse, as a tool in broad water resources and water quality planning, is many times greater than current practice and should be routinely considered and developed to meet non-potable demands. As could be expected, activity with regard to reuse appears to be much intensified in water-short areas of the country, for instance in the arid West. The Water Resources Council (WRC) report, "The Nation's Water Resources, 1968", cites water shortage problems in 9 basins--Arkansas-White-Red; Texas-Gulf; Rio Grande; Upper Colorado; Souris-Red-Rainy; Missouri; Lower Colorado; Great Basin; and California-and pointedly shows that these problems will worsen by 2020 unless remedial measures are applied.

In addition to reuse of wastewaters, attention is being given to weather modification, desalination, water conservation, interbasin transfer, tapping of the geothermal deep-water reservoirs and other approaches to conserve existing as well as tap new sources. Reuse should be considered in the light of water quality, environmental, ecological and economic aspects as well as the public health aspects; it should provide a vital link in meeting needs in water short areas.

REUSE APPLICATION AND PUBLIC HEALTH PROBLEMS

Taking a national view of fresh water demands, it may be seen from the 1968 WRC report that for year 2020, electric power (cooling water) will be first in demand (410 BGD); self-supplied industrial, second (210 BGD); irrigation, third (161 BGD); and municipal, fourth (74 BGD); with minor residue demands for livestock and rural domestic. Logically, one would expect that priorities for reuse would pattern after demand with electric power (cooling) first, industrial second, etc. Such a pattern of application would ideally suit health protection-water quality relationships since cooling and most industrial uses would present low health risks; irrigation for some crops would be potentially hazardous, but not for others; and municipal uses would offer the greatest human contact and the largest potential danger.

The problem may not be handled so simply on gross utilization terms since each call for water reuse will be situational, depending on geographic location, climate, public attitudes, the availability of wastewater sources and of potential water users, etc. One community may be non-conservative in utilizing its fresh waters and be willing to treat and recycle wastewaters in order to continue its easy-water practices, while another community with a similar policy and an abundant supply of cheap water may be unwilling to treat and recycle wastewater just to conserve water for use by others--for instance for irrigation or municipal purposes elsewhere. In one case, a needy municipality may be in a position to utilize industrial wastewaters and, in another case, a needy industry may be situated so as to use municipal wastewaters. In any event, the technology is available for the treatment and reuse of many wastewaters for many purposes and such reuse should be broadly considered in the management of water resources.

Public health problems do occur and require attention as outlined below.

<u>Industrial</u>

The reuse of water by industry should be encouraged where it is technically and economically feasible. Quality needs for industrial uses vary so widely that it is not possible to generalize on this subject; however, except for food processing industries, they are usually lower than drinking water requirements.

<u>Groundwater Recharge</u>

Groundwater recharge can be used to raise or maintain the level of groundwater and/or to prevent the intrusion of salt water. For most recharge applications through spreading and percolation of reuse waters on the surface, quality requirements for health protection would be enhanced by natural filtering processes. However, percolation into a shallow basin used for drinking water supply should receive careful attention and the recharge of reuse water by subsurface injection should not be implemented without strict controls and a clear demonstration that such disposal will not harm present or potential subsurface water supplies or otherwise damage the environment.

<u>Recreation</u>

Indirect reuse of water for primary contact recreational purposes is clearly recognized in the section on recreational uses in <u>Water Quality Criteria</u>[1] by way of the recommended limits for fecal coliform organisms and the recommendation that sanitary surveys be conducted to determine the degree of threat of pathogens from specific sources.

The hazards associated with direct contact recreation in waters receiving inadequately treated waste discharges are chiefly biological and are usually associated with the transmission of infectious diseases that may enter the body through the mouth or nasal passages or other portals such as the eyes, and certain areas of the skin. Numerous examples may be given of both direct and indirect use of treated wastewaters for recreational purposes and this appears to be a valid practice where health requirements can be met. However, much remains to be known about the health relationships of water quality and recreational use. For example, water high in nutrients may serve as a culture for pathogenic bacteria. Further research and epidemiological investigations into water quality and health relationships are urgently needed.

Irrigation

The reuse of waters for irrigation is and should be a satisfactory mode of reuse. Water quality requirements for crop protection relate primarily to salinity and toxic compounds. For irrigation of non-food or shelled-food crops, health considerations would be minimal but for irrigation of other food crops or of pasturage for food-animals, the hazards are significant unless the water is adequately treated. Much study and development of safeguards should precede this latter use.

Municipal

The concurrent use of the Nation's rivers and lakes for both water supply and waste disposal has been practiced for many years in many areas of the country. It is estimated that 50% of the Nation's population now derives their water supply from surface sources which have also received a variety of industrial wastes, untreated sewage, urban runoff and effluent from a variety of sewage treatment plants. Public health officials have relied upon time of travel or storage and treatment to protect the public against infectious diseases and toxic substances. Water quality standards and treatment requirements applicable to surface sources used for water supply have permitted the discharge of relatively high quantities of wastes. The continuing development of new advanced wastewater treatment technologies and implementation of new standards will necessitate a reappraisal of historical philosophies.

Indirect reuse for municipal public water supply is a fact of life; however, direct reuse is a new matter requiring careful research and investigation before introduction. Currently, there is insufficient data to support safety of direct interconnection of wastewater reclamation plants into municipal water supplies. However, the direct connection of municipal renovated water to supply industrial water needs is desirable and should be exploited where practical.

Health problems, in a direct interconnection or in a recycling situation, relate to viruses, bacterial build-up, chemical build-up, the possibility of accidental spills or sabotage and a record of questionable reliability in the operation of wastewater treatment plants. Viruses are difficult to identify and measure and are more resistant to disinfection than bacteria. Carbon columns and other possible advanced waste treatment elements may harbor bacteria or their metabolites and contribute to the development of unhealthful levels of bacteria in a recycling situation.

The direct introduction of chemicals from a wastestream and their build-up through potable system-waste system recycling can present increased long-term chronic hazards, presently undefined. Accidental spills or sabotage present an acute threat which cannot be disregarded, as any-one can throw anything down the drain. Because of these, even if other objectionable problems were solved, some system of holding and dilution reservoirs may inevitably need to be provided between the reclamation plant and the potable water intake together with biological and chemical monitoring. With regard to the reliability of reclamation plant operation, studies[2] in California have shown that 60% of wastewater treatment plants studied had some breakdown during the year. Observations of engineers and others confirm that reliability is a common problem in wastewater treatment plants; safeguards must be provided to prevent the introduction of non-treated or poorly treated wastes into a potable water system.

CONCLUSIONS

1) The purposeful reuse of treated wastewaters has a large potential in helping to meet water supply needs. Expansion of reuse as a tool of water quality and water resources management should be encouraged as long as measures are taken to protect the public health.

2) We do not have the knowledge to support the direct interconnection of wastewater reclamation plants into municipal water supplies at this time. The potable use of renovated wastewaters blended with other acceptable supplies in reservoirs may be employed once research and demonstration has shown that all of the following conditions would be met:

   a) is protected from hazards to health

   b) offers higher quality than available conventional sources

   c) results in less adverse ecological impact than conventional alternatives

   d) is tested and supplied using completely dependable chemical and biological control technology

e) is more economical than conventional sources

f) is approved by cognizant public health authorities

3) An accelerated research and demonstration program is vitally needed to:

a) develop basic information and remedial measures with respect to viruses, bacteria, chemical buildups, toxicological aspects and other health problems; develop criteria and standards to assure health protection in connection with reuse; and

b) upgrade the treatment process design and operation so as to assure continuously safe service to the public; provide economic and other analyses to facilitate the planning and design of effective regional solutions to problems of water-shortage and water quality.

REFERENCES

[1]Report of the National Technical Advisory Committee to the Secretary of the Interior, Water Quality Criteria, April, 1968.

[2]Ongerth, H.J., Jopling, W.F., and Deaner, D.G., "Fitness Needs for Wastewater Reclamation Plants", Journal of the American Water Works Association, Oct., 1971.

APPENDIX A

DEFINITIONS AND DISCUSSION OF DIFFERENCES FOR DIRECT AND INDIRECT REUSE

Definitions are derived from a report of the National Water Commission, "Wastewater Reuse," by Jerome Gavis, July 1971, as follows:

1) Direct Reuse: is the direct routing of treated wastewater effluents to the point of use.

2) Indirect Reuse: is the discharge of treated wastewater where it is subjected to natural purification processes and dilution before being withdrawn for use.

Differences in the two types of reuse that must be considered in any drinking water application are as follows:

1) Direct reuse is more vulnerable to sabotage, operational failure and the accidental spill of toxic or hazardous substances into the water-wastewater system. The provision of fail-safe equipment, processes and holding reservoirs may be necessary to meet this problem.

2) Direct reuse allows no margin for error in the destruction of pathogenic viruses, bacteria and other microorganisms.

3) Direct reuse could result in the buildup of trace substances to many times their usual concentration; depending on the degree of reuse and the efficiency of treatment, the concentration factor could run up to nine times.

Many of the factors influencing direct reuse may come into play for indirect reuse. If the time and dilution factors before indirect reuse are small, the impacts of dilution and natural purification may be minimal. Yet the question of what time and dilution factors are adequate cannot be answered on the basis of today's knowledge. Research to acquire new basic knowledge and common sense in the application of today's limited knowledge is essential. Also, it is essential that each reuse situation be treated on an individual basis, taking into account all factors.

APPENDIX B

EPA POLICY STATEMENT ON WATER REUSE

The demand for water is increasing both through population growth and changing life styles, while the supply of water from nature remains basically constant from year to year. This is not to imply that we are or will shortly be out of water, although water shortages are of great concern in some regions and indirect reuse has been common for generations. We must recognize the need to use and reuse wastewater. Therefore,

1) EPA supports and encourages the continued development and practice of successive wastewater reclamation, reuse, recycling and recharge as a major element in water resource management, providing the reclamation systems are designed and operated so as to avoid health hazards to the people or damage to the environment.

2) In particular, EPA recognizes and supports the potential for wastewater reuse in agriculture, industrial, municipal, recreational and groundwater recharge applications.

3) EPA does not currently support the direct interconnection of wastewater reclamation plants with municipal water treatment plants. The potable use of renovated wastewaters blended with other acceptable supplies in reservoirs may be employed once research and demonstration has shown that it can be done without hazard to health. EPA believes that other factors must also receive consideration, such as the ecological impact of various alternatives, quality of available sources, and economics.

4) EPA will continue to support reuse research and

demonstration projects including procedures for the rapid identification and removal of viruses and organics, epidemiological and toxicological analyses of effects, advanced waste and drinking water treatment process design and operation, development of water quality requirements for various reuse opportunities, and cost-effectiveness studies.

CHAPTER IV

STATUS OF WASTEWATER REUSE IN SOUTH AFRICA

L. R. J. Van Vuuren

Like most other countries, South Africa is confronted with problems of water pollution and diminishing water supplies. Direct reuse of wastewaters for irrigation and cooling and indirect reuse for domestic purposes have been practiced for several decades. More recently, the need for direct reuse has come to the foreground and research has been focused on wastewater treatment technology for implementation in various parts of the country.

The reuse of effluent for agricultural, industrial, recreational or direct municipal purposes already forms an integral part of the country's overall water management practice.

WATER BALANCE

The country's average annual rainfall of 487 mm is theoretically equivalent to 1 630 Gℓ/d. Ninety-one per cent of the rainfall is lost by evaporation and transpiration and only 9 per cent reaches the rivers. The total run-off is comparatively small and in fact less than the run-off of any one of the major rivers of Africa, e.g. the Zambezi River.[1] The assured run-off which can be made available by providing storage is 57.3 Gℓ/d. Underground supplies are estimated to be 3.1 Gℓ/d, giving a total supply of 60.4 Gℓ/d.

Irrigation demands can be expected to reach a total of 34.8 Gℓ/d by the end of the century. At an estimated 7 per cent per annum rate of increase the demand for urban and industrial use will be 45.5 Gℓ/d by the year 2000, giving a total demand of 80.3 Gℓ/d as against the assured supply of 60.4 Gℓ/d. This implies a deficit of 20 Gℓ/d, i.e. some 25 per cent of the potential demand. The assured supply can, however, be increased to 75 Gℓ/d by increasing the net yield of impoundment reservoirs. In this case, the deficit would be reduced to 6.6 per cent.

These figures indicate that South Africa is heading for a substantial water shortage.[2] On a regional basis the problem may become more accentuated, and, in certain industrialized areas of the country, further progress is already prejudiced by water shortages.

The solution to the problem must be sought in better utilization of the available water in which reuse must play a vital part. The challenges posed by this situation have forced the acceptance of the inevitable fact that water supply, wastewater reuse and the control of pollution are inseparable components in a broad water conservation plan for every metropolitan area as well as for the country as a whole.

AVAILABILITY OF WASTEWATER FOR REUSE

In South Africa wastewaters are currently being used to a limited extent for a diversity of applications. Table 1 shows the average daily volumes of sewage effluent available and its usage in the twenty major cities and towns, as well as in some other minor towns and industries.

These sources, representing a population of 5.8 million people, produce an average 1 230 Mℓ of treated sewage effluent per day or 210 ℓ per capita per day. At present 31.9 per cent of this effluent is reused: 8.7 per cent for power station cooling; 16.1 per cent for irrigation of crops, parks and sports fields; and 7.1 per cent for industrial purposes. This last figure includes the utilization of an average 3 Mℓ/d for domestic consumption at Windhoek.[3]

In the case of the Vaal River Triangle, often called the industrial power house of South Africa, the reuse pattern changes drastically, mainly because the water resources for this area are limited. Of the 640 Mℓ sewage effluent available

TABLE 1

Daily Volumes of Sewage Effluents Available from Some Major South African Towns and Industries and Their Usage

Town	Population (1971)	Total volume effluent Mℓ/d	Power stations cooling Mℓ/d	Irrigation Mℓ/d	Industrial Mℓ/d
Johannesburg*	1 181 321]	317.8	54.5	113.5	-
Roodepoort*	132 970]				
Durban	716 585	229.3	-	-	10.2
Cape Town	651 090	143.0	9.1	0.5	-
Pretoria*	518 314	86.0	37.6	16.5	-
Port Elizabeth	390 982	88.0		6.8	-
Germiston*	253 500	52.6	-	8.0	-
East London	205 789	3.3	-	-	-
Bloemfontein	160 000	25.0	6.5	0.3	-
Benoni*	142 630	20.4	-	2.0	2.0
Springs*	141 690	29.5	-	-	29.5
Welkom	135 700	40.4	-	-	13.2
Pietermaritzburg	123 031	27.3	-	6.8	-
Kimberley	115 200	8.0	-	1.6	1.1
Carletonville*	103 500	4.5		4.5	-
Boksburg*	95 950	27.3	-	-	-
Vereeniging*	93 090	10.2	-	-	-
Krugersdorp*	91 100	17.0	-	13.6	-
Brakpan*	85 702	7.0	-	-	-
Windhoek	79 000	6.2		-	3.0+
Kempton Park*	71 160	25.5	-	-	-
Klerksdorp*	65 050	5.8	-	5.8	-
Randfontein*	50 398	4.5	-	1.4	-
Bellville	46 700	9.1	-	-	1.1
Grahamstown	41 375	2.3	-	2.3	-
Worcester	40 590	5.9	-	5.9	-
Westonarea*	40 027	6.8	-	6.8	-
Parys*	17 357	1.4	-	-	-
Sasol*	30 230	23.0	-	-	23.0
Slurry	1 000	2.1	-	-	2.1
Ulco	2 550	0.1			0.1
King William's Town	16 600	2.3	-	2.3	
Modderfontein	6 400	1.9			1.9
T o t a l	5 845 581	1 233.5	107.7	198.6	87.2
Percentage			8.7	16.1	7.1
Vaal River Triangle -T o t a l	3 113 989	641.2	92.1	172.1	56.4
Percentage			14.4	26.8	8.8

* Situated in the Vaal River Triangle

\+ Average volume reclaimed for domestic use daily, 50 per cent are being reused: 14.4 per cent for power station cooling; 26.8 per cent for irrigation; and 8.8 per cent for industrial purposes.

AGRICULTURAL REUSE

The use of treated sewage effluents for irrigation has been practiced in South Africa for many years without any apparent deleterious effect on crops and soil. Before embarking on irrigation schemes using sewage effluent, several factors relating to quality requirements for plants, soil structure and drainage, pathogenic loading and underground pollution have to be considered. When considering sewage effluent for irrigation, good drainage is of paramount importance because the effluent must be irrigated throughout the year, even during periods of excessive rainfall.

Irrigation with sewage effluents is an important adjunct of unrestricted reuse, since it provides bleed-off which is essential for maintaining a total dissolved solids equilibrium in a partially closed system. Henzen[4] showed that an equilibrium level of 530 mg/ℓ total dissolved solids can be maintained if 80 per cent of the available sewage effluent in the Johannesburg metropolitan area is reclaimed and 20 per cent used consumptively for cooling and irrigation purposes.

The presence of pathogenic organisms in sewage effluents precludes their use for the irrigation of certain crops, especially those which may be consumed raw. The major portion of sewage effluent reused for irrigation purposes is being applied for pasturage irrigation. Of these schemes the most important is that of the City Council of Johannesburg where a total volume of 113.5 Mℓ/d sewage effluent is being applied at a rate of 230 cm/a.[5] This is a rather high application rate with the result that between 40 and 50 per cent of the effluent applied finds its way back to the river either as seepage or as run-off, particularly during wet weather.

At this application rate, the potential fertilizing value of the effluent (34 mg/ℓ as N and 23 mg/ℓ as PO_4) is equivalent to applications of 730 kg nitrogen (asN) and 540 kg phosphorus (as PO_4)/a/ha.

The irrigated land is divided into uses for winter and summer grazing and summer crop production. The total summer crop production for 1970 was 9,000 ton hay and 7,000 ton silage and the overall carrying capacity of the farms averages at 4.2 animals/ha.

INDUSTRIAL REUSE

The population and industrial activity of the country is highly centralized. About 20 per cent of the total water consumption is used by cities, towns, industry, mining and power generation.[6] It should be noted that industry and mining alone produce 40 per cent of the country's gross national product of which 81 per cent is contributed by the four main metropolitan centers.[7] The most important of these centers is the Pretoria/Johannesburg/Vereeniging complex (Vaal River Triangle), which is responsible for about 45 per cent of the country's industrial production. However, natural water resources in this area are limited, with the result that inter-basin transfers and effluent reuse will be inevitable to ensure sufficient water by the end of the century. At present some 23 per cent of the purified effluent available in the Vaal River Triangle is reused directly in industry and power generation.

Another important center of economic activity is the Western Cape where 11 per cent of the purified sewage effluent available is presently being reused, mainly for power generation. With the exploitation of all the available sources in this area including purified sewage effluent, there would be sufficient water in the foreseeable future.

The other important metropolitan centers, such as Durban and Port Elizabeth, have a reasonably assured supply of raw water for the future, although economics might swing the balance in favor of reuse of wastewater.

Reuse For Cooling Purposes

There are two basic methods by which industry can reduce their potable water intake; namely, internal reuse of process water and wastewater reuse.

About 67 per cent of the total demand for industrial water, the mining industry excluded, is required for cooling purposes, while four per cent is used for steam generation.[8] The extent to which purified sewage effluent is currently being used as cooling water for power generation plants is reflected in statistics as shown in Table 2.

For power station cooling, the major problem is control of the pH, alkalinity and nitrogen-phosphorus relationships. A further problem is biological fouling as a result of excessive growth of bacteria, fungi and algae. Excessive biological growth is controlled by chlorination or addition of slimicides to the water circuit. Where chlorination is used, a shock dosage of the order of 5 to 7 mg/ℓ or even less.[9]

TABLE 2

Reuse for Cooling in Power Stations

Power stations	(Power Station) capacity MW	Consumption of reclaimed sewage effluent Mℓ/d
Cape Town (Athlone)	150	9.1
Bloemfontein	50	6.5
Johannesburg (Orlando)	300	22.7
Johannesburg (Kelvin)	360	31.8
Pretoria West	250	19.8
Pretoria, Rooiwal	120	17.8

Pulp and Paper Industry

South African Pulp and Paper Industries (SAPPI), near the city of Springs, was the first large manufacturing industry in this country to utilize purified sewage effluent as the major part of its water supply. The present water usage is made up of 16 Mℓ/d from the Rand Water Board and a further 27Mℓ/d of purified sewage from the Springs Municipality.

Initially, the purified sewage used for process water received only limited tertiary treatment consisting of sand filtration and low level chlorination.

The demand for paper of a higher brightness called for further refinement of the purified effluent, which contains heavy metals, particularly iron manganese and copper, and organics, which are known to affect paper brightness. Research was conducted using various adsorbents, oxidants and flocculants such as lime and aluminium sulphate, to improve the water quality. These studies culminated in the design and construction of a full-scale advanced treatment plant which was commissioned in July, 1970.

The full-scale plant comprises a flotation tank of 750 kℓ capacity; feederline (0.6 m) with booster pump; aeration vessel with high speed disperser and air compressor operating at 10 psig; storage tanks and dosing equipment for aluminium sulphate, sodium hydroxide and chlorine; and auxiliary equipment such as pH and flow recorder controllers (Fig. 1).

Aluminium sulphate is dosed at 75 mg/ℓ into the feedline at a point succeeding the aeration stage. Approximately 1.4 mg/ℓ of polyelectrolyte is added for improved flocculation and flotation and sodium hydroxide (10 mg/ℓ) is dosed in the effluent launder to adjust pH value. Approximately 3 mg/ℓ of chlorine is added as a measure against algal growth, prior to filtration. Operational results are shown in Table 3.

The reclaimed water is of such a quality that it can be used in all sections of the mill without deleterious effect on the quality of the product paper. Very low turbidities (0 to 1 mg/ℓ) suspended solids are carried over from the flotation unit which has a hydraulic retention of less than 30 minutes.

position figure

Figure 1.

SAPPI SEWAGE WATER PURIFICATION SIMPLIFIED FLOW SCHEME

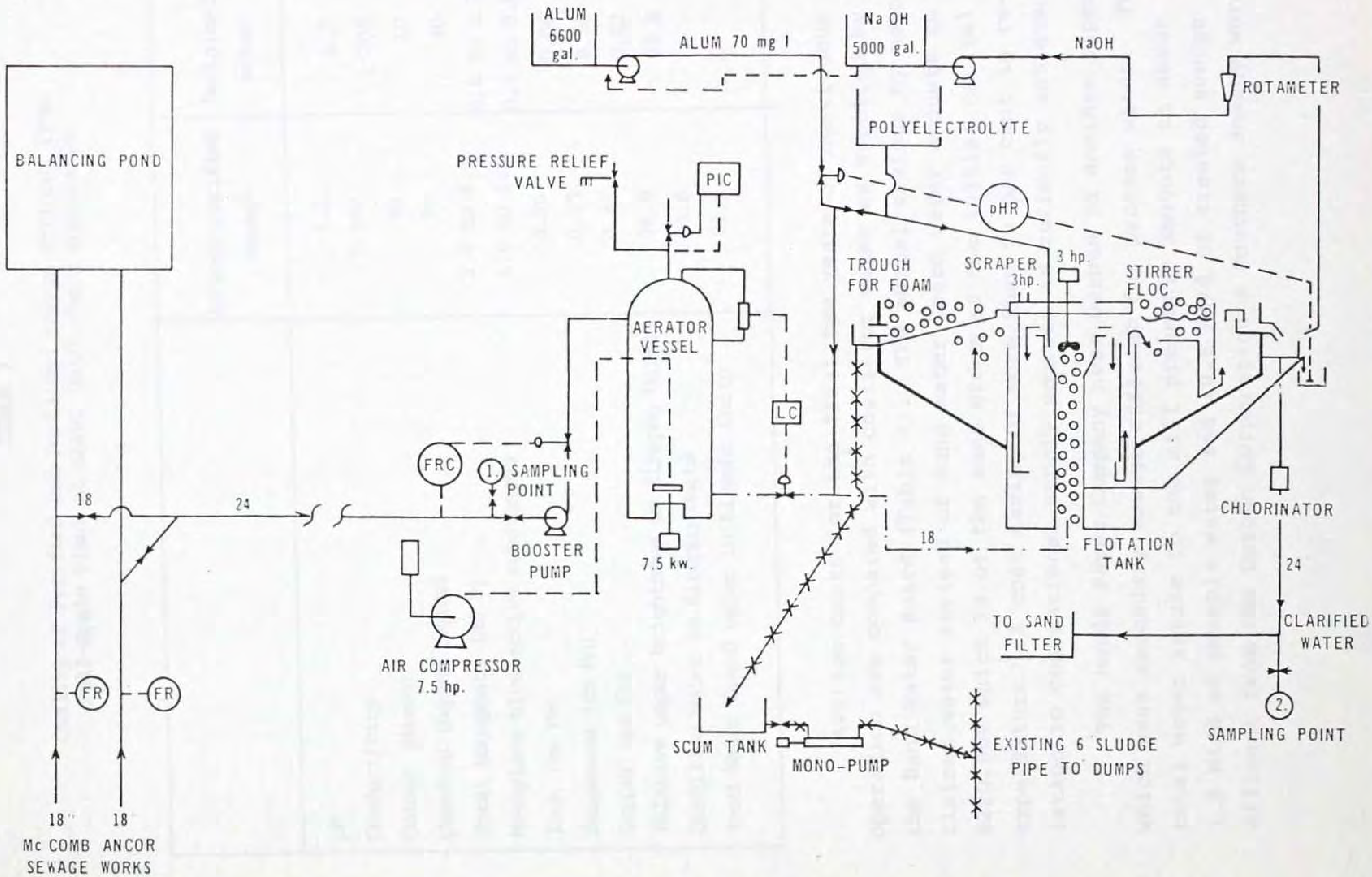


TABLE 3

Quality of Purified and Reclaimed Sewage Effluent from Full-Scale Plant at SAPPI (mg/ℓ where applicable)

	Springs purified sewage	Reclaimed water
pH	7.2	6.7
Conductivity	1 100	1 200
Colour (Hazen)	40	10
Chemical oxygen demand	75	40
Total phosphate (as P)	2.6 to 6.7	0.6 to 1.2
Methylene blue active substances	1.0 to 1.5	0.7 to 0.9
Iron (as Fe)	0.26	0.06
Manganese (as Mn)	0.55	0.50
Copper (as Cu)	0.45	0.02
Relative paper brightness in Elrepho Units	76.9	84.4
Distilled water in Elrepho Units	85.6	
Rand Water Board water in Elrepho Units	82.4	

Average costs for the first two years of continuous operation are compared with costs for water as supplied by the Rand Water Board (Table 4). The annual savings by using reclaimed water instead of Rand Water Board water amounts to $220,000 which is of the same order as the initial capital expenditure. A cost saving of more than 50 per cent in relation to conventional supply sources is currently achieved.

The Mondi Paper Company near Durban is another paper mill which uses secondary sewage effluent for process water. The total water intake to the mill presently amounts to about 1.6 Mℓ/d of potable water and 10.6 Mℓ/d of treated sewage effluent from the Durban Corporation's southern sewage works.

TABLE 4

Treatment costs at SAPPI's water reclamation plant (1971)

	S.A. cents/kℓ
Rand Water Board water	3.52
Springs purified sewage	0.22
Operating costs (chemicals, maintenance and supervision)	1.21
<u>Capital expenditure</u>	
R159,000 at R14,000 per annum,	
25 Mℓ/d for 325 days per annum	0.17
Total cost, reclaimed water	1.60

The factory's advance treatment plant has a capacity of 11.5 Mℓ/d, and incorporates chemical flocculation, foam fractionation, sand filtration and activated carbon treatment for which the carbon is regenerated on site.

Preliminary costs estimates (1974) indicated a total cost figure of about 9 c/kℓ for the reclaimed water produced.[10]

The Chemical Industry

One of South Africa's largest industrial consumers and also the largest dynamite factory in the world, African Explosives and Chemical Industries[11], attacked their problem of water use, reuse and effluent control in an admirable manner. Their Modderfontein factory near Johannesburg had a potable water consumption in 1968 of between 450 and 500 Mℓ/month. Intensive recycling and reuse of process waters reduced the factory's total fresh water requirements to 430 Mℓ/month in 1973. Additional utilization of various classes of wastewaters, particularly for cooling purposes, reduced this volume still further. During the period 1962 to 1968, the flow of strong effluent from the factory was reduced by more than 80 per cent.

The stronger effluent, containing an appreciable amount of ammonium sulphate and ammonium nitrate, is used as a diluted liquid fertilizer for growing grass on an extensive area of land owned by the Company. In this way, waste nitrogen salts are removed from the water environment.

Other Industries

The slurry process for the manufacture of Portland Cement can utilize treated sewage effluent effectively. The effluent quality need not be of a high standard since all the water and organic matter is volatilized in the rotary kilns. The Portland Cement factories at Slurry and Ulco together use 2.2 Mℓ/d of treated dewage effluent in their slurry processes.

Other industrial application of treated sewage effluents include:

1) 1.1 Mℓ/d for washing purposes at the De Beers Diamond Mines, Kimberley.
2) 1.1 Mℓ/d by South African Board Mills at Bellville.
3) 23 Mℓ/d by Sasol (the oil-from-coal industry) for the conveyance of ash from the power station followed by maturation pond treatment and subsequent discharge into the Vaal River.
4) 13.2 Mℓ/d by gold-mines in the Welkom area particularly for slurry conveyance.
5) 2 Mℓ/d for cooling of plate metal and rollers in a steel mill at Benoni.

In general, it can be said that the major industries in the Republic are already water conscious, and that these industries are endeavoring to modernize their factories and to keep abreast of new developments in order to cut down effluent pollution and fresh water requirements.

Unfortunately water consciousness is largely lacking among industries which discharge their effluents into municipal sewers. This is no doubt inevitable as long as water remains relatively cheap (7.4 to 11.5 c/kℓ to industry). Regulations for the discharge of effluents into municipal sewers are currently still based on limiting the concentration of pollutants, which does not encourage water conservation. The use of reclaimed effluents by industry therefore probably constitutes the most effective means for the conservation of water.

DIRECT AND INDIRECT REUSE OF WASTEWATER

With regard to the domestic use of reclaimed water, an objective appraisal of the question of direct and indirect reuse of wastewaters is very necessary. This is a vexing and controversial issue which in some countries has precipitated a stalemate in pollution control, in wastewater reuse, and in the upgrading of conventional water purification facilities.

It is necessary to state emphatically that the intake water for potable reclamation should consist of predominantly domestic wastewater which has undergone effective oxidative biological stabilization by any of the recognized systems.

The reservations which have been expressed regarding wastewater reclamation for domestic reuse, namely the risk of infections, chronic toxicity, carcinogenic effects, sex hormone effects, and radiological effects, may apply with equal force to many conventional water purification plants treating natural waters which may be polluted. A critical evaluation of existing conventional water treatment plants is therefore necessary.

Direct Reuse

The first plant for the reclamation of sewage for the direct potable reuse was commissioned in Windhoek, South West Africa, in October 1968, and up to the end of 1970, had produced 1.8 Gℓ of reclaimed water.[12] The public's favorable acceptance of the reclaimed water is ascribed to the progressive disclosure of information via the press and invitations to visit the plant.

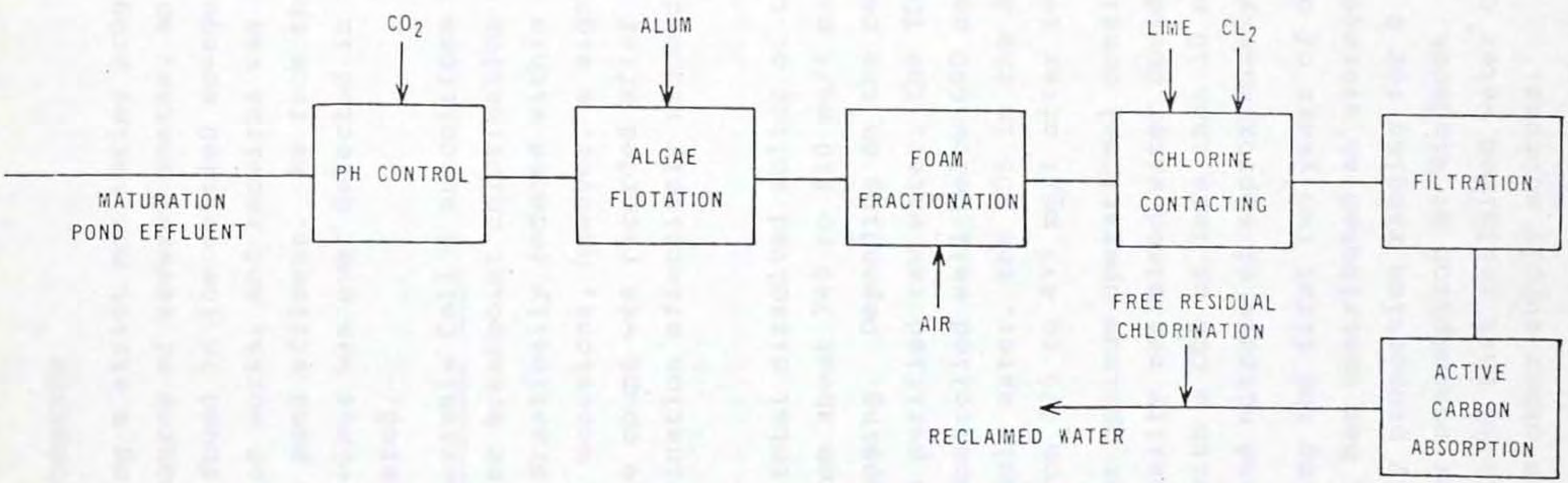
The raw water is derived from a biological sewage treatment plant followed by further biological purification in nine maturation ponds. The reclamation plant has nominal capacity of 4.5 Mℓ/d and it essentially comprises additional facilities for algae flotation, foam fractionation, breakpoint chlorination and adsorption of organics onto activated carbon (Fig. 2).

A surface water supply undergoes purification in a conventional plant situated side by side with the reclamation plant.[13] The reclaimed water, after carbon adsorption, is blended with purified surface water and the admixed streams are then post-chlorinated to a free residual of 0.2 mg/ℓ chlorine.

Position figure

Figure 2

SCHEMATIC FLOW DIAGRAM OF WINDHOEK WATER RECLAMATION PLANT



PLANT PERFORMANCE

During a strict monitoring program which was followed over the course of several months, an average of 20 $TCID_{50}/m\ell$ virus was found in the settled sewage entering the sewage purification works, and reovirus was also isolated from the maturation pond effluent. As from the foam fractionation stage, no virus was ever detected in any of the hundreds of samples tested.

Escherichia Coli I or coliform bacteria were never recorded after breakpoint chlorination whereas the total plate count was drastically reduced within acceptable low levels. On several occasions, however, a significant increase in the total plate count was recorded after carbon adsorption, but post-chlorination effectively reduced these counts to below 100/mℓ.

The total dissolved solids of the reclaimed water increased from about 740 to 810 mg/ℓ mainly as a result of chemical dosing. Depending on the ratio of admixture of reclaimed water with purified raw water, the TDS of the blended water could be controlled well below 600 mg/ℓ. After further diultion with borehole water, the TDS in the distribution system increased from 375 to 475 mg/ℓ after integration.

After optimum operational conditions were established, a final quality reclaimed water could be produced prior to blending with a COD of less than 10 mg/ℓ, ABS of less than 0.2 mg/ℓ and nitrate of approximately 3 mg/ℓ.

During the first two years of operation, the reclamation plant has contributed an average of 13.4 per cent, with the monthly proportion ranging for 0 to 27.7 per cent of the total water consumption at Windhoek. Cost estimates during 1970 confirmed that reclaimed water could be produced competitively with other supply sources.

Towards the beginning of 1971, the Swakop River water supply scheme was completed and following good rains in this area, the water situation was less critical. The water reclamation plant, therefore, was operated for short periods only and later, due to a progressive further deterioration in the raw water intake quality, stopped while extensions to the sewage works were made.

Modifications to the reclamation plant comprising high lime treatment and ammonia stripping are currently (1975) being implemented with the view to achieve a higher ultimate utilization factor. Recommissioning of the plant is anticipated for September, 1975.

Although the critical water supply situation at Windhoek did not allow for a long and detailed epidemiological study before the introduction of reclaimed water, data were available from hospital and laboratory records on typhoid, other salmonella, shigella and infectious hepatitis cases as far back as 1964. This valuable record served as a good basis against which the epidemiological studies, which were carried out during the operation of the reclamation plant, could be judged.

The success of the Windhoek reclamation scheme activated a concerted research effort by the National Institute for Water Research at the experimental wastewater reclamation plant, Pretoria, on reduction of purification costs, improvement of unit processes, and the development of a multiple safety barrier reclamation system. By modifying the present Windhoek reclamation plant in accordance with the findings of this work, the full exploitation of millions of kiloliters of purified sewage effluent (now running to waste daily) as a permanent component of Windhoek's water economy in both the short and long term, has become a practical reality. Realizing these implications for Windhoek's future development when the Swakop River water supply is exploited to its full capacity within the next five years, the Municipality of Windhoek has agreed to continue with water reclamation as a research and development project with financial support from the Water Research Commission.

Indirect Reuse

In South Africa several examples can be quoted where indirect reuse of domestic effluents is practiced. In the Johannesburg/Pretoria area a substantial flow (321 Mℓ/d) of purified sewage, which is not utilized for industrial or agricultural reuse, finds its way in natural streams and water courses and thus indirectly into domestic water supplies. The increasing signs of eutrophication and deterioration in chemical and biochemical quality in these catchments are a matter of grave concern and in some instances the conventional water purification plants have reached the stage where advanced techniques such as activated carbon treatment have become a dire need. The major problems encountered are the presence of algae and aquatic plants, and the occurrence of dissolved organics, nitrogen and phosphorus. The following case histories demonstrate typical examples of the extent to which treated sewage effluents are used indirectly.

HARTBEESPOORT DAM

This impoundment reservoir essentially serves as an irrigation supply source for an area of about 13,400 ha. It also serves as a recreational area for aquatic sport such as angling, boating and skiing. The township of Brits, population 20,000, and several smaller communities obtain water for their domestic and industrial needs from this impoundment.

The average flow of the Crocodile River feeding this dam is 402 Mℓ/d. The Johannesburg Metropolis within the catchment of the Crocodile is expanding rapidly and approximately 47 Mℓ/d of purified sewage is disposed of into this catchment. An average 10 per cent of treated sewage enters the Hartbeespoort Dam, and during the dry season can be as high as 50 per cent. The nutrient load is reduced by storage in the dam, but approximately 1.7 mg P/ℓ, and 1.4 mg N/ℓ still occur on average in the water extracted for irrigation and domestic purposes. These nutrients obviously do not pose a problem as regards the quality for irrigation purposes. However, as a source for domestic water supply these nutrients cause operational problems and on several occasions public complaints of taste and odor in the domestic water supply have been received.

The existing water treatment works at Brits, completed in 1958 with a capacity of 3.5 Mℓ/d, has become inadequate to meet growing demands in this rapidly developing area. The works is based on a conventional design comprising clarification, filtration and disinfection. A new treatment works has recently been constructed where breakpoint chlorination and activated carbon units will be included in order to adequately treat the increasingly polluted intake water.

RIETVLEI DAM

This impoundment receives approximately 25 Mℓ/d of purified sewage from the township of Kempton Park together with an average 25 Mℓ/d run-off. Treated sewage effluent therefore constitutes an appreciable proportion of the inflow into a dam which contributes to the potable supply for the city of Pretoria. The proportion of treated sewage in this dam is therefore higher than that of the Hartbeespoort Dam but indications are that the self-purification capacity of this river is superior to that of the Crocodile River. Nevertheless, over the past years the problem of increased eutrophication also has a significant effect on the control and operation of the water treatment plant, which has a capacity of 25 Mℓ/d.

Investigations are currently under way to improve separation of algae by the addition of ferric salts and polyelectrolytes. Studies on phosphorus removal from the purified sewage at source using chemical addition are also to be carried out. Future expansions to the sewage works will be based on current technological developments in the field of biological denitrification and phosphorus removal.

BON ACCORD DAM

This dam receives a relatively small stream of natural run-off which is heavily polluted along its course with purified sewage, agricultural seepage water and industrial effluent. During the dry season, the upper reaches are essentially fed by purified sewage from the Daspoort sewage works (19 Mℓ/d) and effluent from a power station and steel foundry (about 10 Mℓ/d). This water enters the Bon Accord Dam at a rate of about 45 Mℓd. The average retention in the dam is 4 to 5 months, allowing for some degree of self-purification; however, this dam also shows marked signs of eutrophication.

During the dry season a minimum of 3.5 Mℓ/d of compensation water is released and during the wet season the dam spills over. About 10 km downstream from the dam, 15 to 25 Mℓ/d purified sewage from the Rooiwal sewage works, is allowed into the river. This river is the source for a purification works supplying a township of 18,000 inhabitants, at a point 20 km further downstream.

In planning this water purification works during 1964, account was taken of the inferior quality of the raw water, particularly as regards organic constituents. Surveys indicated the presence of 1 to 3 mg MBAS/ℓ and COD of about 30 to 40 mg/ℓ. The presence of 5mg P/ℓ and 6mg $NO_3(N)$/ℓ confirmed the presence of a substantial proportion of purified sewage.

The water purification works has a capacity of 4.5 Mℓ/d and consists of facilities for lime and alum flocculation, sedimentation, breakpoint chlorination, rapid gravity filtration and active carbon adsorption treatment.

The purified water is of acceptable potable quality but chemical treatment costs are relatively high due to activated carbon treatment. Phosphorus is reduced below the 1 mg/ℓ level and COD below 15 mg/ℓ. Presumptive E. coli I has never been detected in the product water.

VAAL BARRAGE

The above case histories of indirect reuse of domestic effluents are typical of several other catchments in South Africa. In terms of quantity these examples represent relatively small volumes of indirect reuse as compared with the Vaal Barrage which receives the major part of the sewage effluent from the Johannesburg metropolis and Vaal Triangle. Because of the high dilution factor in the latter, the eutrophication effect is, however, less pronounced, although it is beginning to cause concern. The quality of the water in the Vaal Barrage reservoir has, however, deteriorated significantly over the past decade. Trends in future development have drawn attention to the need for more sophisticated sewage treatment plants and higher quality standards for domestic effluents in order to reduce pollution loads in this highly industrialized area. The implementation of activated sludge systems based on the principle of nitrification and denitrification and biological and chemical precipitation of phosphorus are envisaged for future and existing treatment plants.

RECREATIONAL REUSE

Direct reuse of sewage effluent for recreational purposes is not practiced in South Africa. The presence of sewage effluents in impoundment reservoirs and rivers as described above, could perhaps be regarded as a mode of indirect recreational reuse. The reason for this approach in South Africa should be seen in the light of the pressing demand for more water for unrestricted reuse rather than for a limited application such as recreation. Research in South Africa is therefore primarily focused on direct wastewater reclamation for industrial and domestic purposes and, as a secondary objective, the prevention of pollution of the water environment.

FUTURE PLANNING

The water resources of the Republic have hitherto been utilized primarily for irrigation. Up to 83.5 per cent of the total supply is currently consumed by agriculture. According to present evidence there is no urgent need for additional large-scale allocation of water for this use and the emphasis is on increased yields of the land already under cultivation. It is therefore anticipated that by the year 2000 the proportion of water used for irrigation will be reduced to about 45 per cent.

The position is different in regard to urban and industrial usage of water. About 50 per cent of the available effluents are already being reused in the Southern Transvaal compared with only about 11 per cent in the Western Cape. The potential of reclaimed water is thus relatively unexploited in the Western Cape. Statistics indicate that existing raw water supplies are already fully utilized and inter-basin transfer is possible only at high costs. Current research is, therefore, intensively directed towards future wastewater reclamation systems for the area.

<u>Cape Flats</u>

An interesting new approach that is being pursued is the utilization of the vast underground storage capacity of sand beds in the Cape Flats area as an evaporation-free underground reservoir.[14] This area ideally lends itself as a storage reservoir for reclaimed wastewater in view of its suitable geohydrological characteristics. Research has reached the stage where a 4.5 Mℓ/d reclamation and recovery plant has been designed which will serve as a research and demonstration plant from which full-scale design criteria could be derived. Unit processes to be constructed are essentially similar to those at Daspoort, Pretoria, with the addition of infiltration and extraction facilities (Fig 3).

RESEARCH AND DEVELOPMENT

Research on wastewater treatment technology is centered at Pretoria under the auspices of the National Institute for Water Research. Experimental facilities at the Daspoort sewage works comprise the Stander water reclamation plant (4.5 Mℓ/d) and several pilot plants (100 kℓ/d) which are operated in parallel using various types of wastewater and employing various process combinations. These include biological denitrification and phosphorus removal and integrated physical-chemical biological systems.

Stander Water Reclamation Plant

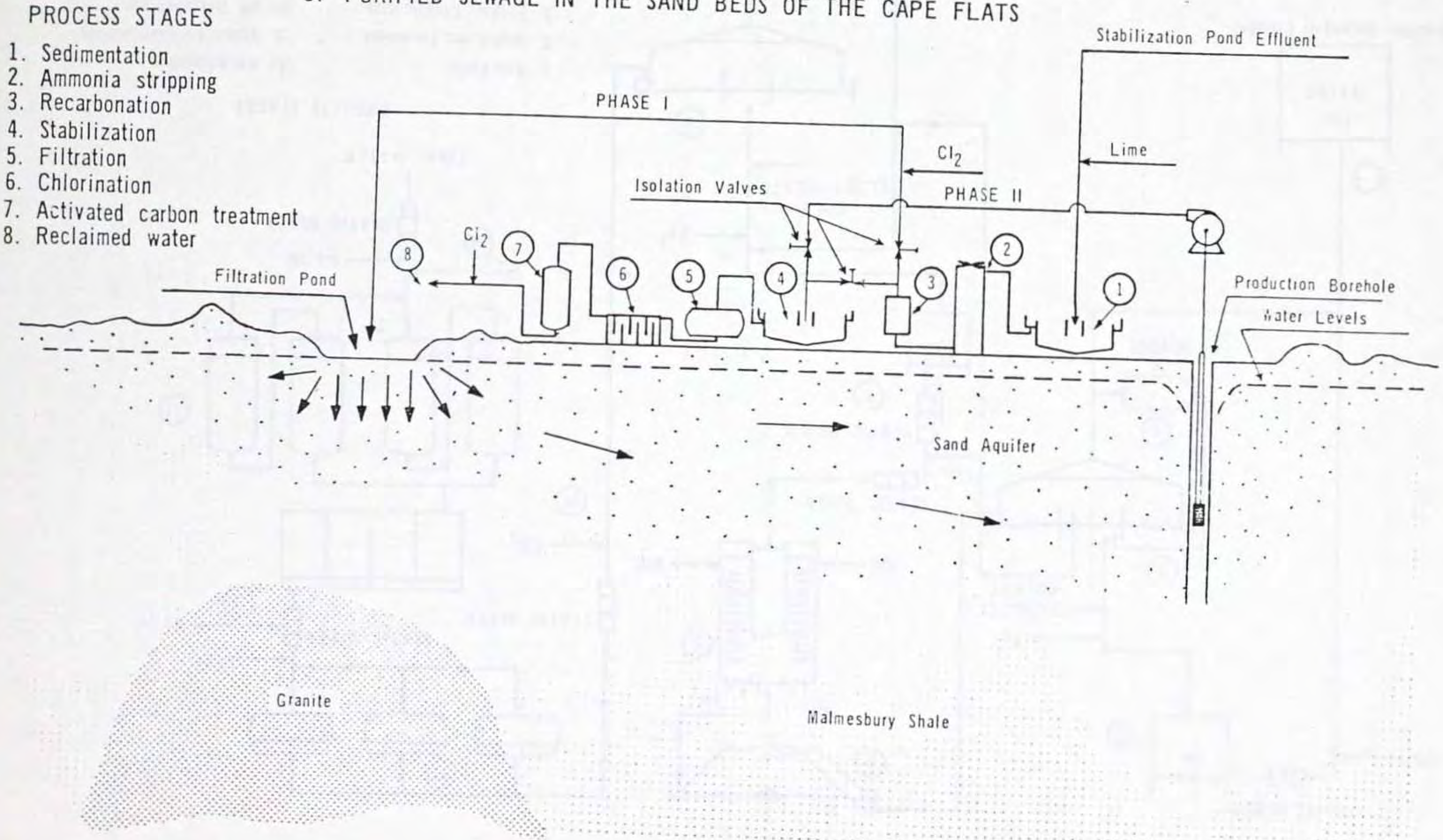
This plant was completed towards the end of 1970 and serves as a research/demonstration facility for the determination of design and operational criteria.[15]

Up to 1974 the plant was operated on an intermittent basis only as this prototype unit necessitated extensive refinements and process modification with a view to optimization of performance and control.[16] These included automatic chemical dosing control, standby equipment, balancing facilities, active carbon regeneration and sludge dewatering. Except for the regeneration furnace, which is still under construction, the major plant modifications have all been implemented and, since the beginning of 1975, operation has been continuous. The reclaimed secondary effluent is currently bled into an existing supply for cooling purposes (Fig.4).

The project is financially sponsored by the Water Research Commission which also supports several other projects including the Windhoek and Cape Flats water relcamation schemes. Satellite investigations involve bio-assaying, epidemiology,

Figure 3

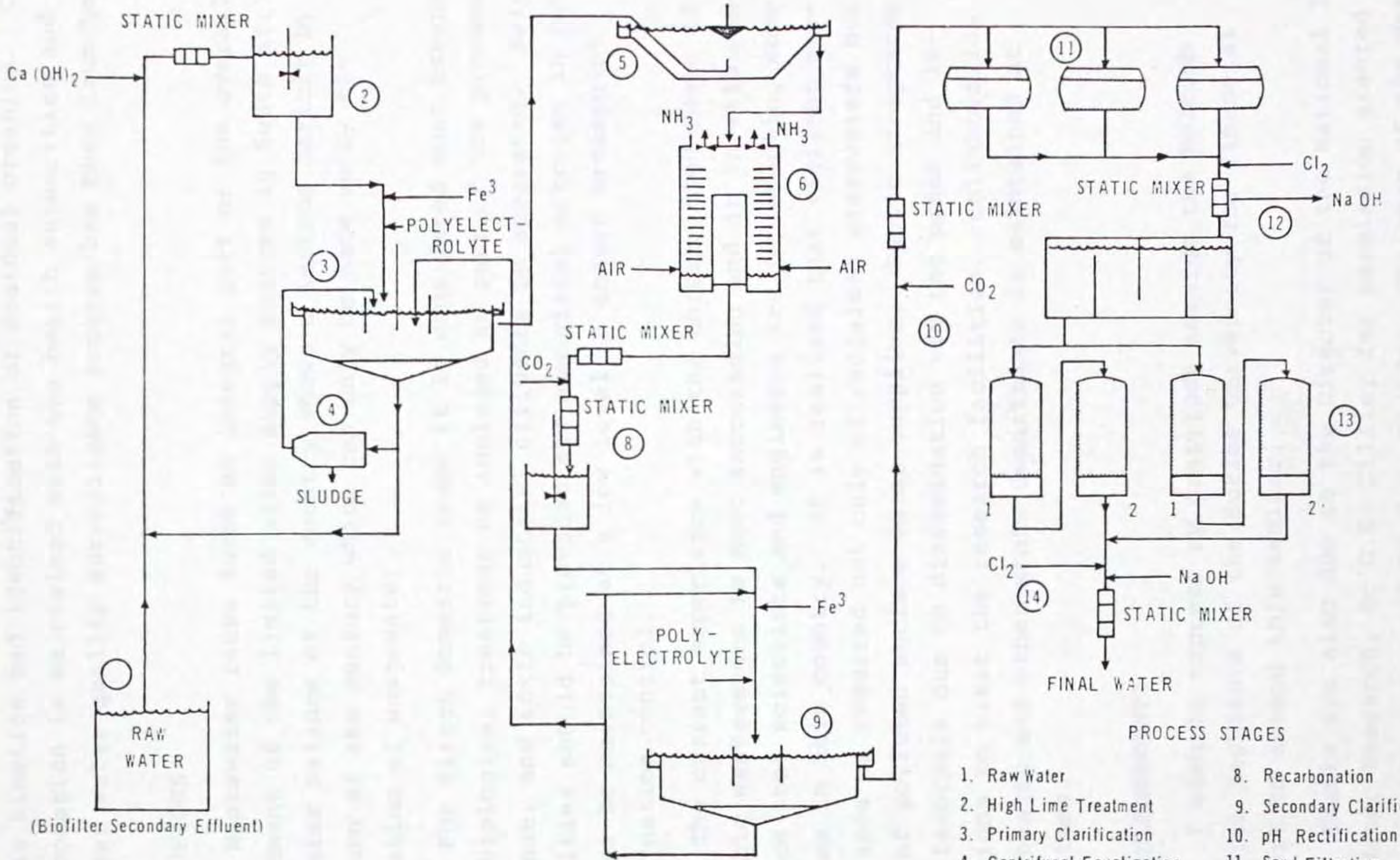
DIAGRAMMATIC REPRESENTATION OF RECLAMATION SCHEME FOR STORAGE OF PURIFIED SEWAGE IN THE SAND BEDS OF THE CAPE FLATS



Position figure

Figure 4.

FLOW DIAGRAM of the 4.5 Ml/d STANDER WATER RECLAMATION PLANT (June 1975)



PROCESS STAGES

1. Raw Water
2. High Lime Treatment
3. Primary Clarification
4. Centrifugal Equalization
5. Quality
6. Ammonia Stripping
8. Recarbonation
9. Secondary Clarification
10. pH Rectification
11. Sand Filtration
12. Breakpoint Chlorination
13. Activated Carbon Absorption
14. Final Chlorination and Stabilization

process kinetics and identification of residual organics. Close collaboration is maintained with the health authorities and a ten year water quality surveillance program has been launched.

CONCLUSIONS

Wastewater reuse forms an integral part of the overall management of the limited water supply sources in South Africa. The water balance of the country shows a serious deficit by the turn of the century which can only be made up by exploitation of wastewater.

For direct domestic reuse it is considered most essential that biological treatment be included as part of the process sequence, and toxic industrial effluents be separated. Balancing facilities should be provided and ammoniacal nitrogen in particular be maintained at a low level to ensure breakpoint chlorination control.

The current experience with the unrestricted reuse of domestic wastewaters is most encouraging and it is with confidence that scientists and engineers are implementing several schemes in this country. It is realized that vigilant surveillance is required not only of reclaimed wastewaters but also of polluted surface water supplies. Public acceptance has been favorable due to dissemination via the press and invitations to visit the research facilities. Collaboration with health and other state departments is maintained at all times.

ACKNOWLEDGEMENTS

I wish to express my gratitude towards the Holcomb Research Institute of the Butler University for financial support to attend this seminar.

Thanks are also due to the Director of the National Institute for Water Research, Dr G.G. Cillie, for permission granted to present this paper and DR G.J. Stander, Chairman of the Water Research Commission, who recommended my attendance.

REFERENCES

[1]Du Toit Viljoen, S.P., 'Oorsig van die toekomstige water-behoeftes van die Republiek van Suid-Afrika'. Convention: Water for the Future, Republic of South Africa, Water Year, 1970, Pretoria.

[2]Stander, G.J. and Clayton, A.J., "planning and construction of waste water reclamation schemes as an integral part of water supply," Journal of the Institute of Water Pollution Control, Vol. 70, No. 2, (1971), pp. 228-234.

[3]Van Vuuren, L.R.J. and Henzen, M.R., "Process selection and cost of advanced wastewater treatment in relation to the quality of secondary effluents and quality requirements for various uses." Paper presented at conference: Applications of new concepts of physical-chemical wastewater treatment, Vanderbilt University, Nashville, Tennessee, Sept. 18-22, 1972.

[4]Henzen, M.R. and Coombs, P., "Reclamation of water: The key to water pollution control." Paper presented at a combined plenary session of the 2nd Rhodesian Scientific Congress, Umtali, 5-11 Sept., 1971.

[5]Bolitho, V., Irrigation farming-City of Johannesburg. Report to City Engineer's Department, Cith of Johannesburg, 1970.

[6]Stander, G.T. and Clayton, A.J., op. cit.

[7]Du Toit Viljoen, S.P., op. cit.

[8]Henzen, M.R. and Funke, J.W., "An appraisal of some significant problems in the re-use of waste water," Journal of the Institute of Water Pollution Control, Vol. 70, No. 2, 1971 pp. 177-186

[9]Stander, G.J. and Fumke, J.W., "Conservation of water re-use in South Africa." Presented at the Symposium on : Conservation of water re-use, Part IV, 59th Annual Meeting, American Institute of Chemical Engineers, Detroit, Michigan,

Dec. 4-8, 1966. Reprinted from: Chemical Engineering Progress, Symposium Series, Vol. 63, No. 78, 1967.

[10]Voysey, J., Personal communication.

[11]Alexander, A.T., "Control of liquid effluent from African Explosives and Chemical Industries Ltd., Modderfontein Factory." Paper presented at: Symposium on chemical control of the human environment, Johannesburg, 1969.

[12]Clayton, A.J. and Pybus, P.J., "Windhoek reclaiming sewage for drinking water," Civil Engineer, ASCE, Vol. 42, No. 9, (Sept. 1972), pp. 103-106.

[13]Van Vuuren, L.R.J., Henzen, M.R., Stander, G.J. and Clayton, A.J., "The full-scale reclamation of purified sewage effluent for the augmentation of the domestic supplies of the City of Windhoek." Paper presented at the 5th International Conference on Water Pollution Research, San Francisco, 26th July-5th August 1970, pp. 1-32/1 - 1-32/9.

[14]Henzen, M.R., 'Die herwinning, opberging en onttrekking van gesuiwerde rioolwater in die Kaapse Skiereiland'. D.Sc. Thesis.

[15]Van Vuuren, L.K.J. and Henzen, M.R., op. cit.

[16]Hart, Oliver O., "Process refinement in the development of a water reclamation system." Paper to be presented at the Workshop: International Association on Water Pollution Research, Vienna, Austria, Sept. 8-12, 1975.

CHAPTER V

SELECTED HEALTH ASPECTS OF RECLAIMED WATER IN SOUTH AFRICA

W. H. J. Hattingh

South Africa is not richly endowed with water and is situated in the drought belt of the globe. Any deterioration in the quality of the available water resources is, therefore, a matter of grave concern. Calculations show that the demand for potable water will outstrip the supply by the turn of the century in less than 25 years from now.

Pollutants dangerous to public health in municipal wastewater range from chemicals, such as carcinogens and heavy metals, to pathogenic microorganisms. There is at present a lack of knowledge as to the occurrence of many of these pollutants in surface waters, sewage and sewage works effluent and their possible effects upon man. Long-term consumption of water containing pollutants might produce chronic or perhaps acute disease with resultant serious economic implications. Existing water purification plants may not be equipped to meet these rapidly changing conditions. Although the efficiency of reclamation plants treating municipal wastewaters for reuse has been intensively studied for the successful removal of many pollutants, the possible effects of the introduction of such reclaimed wastewater on the health of the receiving community must be assessed.

A program was, therefore, drawn up and is being carried out to determine the health aspects of reclaimed wastewaters, by the collection of information on the type and quality of the constituents in municipal wastewater, reclaimed wastewaters and other waters, using chemical, microbiological, cytotoxicological, bio-assaying, immunological and epidemiological techniques. These data form a base line on which variations in the quality of reclaimed and other waters are measured, now and in the future, so that the health of the receiving communities may be protected.

RESEARCH PROGRAM

A comprehensive water quality surveillance program commenced in 1973 in two areas of Southern Africa.

The safety of the waters in these two areas for potable use will be evaluated by the interpretation of data obtained from:

1) the chemical and microbiological qualities of the waters;

2) the use of cell culture systems to test the water for possible toxicity;

3) an investigation into the possibility of the spread of R^+ bacteria by polluted waters;

4) the determination of long-term effects of possible pollutants by means of the bio-assaying of different waters using experimental animals such as rats, mice, fish, dogs and primates;

5) a limited epidemiological survey in area 1; and,

6) virus and serum banks of specimens collected in (1) and (5) which may be used for retrospective immunological studies, if necessary.

The analytical procedures followed in the program have been outlined elsewhere (Nupen and Hattingh, 1975).

RESULTS

The first two years of the ten year program have been completed, and it is too early to draw conclusions. A brief summary of available results will be discussed here.

Methods Development

Analytical methods to measure the sanitary quality, trace elements, pathogenic bacteria, viruses and parasites have been developed and are being applied with success. Analytical methods to concentrate and identify trace quantities of organic chemical residues are almost non-existent and must be developed.

Microbiological Quality

Viruses. Of particular concern is the possible presence of viruses. This problem can be solved by proper disinfection with chlorine. We have never had an outbreak of bacterial or viral diseases when a drinking water was well chlorinated, i.e. at least to breakpoint chlorination. Therefore, the tendency has been to swing away from bacterial and viral diseases to that of organic residues.

Virus evaluation. The methods that we apply for virus evaluation seem to meet with approval by other researchers. There is, however, some controversy as to the volume of water that should be analyzed, i.e. from one litre up to more than 1200 litres. The rationale behind this reasoning is not clear, since in the beginning one litre was good enough, then it was stepped up to 10 litres and now 1200 litres. If this type of pressure is maintained, then eventually we may have to assay a whole reservoir for virus before it would be acceptable. The major obstacle is in the filtration of such a large volume of water for organisms less than 0.5 μm in size. In the Republic of South Africa, we confine the sample for assay to 10 litres.

Bacteria. As far a bacteria are concerned, we know all those that are harmful to man. They were described many years ago. The first scientific evidence that water was a carrier of disease was in 1854 in London, where cholera was the agent. This led to the water being rendered safe by chlorination -- in other words, disinfecting the water. Those few instances where an outbreak of disease has been experienced, such as cholera in India, have been due to gross pollution from untreated sewage. But under controlled conditions, where proper disinfection has been applied, we have never had an outbreak of disease. It has been the experience in our country that whenever bacteria or viruses, or both, have been isolated from a potable water, proper disinfection had not been achieved. It could be traced back to bad operating practice or inadequate control of disinfection. To date, we have not isolated any virus or pathogenic bacteria from reclaimed water.

A bacterial problem that has arisen in the last few years is that of antibiotic microbial resistance. The bacterium E. coli is generally regarded as an indicator of faecal pollution. This bacterium has the ability to transfer resistance to antibiotic compounds to other pathogenic bacteria. This acquired resistance makes them resistant to treatment of diseases by antibiotics, with resultant serious complications. However, the behavior of these bacteria is similar to the "wild" type and they are equally susceptible to chlorination. They can, therefore, easily be removed in water purification plants.

Their occurrence in the water environment is at present being studied by this Institute and a number of papers have been published on this subject (Nupen and Hattingh, 1975).

Parasites. The parasites present in purified effluents (humus tank effluent) are removed in the first stage of the reclamation plant, i.e. by high lime treatment. We still do not know if the parasite ova present in the lime sludge are viable or not. Until a few years ago, we were quite happy that composting of sewage sludge would destroy these ova. However, bettwe analytical techniques proved that this was not the case.

Disinfection

We believe that proper disinfection by chlorination, i.e. breakpoint chlorination, renders a water microbiologically safe. Ozonation as another means of disinfection is being studied. Ozonation has the advantage that organic material may be oxidized to CO_2 leaving no additional tastes and odor as chlorine often does.

We believe that chlorination of purified sewage effluents is wrong and for that reason it is not practised in South Africa. Chlorination has only one application and that is in the disinfection of potable water. Potable water contains little organic material and, therefore, the risk of producing chlorinated hydrocarbons is much less. Chlorination of purified sewage effluents gives rise to a false sense of security--it is like sweeping dust under the carpet. A count of zero E coli does not mean that the water is safe. Many viruses are still present and the hazard is as great as ever--apart from the possibility of producing chlorinated hydrocarbons.

SETTING OF STANDARDS

The rationale for setting standards to ensure that drinking water does not constitute a health hazard is at present under review. We find that, as better and better analytical techniques become available, there is a tendency to lower the limits for certain standards. The question then arises is this really necessary?

There is also a tendency to include more and more compounds and not to omit others that are perhaps less important.

Are we going to end up with a list of standards containing 400 compounds, or are we going to select only those of proven harmful effect upon man? Are we striving to obtain a sterile environment or are we going to be reasonable and allow chemicals at certain concentrations?

A safety factor is built into the setting of a standard which does not mean that, if the standard is exceeded, everybody is going to drop dead. It is only a guide as to the level of a toxic material which can be tolerated over an extended period of time. Opinions have been expressed that a reservoir of water should be fully analyzed before its use. We feel that this is impossible. Some analyses, such as virus evaluations, take up to 30 days before an answer is obtained. Are we going to build reservoirs for a large city to retain a day's consumption for 30 days? Therefore, we believe that technology is available to produce water of good quality. Analytical results may then be used to confirm that this technology and the control of the water purification processes have been correctly applied.

The more standards that are proposed, the longer it takes to analyze a sample, the more complicated a routine analytical control laboratory becomes and the higher the standard of education that is required from the analysts. There is no point in setting a standard if the analytical method is not available and if the standard cannot be enforced. If the latter constraints cannot be overcome, then it is better to have no standard at all. Are we striving to obtain a sterile world or are we going to accept the fact that the quality of our waters is going to deteriorate in any event? If we are confronted with the choice of drinking water or dying of thirst, which is it going to be? We must develop technology to prevent the deterioration of our waters, but let us not forget the possible intake of toxic substances from other sources, such as food. All that is needed is a balanced outlook on the environment.

TRACE ORGANIC RESIDUES

My remarks are confined to the determination of organic residues in potable water only and the answer is not as simple as it might appear. Too little is known about these compounds. The National Institute for Water Research has tackled this problem in two ways:

1) using biological evaluation techniques in which different animal sensors are used to study possible effects of water containing organic material; and
2) developing analytical techniques (chromatography and mass spectrometry) to separate, concentrate and identify the organic material present in potable water.

While the chemical methods are being developed, we are busy with the production of an archive of results by means of "finger-printing". This means that we are watching for any increase in the levels of organic material with time. If this occurs, the source of this material would be located and eliminated, if necessary.

Bio-evaluation of an extract of organic material from spent activated carbon gave negative answers. An additional experiment, where rats are drinking potable water prepared from different sources, is in progress. No results are available as yet. Bio-evaluation techniques using uni-cellular organisms are presently being studied and will be introduced as soon as possible. The advantage of these sensors is that lifespan is short and results can be obtained in a shorter period of time.

A determination of the volatile constituents present in water has been carried out. Results show that the concentrations of the volatile compounds are much less than those reported for the United Stated waters. This is perhaps due to the fact that the Republic of South Africa has not developed to the same extent as the United States of America and, therefore, we have less industrial effluents to cope with.

Polyaromatic hydrocarbons are being determined in our water using the method of Borneff and Kunte. This allows comparisons to be made with other findings throughout the world. A collective standard for these compounds has been proposed by the World Health Organization. Results showed that reclaimed water was of a much better quality than tap water prepared from a surface supply. The number and concentration of the compounds present in the raw water intake to the reclamation plant was drastically reduced in the final water. Studies are presently underway to identify these compounds by mass-spectrometry.

The identification of the small amount of organic material present in potable waters rests on the fact that this material must be isolated and concentrated from the aqueous phase, without altering the molecular structure of the organic material. This latter constraint is an important one since a change in molecular structure may change the toxicity of a molecule or vice versa. A large amount of research is going into this problem. None of the concentration techniques we have used proved to be satisfactory. It would seem that a combination of techniques would have to be used. The molecular size distribution in purified sewage effluent and reclaimed water is vastly different. The former water consisted mainly of molecules of molecular weight larger than 100,000. However, the reclaimed water consisted mainly of molecules with molecular weights less than 500. These molecules have molecular weights similar to some inorganic chemicals and to separate them is difficult.

The approach to date has been to extract certain known groups of compounds (such as pesticides) with solvents and to analyze these groups. Progress has been made and enough information has been obtained to form a baseline for 1974. The mass spectrometer is used for final identification of the compounds isolated and separated by other methods. A word of caution is needed here, since to generate results is no problem, but identification and interpretation is not so easy. That is why we have so much controversy about the DDT issue.

EPIDEMIOLOGICAL STUDIES

Epidemiological studies, we believe, will be very difficult to carry out. We are not talking about a water containing concentrations of compounds with acute toxicity to man, but at worst of sub-lethal concentrations. To assess the influence of a parameter with no clear cut disease pattern is impossible. Water is only part of the total intake of any compound and it is often true that the concentration of such a compound is many times less in water than in some foods. Once again the total intake of a compound must be assessed and the amount ingested via water determined. If the contribution of water is negligibly small, why have such a strict standard for water?

Death certificates as a tool in gathering epidemiological information seem to have serious complications. The cause of death is not always meticulously recorded. Therefore, death certificates might be misleading. I believe that the U.S. Cancer Research Institute has overcome a lot of the difficulties and that death notification is much better than it used to be. We are, however, conducting an epidemiological survey in Windhoek, South West Africa. Windhoek is a small town in an arid region and the only hospital treats all the patients in the town.

The medical profession, therefore, has direct access to all cases admitted and these may then be carefully studied to obtain a disease pattern of the town. At this stage, no change in the normal disease pattern has been observed. A number of other avenues have been explored with little in the way of positive results. This area still remains rather obscure and we believe that more positive results would be obtained by watching the quality of the water in time supplemented by bio-evaluation of the different types of water.

QUESTIONS AND ANSWERS

Q: This morning we had a representative from the Environmental Protection gency giving us the Agency's policy statement which was fairly conservative in its attitude to reuse of wastewater. Apparently the attitude of your agency in South Africa is quite different. When you advocate reclamation, do you see any indication either at the professional level, or with administrators, that there seems to be a shifting or easing of the United States policy in this?

A: Well, I don't want to get into politics, but I must explain that the position is really quite different in our country. You have got the situation in the United States that everybody can sue everybody. All actions of the U.S. Environmental Protection Agency can be and are tested in court. That makes life very difficult for the EPA, since no matter what they do, somebody takes exception and a court case is looming.

Secondly, the structure of our Council for Scientific and Industrial Research differs widely from the EPA. Our President is a scientist and he reports directly to the Minister of Planning and the Environment. The head of the EPA is a lawyer. Our scientific views are, therefore, not as prone to political pressures as in the U.S.A. I have indicated that in the Republic of South Africa by the year 2000, twenty-five years from now, we are not going to have enough water. We are faced with that problem today. I have also indicated that if water had not been reclaimed, Windhoek would have been without water for over a week. Now what would those people have done? There was not another source in the vicinity; South West Africa is a dry, arid country.

Those are the problems we are confronted with. We cannot supply more water; we just don't have the water to supply, but people must live. We, therefore, advocate reclamation of water. We were forced into the position where we had to provide the water before all these studies that we are doing at the moment, could be completed. So I do find that the EPA is perhaps more skeptical than we are; possibly they are investigating these things more thoroughly, with more manpower and money available to them than we have. For instance, we have only one person on the gas chromatography-mass spectrometer analytic (GC-MS) unit.

Fortunately, we don't have the extremes of pollution that you have to contend with in this country. Our effluent standards were promulgated many years ago. They have proved adequate up to now for controlling problems of pollution, except for nitrogen and phosphorous. The nitrogen and phosphorous limits are too high and we are faced with eutrophication. So, therefore, the possibility of lowering the phosphorous concentrations of effluents is presently being discussed. I think this will come about and we are doing extensive work on phosphorous removal. The answer to your question is then that we are more positive about reclamation since we are facing a more serious problem.

Q: Without chlorination of effluents, do you have any problems in using this water for irrigation of crops that will be directly consumed?

A: This is again rather a long story. A few years ago our Department of Health issued what might be called an in-house guide, as to what could be done with this water and what should be done. Now you must remember that all our purified sewage effluents in South Africa receive secondary treatment. One is allowed to use them for spray irrigation, except for crops that are eaten raw. I don't know what the simple answer to this question is, because the water is potentially dangerous, and from my point of view I would hesitate to allow the unrestricted use of purified effluents. But it is not that easy. I have seen with my own eyes, at the sewage works, people drinking purified sewage effluents, which are used for irrigation. Nothing has happened. However, this observation still does not condone the use of such waters.

I think it is true for most people working at sewage irrigation works that one seldom finds any of those people complaining of diseases. They seem to acquire an immunity and this brings us back to the philosophy of our story. Are we trying to create a sterile world? If so, then for how long? The more one is subject to these microbial diseases, the greater the chance of building up an immunity.

It is well-known that there are great problems in keeping sterile laboratory animals in laboratories. The extreme precautions taken to prevent entry of any diseases are well known. Are we striving to do this for man? Dr. Gear, of our Poliomyelitis Research Institute, has made the remark that the more sanitary conditions we provide in undeveloped areas, the more the disease bilharzia (schistosomiasis) is spread among the inhabitants of those areas. It is well known that the spread of this disease is on the increase, in spite of providing more sanitary facilities, teaching people sanitary habits, etc. Where are we going? So the final answer to your question is not as simple as it might be thought. The last word about chlorination and its application has not yet been spoken.

Q: Along with the notion of an immunological build-up, I read recently that there are different rates of mono-nucleosis and polio according to social class, where upper-middle class and upper class children had higher rates of mono and polio than the lower class children. Please comment on this.

A: Look at the outcome. A large proportion of our population in South Africa is black. They live under more primitive conditions than we do. However, polio is not known among them. Very few of them die of heart attacks. However, they get cancer of the esophagus, mainly due to the food that they eat being prone to fungal attack and toxins being produced. The grain that they harvest every year is put into containers and then kept in the container for the whole year. Now we know that different species of fungus grow and toxins are produced. Some of these toxins produce cancer. Therefore, the incidence of that type of cancer among these people is very high, but not among the white population. The latter group, however, die of heart attacks and heart diseases.

Apart from the food that the Blacks eat, they lead a more restful life. I am a believer that it is not the restaurant that kills us, it is tension. It is not overweight, but tension.

Q: I don't know whether you can answer this or not, but how effective are vegetables and plants that are acting as a strain on bacteria and viruses as well? In other words, if you use sewage or non-potable water for irrigation, does that really get into the vegetable or fruit?

A: I don't know outrightly, but I would say yes it does. Therefore, the foods that we boil are the safest. That is why we specify that crops that are eaten raw may not be irrigated with purified sewage effluents.

Q: In other words, the membranes don't strain them out?

A: No. Remember that any virus penetrates a cell, i.e. the host, to produce more viruses. I don't want to get into the argument as to whether viruses are alive or not, but let us regard them as alive. They attack the host, and they will simply invade the host. That happens. So that is why we specify that foods eaten raw may not be irrigated in this way.

CHAPTER VI

ECONOMIC CONSIDERATIONS IN THE REUSE OF URBAN WATER

Jerome W. Milliman

There appears to be a growing realization that reuse of urban wastewater can be a promising source of water supply. Several basic factors are responsible for this growing awareness.

First, increasing urbanization and industrialization throughout the world are clearly exerting greater pressures on limited fresh water resources. As a result fresh water sources are becoming scarce and costly.

Second, more and more communities are turning to polluted sources to meet their needs for new supplies. It has been estimated that about one-third of the United States population now uses water that is in part made up of wastewaters discharged only hours earlier from municipal or industrial sewers.[1]

Third, the costs of treatment of wastewater are rising as a result of higher standards imposed on the treatment of wastewater before discharge. In some cases, the quality of wastewater discharged may exceed the quality of intake water into the system. When high quality water is produced by waste treatment plants the economics of reuse of wastewater becomes a serious consideration. This matter will become important when cities attempt to meet the zero-discharge goal set forth in the 1972 Federal Water Pollution Control Act (PL 92-500).[2]

Finally, important developments are taking place in the technology of advanced wastewater treatment. Progress is being made in processes for dealing with virus removal, heavy metals and toxic organic materials. Increased attention is being given also to problems of system reliability and to monitoring capabilities.[3] It is now realized that most of the reservations which have been expressed regarding reuse of wastewaters apply with almost equal force to many conventional water treatment plants.

Increasingly, it is being recognized that the science and technology of water supply and water pollution control are much the same. What remains is a need to develop common institutional arrangements for the joint planning and management of water supply and waste treatment of systems. It is also clear that the economics of water supply and the economics of wastewater treatment must be brought together in a common systems orientation or a common framework.

The present indirect use of wastewaters for urban water supplies is largely unplanned. Concern has been expressed with serious problems concerning the safety and reliability of treatment of conventional water supplies. This concern now extends to the planned reuse of wastewater. Yet, it seems inevitable that planned reuse of wastewater must be given serious consideration. The question is how can we best plan to make reliable and safe the reuse possibilities. It is also a question of how we can make reuse of wastewater economic and efficient.

GENERAL ECONOMIC FACTORS FOR REUSE OF WASTEWATER

The proper perspective for economic planning for the reuse of urban wastewater must be that of viewing reuse as part of the <u>overall problem</u> of efficient management of water resources in general. The activities of water supply, wastewater disposal, water quality management and possible reuse of wastewater are clearly inter-dependent <u>within</u> given urban areas and also <u>across</u> common watersheds or water basins.

It can be argued that the widespread and growing concerns about: a) safety of municipal supplies; b) water shortages and rising costs; c) environmental quality and need for higher standards for wastewater discharges are largely problems of inadequate institutional arrangements for the management of water resource and the failure to use economic principles.[4]

There are four factors governing economic planning for the possible reuse of wastewater:

1) Establish systems of regional water management.

2) Within urban areas establish unified management of investment, pricing and operating decisions for water supply and waste disposal.

3) Adopt user charges for water supplies and the treatment of wastewater based upon marginal costs.

4) Management and planning policy must rely on evaluation of benefits and costs of programs and projects for water resource investments and environmental quality management.

<u>Systems of Regional Water Management</u>

The need to develop regional systems of water management is probably best argued by Knesse and Bower [5] in their study of regional water quality problems. They argue that regional authorities are necessary to a) internalize major offsite costs of water pollution by balancing gains and costs between up-stream and down-stream users; and b) take advantage of large-scale treatment measures which might not be economical or available to individual cities of firms.

Although their work is primarily directed toward regional water quality management, it is clear that water quality management should be directly related to the total management of the hydorlogic unit,including use of water for hydropower, recreation, flood control, navigation, and water supply.

In addition to a regional approach, Kneese and Bower stress the need for effluent charges as a means to provide economic incentives to minimize the costs of attaining environmental quality. Present water pollution control efforts in the United States have failed to emphasize comprehensive river basin planning and have not employed the effluent charges as a means of reducing the output of industrial and municipal water-borne wastes. [6]

The proper framework within which to view the desirability of reuse of wastewater is clearly within a regional context. First, all water resource management should be coordinated across uses within a basin. Second, it is clear that there may be economies of scale in the treatment and transmission of wastewater for reuse which may not be available to an individual city. Third, reuse of wastewater upstream may have down-stream benefits and costs which may not be considered unless a regional management framework is provided. Okun is one of the few technical scientists to emphasize the importance of a regional approach in planning for water reuse.

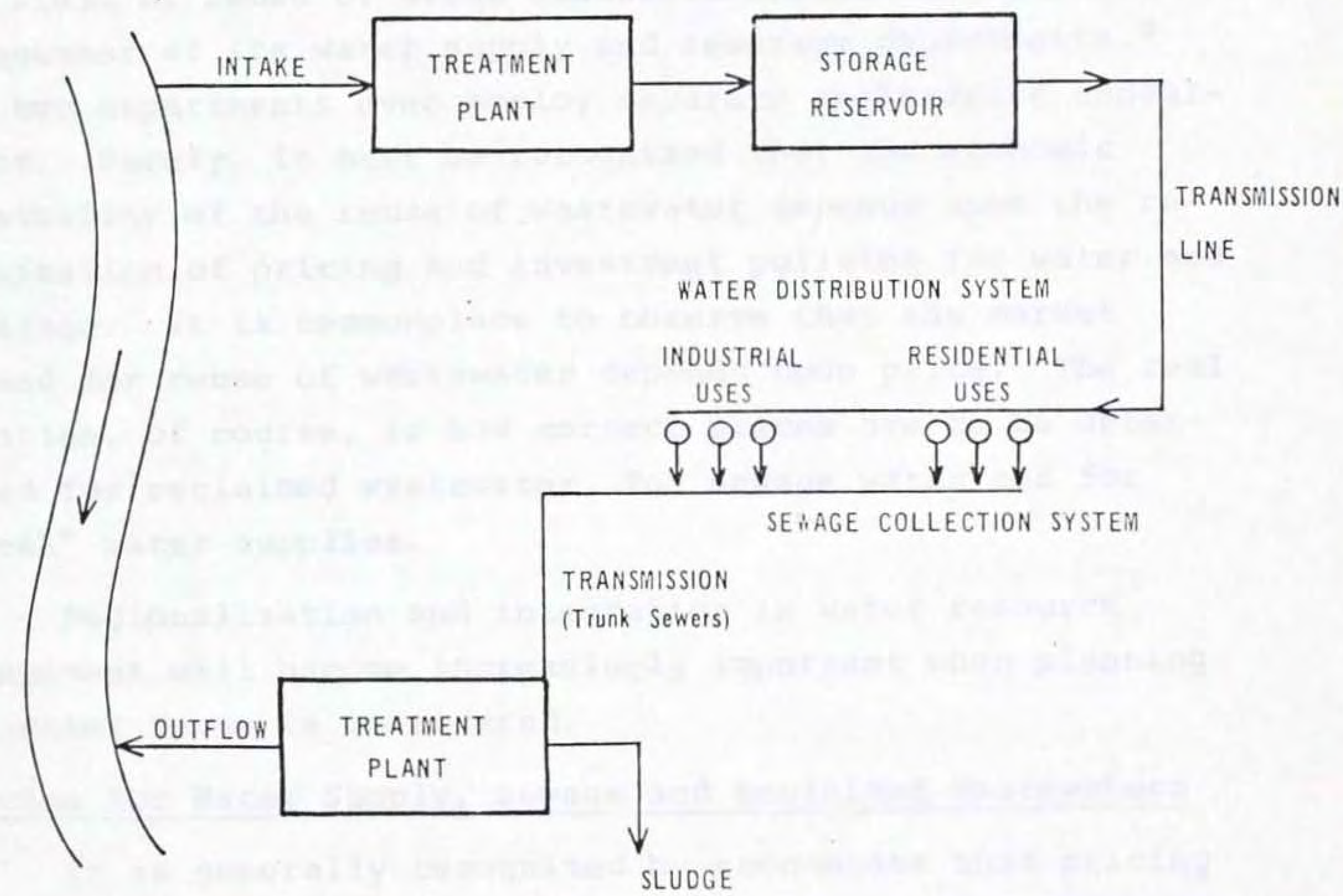
Integration of Water Supply and Sewerage Systems

As Figure I illustrates urban water and sewerage systems are part of a combined overall system. The supplying of urban water is only part of the system. The full system consists of supply, purification, storage and delivery of water to users followed by collection, treatment and disposal of wastewater.

All too often, water and sewerage systems within an urban area are administered independently so that the advantages of a system point of view are lost. Pricing and investment decisions for urban water supply are uniformly made without adequate appreciation that they are interdependent with the same decisions for sewerage. Combined planning and

Figure 1.

TYPICAL COMBINED WATER-SEWERAGE SYSTEM



management of water and sewerage systems within an urban area offers many advantages from technical, managerial, economic and social points of view.[7] Clearly, if we are to consider reuse of wastewater, integrated water and sewerage management will be even more important.

Yet, Colorado Springs, which is cited as a pioneer in the field of reuse of urban wastewaters, still has separate management of its water supply and sewerage departments.[8] The two departments even employ separate engineering consultants. Surely, it must be recognized that the economic feasibility of the reuse of wastewater depends upon the rationization of pricing and investment policies for water and sewerage. It is commonplace to observe that the market demand for reuse of wastewater depends upon price. The real question, of course, is how correct prices are to be determined for reclaimed wastewater, for sewage water and for "fresh" water supplies.

Regionalization and integration in water resource management will become increasingly important when planning for water reuse is considered.

Pricing for Water Supply, Sewage and Reclaimed Wastewaters

It is generally recognized by economists that pricing policies for urban water supply and sewage leave a great deal to be desired. It is also understood that economic analysis of urban wastewater reuse depends upon its costs of production and its price relative to alternative water sources available to prospective users. Unless "correct" prices are charged for "fresh" water supplies and unless the costs of wastewater treatment are correctly estimated and assessed, it will be impossible to determine the economic feasibility of wastewater reuse.

Economists agree that prices for water supplies should be based upon the marginal costs of production and delivery and the marginal costs of waste disposal. When marginal costs of service differ, then marginal cost prices should differ in corresponding fashion. Yet, the conventional practice in the municipal water supply industry is to base prices or rates upon average costs.[9] In an age when costs of new supplies are rising, average cost pricing will seriously underprice water to final users. On the one hand, if water rates for conventional supplies are too low, water consumption will be excessive thus increasing the "need" for reuse of wastewater. On the other hand, excessively low prices for conventional supplies may make "correct" prices charged for reclaimed water appear too high in relation to alternatives available to potential users.

In addition to the widespread use of average cost pricing, the water supply industry generally charges uniform rates which fail to reflect costs of service which vary over time and space.[10] For example, peak season pricing has seldom employed even though water commodity costs and water system costs are much influenced by seasonal use. It is also clear that the costs of serving suburban customers may be much greater than service costs to high density areas. Uniform prices across time and space clearly produce inefficiencies in current water use. Again, inefficient prices for conventional supplies will make it virtually impossible to estimate "correct" prices for reclaimed water supplies.

<u>Cost-Benefit Analysis for Water Supply, Sewerage, and Reclaimed Water</u>

It is important that the economic feasibility of reuse of wastewater must be determined by careful cost-benefit analysis. It is also acknowledged that cost-benefit analysis of urban wastewater reuse on a <u>regional level</u> is a complex task requiring careful study. There can be no quarrel with these statements. Yet, the irony of the matter is that the same kind of careful cost-benefit analysis has not (and is not) been employed on conventional municipal water supply and sewerage projects.

In conventional planning, the water industry traditionally forecasts water requirements (independent of prices, benefits and costs) and then designs new capacity to meet requirements. After the engineering and physical planning have taken place computations are made to determine accounting costs and the rate level (based upon average costs). On the one hand, it is evident that physical and financial planning are now basically separate activities which bring in the demand relations only by the back door. On the other hand, current practices concentrate upon financial feasibility (the self-liquidating character of the project) and virtually ignore a economic evaluation of general benefits and costs.[12]

In summary, the seriousness with which we approach economic planning for wastewater reuse will depend on these four factors affecting economic efficiency: use of a regional approach; integrated planning across urban water supply and water disposal systems; greater attention to rate structures based upon marginal costs; and greater use of cost-benefit analysis for water supply, for waste disposal and for wastewater reclamation.

SPECIAL ECONOMIC FACTORS IN REUSE OF WASTEWATER

The reuse of municipal wastewater in the United States in 1971 took place at approximately 358 locations generally located in the southwestern states of Texas, California, New Mexico, Nevada, Colorado and Arizona.[12] Total reuse volume on an annual basis was estimated at 133 billion gallons (exclusive of groundwater recharge). Treated urban wastewater was being used successfully for irrigation of a wide variety of crops and landscaping, for industrial cooling and process water, and recreational lakes. At one site, Grand Canyon

Village, treated wastewater was used for toilet flushing. Irrigation use comprised 77 billion gallons or 58 percent. Industrial use was 53 billion gallons or 40 percent. However, the bulk of the industrial reuse was due to one user - the Bethlehem Steel Plant in Baltimore, Maryland which used 44 billion gallons annually.

Reuse abroad takes place at approximately 55 sites with the bulk of the use taking place in Australia, Japan, Israel, South Africa and Mexico. The most well-known reuse takes place in Windhoek, South Africa where reclaimed sewage is used for direct potable use with monthly proportions going up as high as 27 percent of total municipal water consumption at Windhoek.

Is the reuse of wastewater economical? The obvious answer is "yes" -- otherwise it would not be taking place. Clearly, the gains exceed the costs to the parties involved. Yet, an extensive study of the literature on wastewater reclamation indicates that the "obvious" answer of economic feasibility is not at all clear-cut. Better answers might be "probably", "perhaps" or simply that "we don't really know". I have searched in vain in the extensive literature on reclamation of wastewater for careful studies of cost-benefit analysis, for careful studies of cost estimation (not just engineering estimates of average costs) and careful studies of price policy and user charges. If such studies exist I cannot find them. It is an interesting commentary on the rapid development of the science and technology of wastewater reclamation that so little attention has appently been paid to the basic economic factors influencing the feasibility of reuse of urban wastewater. In the remaining part of this paper, I will make some scattered comments upon some special economic factors which might influence the reuse of urban wastewater.

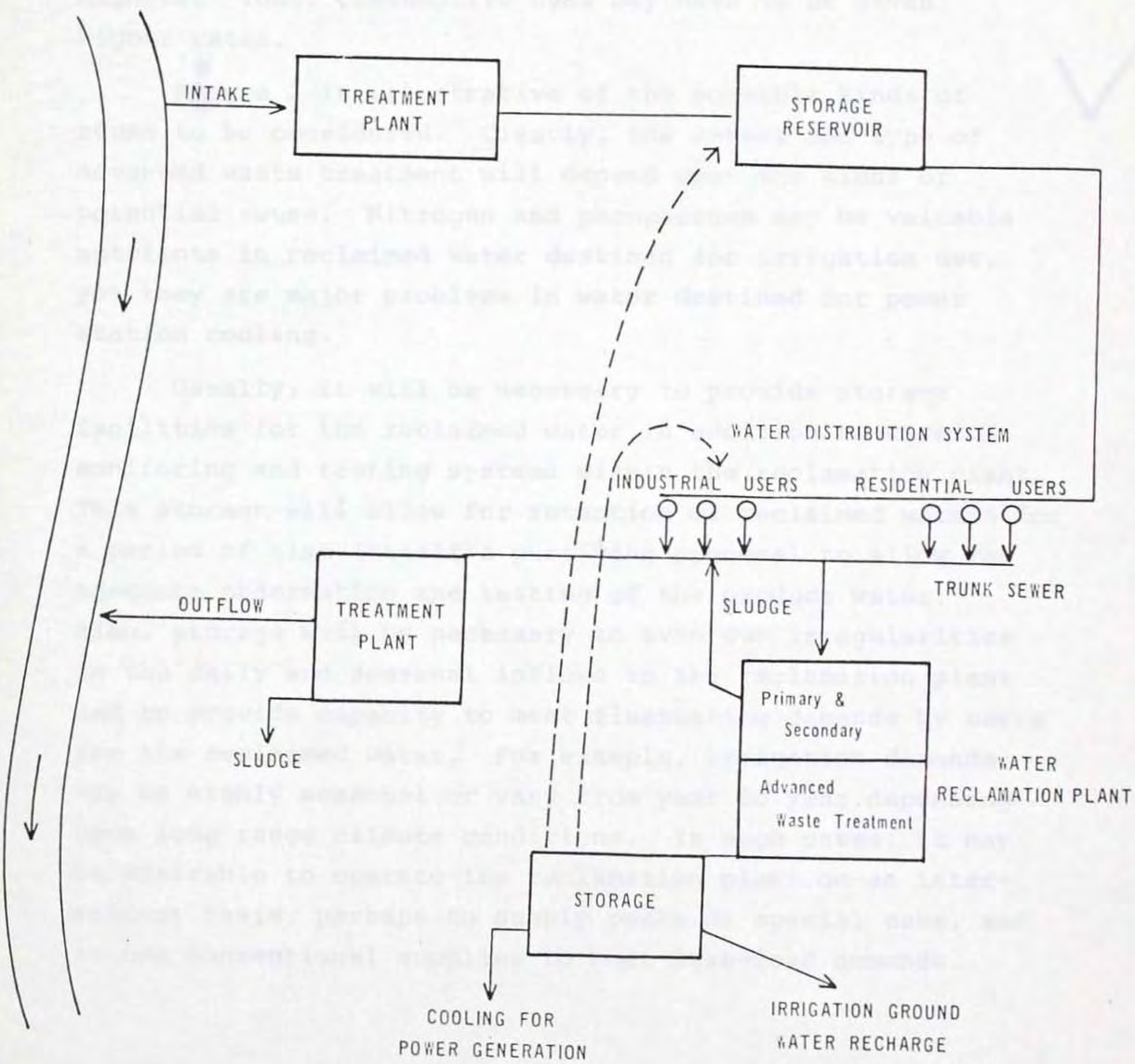
Integrated Management of Water Supply, Waste Treatment and Water Reclamation System

Figure 2 illustrates a hypothetical system combining water supply, waste treatment and wastewater reclamation for an urban area. The figure should make it clear that the administration and control of community water supply and community wastewater disposal (and reuse) system should be combined if possible.

There are definite economies to be derived from combined management including the sharing of technical personnel and monitoring and testing facilities and in integrating the physical layout of services and minimizing costs of the total system. For example, a water system is less costly when service can be made by gravity flow; the same logic applies to the operation of the sewerage system. If wastewater is not reclaimed, it may be economic to have the waste treatment plant located at the lowest elevation in the system. Yet, when a water reclamation plant is being considered, its location must be carefully planned, not only to intercept and treat only high quality wastewater (little or no industrial wastes), but also to minimize pumping and conveyance costs to potential users of the reclaimed waters. The costs of separate distribution lines for conveyance of reclaimed wastewater to potential users may greatly affect the market demand for reclamation.

The payment for the collection and treatment of wastewater should be considered as an integral part of the water supply service, and water charges should include these costs.[13] At present, this is more the exception rather than common practice. When reclamation of wastewater is considered it will be even more important to rationalize common water and sewage user charges. For example, the costs of reclamation will be very sensitive to the quantities and qualities of the wastewater. Municipal water use which seriously degrade waste-

Figure 2.
SIMPLIFIED WASTEWATER REUSE SYSTEM

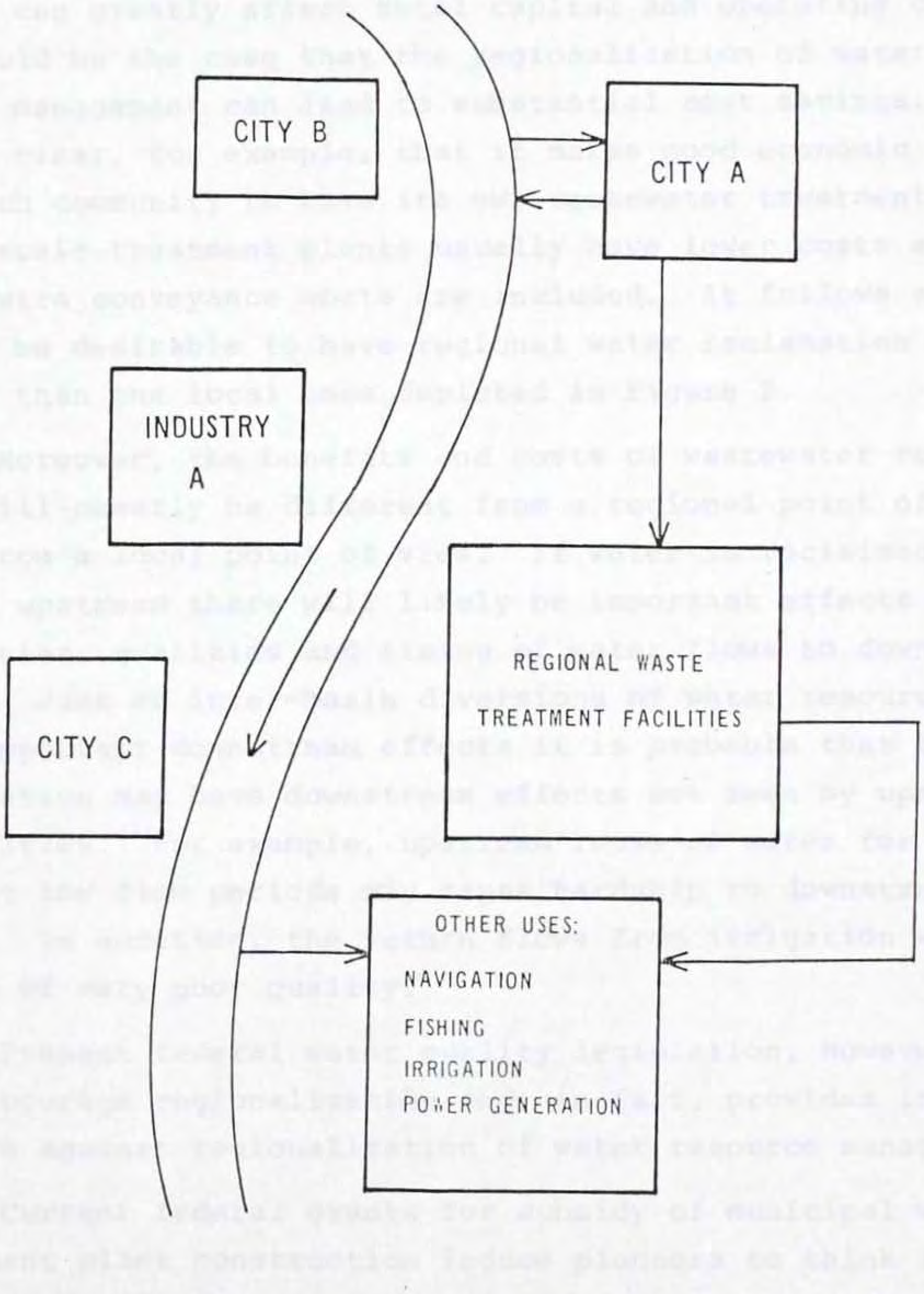


water and make it more difficult to practice reclamation should be charged higher prices. Also, uses which do not return water to the system (e.g. lawn watering, car washing) may reduce return flows and affect the quantities to be reclaimed, particularly on a seasonal basis. It is possible, for example, that these consumptive water uses may reduce flows to reclamation plants at the very time that the seasonal demands for reclaimed water are the highest. Thus, consumptive uses may have to be given higher rates.

Figure 2 is illustrative of the possible kinds of reuse to be considered. Clearly, the extent and type of advanced waste treatment will depend upon the kinds of potential reuse. Nitrogen and phosphorous may be valuable nutrients in reclaimed water destined for irrigation use, yet they are major problems in water destined for power station cooling.

Usually, it will be necessary to provide storage facilities for the reclaimed water in addition to careful monitoring and testing systems within the reclamation plant. This storage will allow for retention of reclaimed waters for a period of time (itself a purifying process) to allow for adequate observation and testing of the product water. Also, storage will be necessary to even out irregularities in the daily and seasonal inflows to the reclamation plant and to provide capacity to meet fluctuating demands by users for the reclaimed water. For example, irrigation demands may be highly seasonal or vary from year to year depending upon long range climate conditions. In such cases, it may be desirable to operate the reclamation plant on an intermittent basis, perhaps to supply peaks or special uses, and to use conventional supplies to meet base-load demands.

Figure 3.
REGIONAL WATER MANAGEMENT



Regionalization of Water Management

Figure 3 illustrates a hypothetical system of regional water management. As indicated above, the case for regional water management is well-established even though the practice of regional management is not common. If the layout of a combined community water supply and community wastewater system can greatly affect total capital and operating costs, it should be the case that the regionalization of water resource management can lead to substantial cost savings. It is not clear, for example, that it makes good economic sence for each community to have its own wastewater treatment plant. Large scale treatment plants usually have lower costs even when extra conveyance costs are included. It follows also that it may be desirable to have regional water reclamation plants rather than the local ones depicted in Figure 2.

Moreover, the benefits and costs of wastewater reclamation will clearly be different from a regional point of view than from a local point of view. If water is reclaimed and reused upstream there will likely be important effects on the quantities, qualities and timing of water flows to downstream users. Just as inter-basin diversions of water resources may have important downstream effects it is probable that upstream reclamation may have downstream effects not seen by upstream communities. For example, upstream reuse of water for irrigation at low flow periods may cause hardship to downstream users. In addition, the return flows from irrigation waters may be of very poor quality.

Present federal water quality legislation, however, does not encourage regionalization and, in fact, provides incentives to work against regionalization of water resource management.

Current federal grants for subsidy of municipal waste treatment plant construction induce planners to think in terms of "end-of-the-pipe" treatment instead of less costly alternatives.[14] Moreover, such subsidies encourage each community to "go-it-alone" and not to consider large scale regional treatment plants. Finally the 1985 target of zero discharge (PL 92-500) will require cities to produce pollution-free treatment. It seems apparent that the 1985 goal of zero-discharge is grossly uneconomic and unrealistic.[15]

Nevertheless, higher standards of municipal water treatment will cause cities to consider reusing high quality wastewater rather than discharging it into rivers making the water available to downstream users. On the one hand, the incremental costs of advanced waste treatment attributable to reuse will decline as the "standard" treatment required of <u>all</u> wastewater is increased. On the other hand, the quality of treated water will begin to more closely approximate the quality of conventional water sources so that recycling will be less objectionable. As a result there may be uneconomic incentives for cities to reuse their own wastewater.

Even if zero discharge is not obtained, it is clear that effects of federal water quality policy may be highly uneconomic from a regional and national point of view. Surely there must be an obligation on decision-makers to examine the benefits and costs of the proposed increases in goals and in the methods for achieving improved environment management of water resources.

<u>Dual Water Systems</u>

If reclaimed wastewater is of the same quality as conventional water sources then there will be no need to consider the cost of dual supply systems. By contrast, if the reclaimed water is of lower quality, then dual systems will be necessary.

Two objections to dual systems are cited: cross-connections and cost.[16] If two systems are present in the same area, one for potable water and one for non-potable water, extreme care must be taken in the layout of lines to avoid cross-connections. This danger is well-recognized and is already part of the planning for conventional water supply and wastewater systems.

The planning of dual systems however, does warrant a good deal of research. If the dual system is just a special line to some irrigation users, to a power plant or to industrial users, the cost might well be reasonable. By contrast, if an existing municipal system is to be replaced more or less in its entirety by a dual system, the cost might be unrealistic. An intermediate case would be the cost of a dual supply system for a new community or a new area. Okun states that the costs of dual systems for new areas might be only 20 percent higher than conventional systems, particularly where the new construction would comprise high-rise multi-family dwellings. The technology for dual systems now exists because the potable water system could use plastic pipe and the pressures required for fire protection would be handled by the non-potable water systems.

The case for dual systems seems more attractive when it is realized that approximately only 10 percent of the potable water supplied in large cities is really used for potable purposes, e.g. drinking and cooking. The remainder is used for industrial use, lawn watering, toilet flushing, fire protection and the like. If commodity costs and costs of treatment are high relative to transmission and distribution costs, it may make sense to consider dual systems. In the past the reverse has been true and we have endeavored to make all municipal water supply meet drinking water standards. Dual domestic systems are already in place in Grand Canyon Village, parts of Hong Kong and in the Bahama Islands. In several cases, sea water has been used for toilet flushing.

One cost of a dual system apparently has not been recognized in the literature. Such systems may require dual metering devices, the possibility of dual billing and dual price policies. Perhaps it might not be necessary to have separate meters for each type of water for each user. It may turn out that only the potable supply should be metered or perhaps even that metering might not be needed at all. This last possibility might be feasible under a dual set of flat price structures based upon probable use indicators (e.g. number of toilets, size of lawn) which might serve as use proxies and avoid either dual or single meters. In any event, it is clear that a great deal more attention would need to be given to the calculation of marginal costs of dual supplies and to price structures and demand elasticities than is the case when only one product water is served to each user.

For the present, it is likely that reclaimed water may be of lower quality than conventional sources so that dual systems of some kind will be needed. There is reason to believe that at some future date the advance of technology and the use of large-scale reclamation plants will make it economic in arid areas of the world to produce reclaimed water of impeccable quality. Under such circumstances there may be no need for dual systems. There would remain the need for integrated system planning and management which could consider the trade off between the extra costs of dual systems versus the incremental of producing reclaimed water which is clearly potable.

REFERENCES

[1]Okun, D., "Planning for Water Reuse", Journal American Water Works Association, 65, (October,1973).

[2]Cleary, E., "Accommodating to New Imperatives in Water Pollution Control", Journal of American Water Works Association, 66, (July, 1974).

[3]Phillips, W., "Direct Reuse of Reclaimed Wastewater: Pros, Cons and Alternatives", Journal American Water Works Association, 66, (April, 1974).

[4]Milliman, J., "Policy Horizons for Future Urban Water Supply", Land Economics, 39, (May, 1963).

[5]Kneese, A., and Bower, B., Managing Water Quality Economics, Technology, and Policy, Baltimore: Johns Hopkins Press, 1968.

[6]Freeman, A., Haveman, R., and Kneese, A., The Economics of Environmental Policy, New York: John Wiley and Sons, 1973.

[7]Milliman, J., General Economic Principles for Sewerage Planning and Operation, Institute for Applied Urban Economics, Indiana University, 1968.

[8]Baumann, D., and D. Dworkin, Planning for Water Reuse, Indianapolis: Holcomb Research Institute, Butler University, 1975.

[9]Hirshleifer, J., DeHaven, J., and Milliman, J., "Water Supply: Economics, Technology and Policy, Chicago: University of Chicago Press, 1960.

[10]Hanke, S., "Water Rates: An Assesment of Current Issues", Journal of American Water Works Association, 67, (May, 1975).

[11] U.S. Environmental Protection Agency, Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater, EPA-670/2-75-038, Cincinnati, Ohio.

[12] Hirshleifer, J., DeHaven, J., and Milliman, J., op.cit.

[12] U.S. Environmental Protection Agency, op.cit.

[13] World Health Organization, Disposal of Community Wastewater, Technical Report Series No. 541, Geneva, Switzerland, 1974

[14] Freeman, A., Haveman, R., and Kneese, A., op.cit.

[15] Kneese, A., and Schultz, C., Pollution, Prices and Public Policy, Washington, D.C.: Brookings Institute, 1975.

[16] Okun, D., op.cit.

CHAPTER VII

DETERMINANTS OF PROFESSIONAL AND PUBLIC RESPONSE TO RENOVATED WASTEWATER

John H. Sims

I will discuss three studies: each contributes to the same goal - namely, to increase your sensitivity to, and your awareness of, the influence your psychological self exerts upon your work.

The points to be made by the first study [1] are two: first, to demonstrate how personality traits are differentially related to professional membership, and second, to show that the psychodynamics that distinguish the members of one profession from those of another can be either functional or dysfunctional, that is, can either aid or hinder the performance of those tasks that define the professional's job.

Studies made on many different occupational groups make these arguments - on artists and physicians, lawyers and chemists, butchers and undertakers, even on engineers and psychologists. But I've chosen a study on federal civil servants (1) at GS levels 14 through 18 for two reasons. First, I thought that this group would be of particular interest to technical experts that also work within the federal government; second, the study is mine, so that I am more knowledgeable of the data and more confident of their significance.

With the second study [2], the focus will be shifted from personality writ large to attitudes writ small. That is, we'll examine how two professional groups, public health officials and water engineers, view the use of renovated wastewater and relate those views to the groups' professional socialization.

Finally, with the third study [3], we'll consider the question of public response to the use of renovated waste-water - a question interesting in and of itself, but taking on a special meaning in the context of comparison with what health officials and engineers think the public response to such use would be.

In the 1960's, a group of social scientists from the University of Chicago, under the direction of W. Lloyd Warner, conducted a study of 7000 federal civil service administrators [4]. As part of this research, several hundred randomly selected career civil service executives of grade levels 14 through 18 in Washington, D.C., were interviewed, usually for about four hours, and were given Murray's Thematic Apperception Test, commonly known as the TAT (5). The interview was directed towards ascertaining how these men perceived the work role of the federal executive and the social structure of the Federal Civil Service, i.e., of the bureaucracy of which they were a part. The Thematic Apperception Test, or TAT, was administered in an effort to identify what, if any, personality characteristics these men might have in common and which, perhaps, would distinguish them as a professional group from other professional groups. My remarks today are based upon the analysis of the TAT protocols of 40 career civil service executives, 20 of whom held top level GS 18 career civil service positions and 20 of whom held GS 14 mid-management positions.

For those of you unfamiliar with the form of the TAT and its rationale, let me discuss it briefly. The TAT consists of a series of pictures which are somewhat ambiguous. For example, Card 1 shows a small boy and a violin. Now there is nothing ambiguous about the fact that the figure in the picture is a young boy and that the other clearly identifiable object in the picture is a violin. But, what the attitude of the boy is towards the violin, what his feelings are about it, etc., are not explicit in the picture. These things must be supplied by the viewer. And indeed, that is exactly what the subject is asked to do. For each picture shown, the subject is directed to tell a story which describes the situation portrayed in the picture and which tells what led up to the situation and how the situation will resolve itself. And he is asked to state what the person portrayed is thinking and feeling.

Now, since the stimuli of the pictures are in these respects ambiguous, the thoughts, feelings and attitudes with which the story-teller endows the portrayed persons are indicative of the thoughts, feelings and attitudes of the story-teller himself. What happens, in effect, when asked to interpret an ambiguous stimulus, is that one projects onto the stimulus one's own view of himself in relation to the world.

Experience has shown that particular cards of the TAT tend to elicit stories from subjects which are relevant to particular areas of personality. For example, Card 1 of the little boy and the violin usually evokes a story which deals in some way with the issue of impulse versus control, with the relationship between personal needs and the demands of cultural agents, particularly with regards to achievement. Another card, number 6BM, which shows an elderly woman with a young man, not surprisingly, tends to elicit stories which deal in some way with the issue of dependence versus autonomy, with the relation between the figure of the son and the maternal authority figure. Thus, through the selection ot TAT cards, it is possible to obtain data pertinent to the particular areas of psychodynamics one wishes to investigate.

The two areas of the personality of federal executives I shall discuss today are: first, achievement, the nature and strength of his desire to achieve, his perception of, and attitudes toward, external pressures to achieve, the difficulties he encounters in achieving and his success and failure in achievement; and, second the relationship to maternal authority figures, the nature and strength of the federal executive's emotional ties to such figures.

Let me begin the discussion of how the federal executive confronts the issue of achievement by reading two contrasting stories told to Card 1, the picture of the boy and the violin. Here's the first story:

> This is a picture of a talented little boy who's always wanted to play the violin. Now his parents have given him one of his own and he is eager to begin lessons. He will practice diligently, many hours a day, but it will not be all sacrifice on his part, for he looks as if he'll enjoy the work. Finally, after many years he'll become a fine professional musician, perhaps even a famous one, a Heifetz.

Now the second story:

> This unhappy little boy is staring resentfully at his violin. His parents have insisted that he learn to play and he doesn't want to. It's practice time again and while he'd like to avoid it, he knows he has to. And so, he'll pick it up and practice his lessons faithfully.
>
> It looks as if this will go on for years and eventually he'll even learn to play the damn thing, but only fairly well, and he'll never really like it.

If you'll buy, temporarily at least, the logic that these stories are indicative of their story-teller's approach to achievement, it is clear that we have here with these two stories, an apple and an orange, that is, the two stories show great differences in the nature and strength of the drive to achieve and in the perception and attitudes toward external pressure to achieve. The first of these stories is not the story of a federal civil service executive at all. It was told by a business executive, in fact, an entrepreneur, the president and managing director of his own manufacturing company. It is typical of such men. The inner motivation to achieve - "he's always wanted to play the violin", "he's eager to begin"; the realization that work is necessary in order to achieve - "he will practice diligently many hours a day"; the pleasure derived from work itself - "it will not be all sacrifice on his part, for he looks as if he'll enjoy the work"; all these are clearly shown in the story.

The second of these stories was told by a high level career federal executive. It too is a typical story of our sample. Here the inner need to achieve is absent and in its place is a conflict between an external pressure to achieve - "his parents have insisted that he learn to play" and his desires, not for achievement in a different area, but for autonomy - "he doesn't want to". Note however, that he doesn't resist; evidently the authority from which the press to achieve emanates is too powerful - "he'd like to avoid it, but he knows he has to. And so, he'll pick it up and practice his lessons faithfully." This is expressed, in psychological jargon, as deference-compliance. That is, he gives in to the demand that he achieve, or rather, he gives in to the demand that he go through the motions to achieve. Now finally, we emphasize what this leads to, namely, <u>work</u>, that is, he will "practice faithfully"; <u>a certain level of achievement</u>, that is, "eventually he will even learn to play the damn thing, but only fairly well"; and <u>continuing emotional resentment</u> - that is, "but he'll never really like it."

When the stories to Card 1 of all 40 federal executives are examined, the over-all picture is to a considerable extent similar to that just presented. The majority see achievement as a conflicted issue. They are either pressed to achieve and don't want to, want to achieve but encounter obstacles, or need to achieve and yet want something else at the same time. In brief, achievement appears to be inseparable from strife.

And when we look at the stories to see how they deal with these conflicts, what sources the men mobilize to meet the difficulties which accrue to achievement, we find them to be essentially passive. The heroes of these stories want to resist but rarely do; they feel resentment and hostility but rarely express it; they fantasize possible actions but rarely take them.

As a result, the issue of achievement is resolved somewhat equivocally - most often the story ends, not with clearcut achievement, nor with clearcut non-achievement, but simply with a giving in, with an acceptance that one must do what one is told to do.

Let us now examine a second area of the dynamics of federal executives - that of the nature of their relation to maternal authority figures. The TAT stories relevant to this issue are those told about a picture that depicts an elderly grayhaired lady who stands with her back turned to a young adult man who is looking downward with a perplexed expression and holds his hat in his hand.

Generally, the federal executives tell two types of stories to this card. The first and most frequent deals explicitly with the classic theme of conflict between parental control and autonomy, between emotional dependence and the breaking of the silver cord. A typical story of this type is the following:

> This shows a mother and her son. The son has just announced to his mother that he intends to leave home and marry a young woman whom the mother does not care for. The young man is wavering about the situation, he feels badly about it. He finally makes up his mind. He will go. But he will not feel good about it.

The majority of federal executives who tell stories of this type portray their heroes as accomplishing the developmental task of breaking the emotional bond with the mother. However, at the same time, their stories show that the breaking away was not easy, that is was in fact, accompanied by feelings of guilt and self-doubt. Rarely is there any evidence that the future holds the promise of reestablishing their relationship with their mother on a new and mature level. Consequently, such stories suggest that although the son has indeed left home <u>geographically</u>, an emotional residue of dependence remains.

The second most common type of story told to Card 6BM runs like this:

> This is a son who has come to tell his mother that her husband has been killed or has died suddenly of a heart attack. She is in a state of shock, trying to think of what she'll do now that she is without her husband. The young man is concerned about his mother's future, worried about whether or not he should take her into his own home as he knows she'll be lonely.

Note please, not a word about his own grief, for it is at least probable that his mother's husband was <u>his</u> father! Stories of this type present the mother figure as stricken by tragedy and in need of aid and comfort by the hero. Yet the hero does nothing to sustain her. Instead, he suggests that he perceives the in-need-of-nurturance mother as a threat to his autonomy. The widowed mother may reactivate a conflict thought to be resolved.

In summary then, we may say that for the majority of federal executives of our sample, even when there is evidence that the struggle for independence from the mother has been obstensibly resolved by the hero leaving home, there remains the latent presence of an unbroken emotional relationship with the mother, a relationship which threatens to reappear if fate should force mother and son together again.

This finished our brief glimpse into but two aspects of the psychodynamics of the federal executive. We turn now to discuss several elements of the structure of Federal Civil Service as they are perceived by the executives themselves.

For the career civil servant by far the most important aspect of the organizational structure of the executive branch of the federal government is the dichotomy of personnel which exists regarding the functions of policy-making (in the sense of making decisions and setting goals) and the functions of administration (in the sense of carrying out or implementing policy.)

This division of function between the elected or appointed political executive who makes policy, and the civil service executive who carries out policy, is by no means a rigid one. Civil service careerists are well aware of the fact that their professional knowledge constitutes an important part of the basis on which policy is made. As one civil servant says: "Government would be in a bad way if it weren't for people who stayed with it and really knew the inside and outside. You can't depend on people who are in and out in a few years."

However, the division between the functions of the political executive and the functions of the civil service executive, though elastic, remains. And civil servants emphasize it:

> It is not fair or right for him, (i.e., for the civil service executive), to make policy decisions. The President selects men for this and the career man is the mechanic of the decision. That doesn't mean that you are a neuter or don't give advice. We help the boss make decisions. But a career man, it is not his prerogative, he is out of bounds if he begins to make policy. The man sitting across the chair has to face the public, the congress and the president, and there should be a clear line.

The executive quoted above voices what is the definitive essence of the role of the career civil service executive - he is the "mechanic of the decision." For, within the executive range, increases in level reflect increases in degree, not kind, in quantity of function, not quality. As you go up the executive hierarchy there is responsibility for a larger number of employees, for a larger geographic area, for a larger budget; however, in terms of both organizational and psychological dynamics, the task remains essentially the same - the carrying out of decisions made by others, the administration of policy.

Let's look now at another element of the structure of the federal civil service. The original purpose of the Civil Service's legislated tenure of job occupancy (it is not easy to be fired) was to preclude political control, thereby protecting its personnel from arbitrary displacement following change of the party in power. Though perhaps never envisioned by its creators, the careerists see the principle and fact of tenure as serving not only to protect them from political change but also from the vicissitudes of a free enterprise economy. Here is what two federal executives have to say about this:

> Being in private industry was a very dangerous proposition. I knew many people who had been employed in private industry and because of economic circumstances, either of the company itself or of the country, that their work had come to a halt and they had been put out of a job. Coming to work for the government, my employment was secure. Industry is a money-making thing. The decisions must be made from a purely economic standpoint. A person as a person gets more consideration in the government. If there was not work in my agency I feel sure that the government would find some kind of employment for me.

> The biggest difference between government and business is that you have the expectation in government that the organization will always need you and always have enough money to pay your salary. In private industry there's always a risk, in government you have your tenure.

We see then that the executives themselves choose as crucial two elements of the structure of the Federal Civil Service: first, the exclusion of policy-making from its functions and the exclusive commitment to being the "mechanic of the decision;" second, its legislated personnel system and subsequent canopy of protection via tenure.

I'm sure by this time, that you are far ahead of me in seeing the possible connections between the federal executive's perception of the Federal Civil Service's structure and those aspects of his personality we've discussed. But let me try to make two of those possible connections more explicit.

To begin, we've all heard the old saying - "Too many chiefs and not enough Indians." Perhaps its orginator was concerned with making a bureaucracy work. For, does a bureaucracy need chiefs or Indians? Would an executive with a high level of need achievement, with an insistence upon his autonomy, with a drive to set up and accomplish his own goals make a good "mechanic of the decision?" Or is the psyhcological base of the efficient administrator the willingness to follow orders or at the very least the begruding deference-compliance to do what he's told? Isn't it possible that what we have learned about how the federal executive feels about achievement, how he operates with regard to achievement is positively functional in terms of serving the purposes of the Federal Civil Service?

Or, to switch the direction of the connection for the moment, can we not see how the nurturant, protective personnel system of the Civil Service serves to fulfill the dependence needs of the federal executive who has never psychologically left home?

Such functional connections between personality, occupational choice and ability are crude I know. I hope they are not so crude as to strain credibility. For, if they make sense to you at all, they will lead you to a most important further point.

Dwarfed by his political superiors, and outside of the tradition of American free enterprise, it has been the lot of the career federal civil servant to be pinned against the wall in the glass case of a stereotype. The popular image of the civil servant is an unflattering one. It is that of a man who "doesn't have the stuff" for making it in the business world, who can't "cut the mustard", and hence has retreated from the aggressive world of competition into the security of the "can't-be-fired" system of the Civil Service. Underlying this negative image is the belief that civil service organizations are second-rate business organizations though they may be larger. The crucial structural and functional differences between then, with the exception of the protective personnel system, are ignored. Thus, the civil service executive is popularly seen as a second-rate business executive. His personality is defined negatively, he lacks qualities rather than possessing them. He lacks ambition, he isn't aggressive, he doesn't have the ability to make decisions, he doesn't have the drive for achievement. In other words, he doesn't possess the personality characteristics of the successful business executive.

As I have tried to make clear however, executive ability is a function of personality dynamics and skills <u>within</u> a social setting. And the very personality characteristics associated with success in the business world may be dysfunctional in the social structure of the civil service organization.

However, even if we insist that the particular personality characteristics of the federal executive that I've described <u>do</u> serve to aid him in the fulfillment of his duties, we can ask, of course, if there might not be others that interfere with his work, or at least, direct or bias it.

Those psychological characteristics - values, attitudes, psychodynamics - that distinguish a given professional group, do not appear by chance; there is a logic to them. Persons and professions seek each other out, first for training, then for practice. That is, professions attempt to select persons whose psychology is in harmony with their defining tasks, their social structure, and their ideology. Conversely, persons attempt to select professions the nature of whose work, social structure and value system they perceive to be in harmony with their personality. Thus, persons become professional apprentices or trainees because both they and their trainers anticipate man and job will be well suited. And the training period is used by both parties to test that relationship, and to increase the degree of "fit". As a result, a professional is far more than an expert by virtue of specialized knowledge; he is a man cut from a certain cloth - identifiable not only in terms of information and skill, but in his ways of perceiving and thinking, in his feeling, his beliefs, in his loyalties and his prejudices.

Little research has been done concerning the psychology of those professionals whose work involves them with environmental problems; rarer still is the study which explores how the psychological characteristics of such groups might influence their work with such problems. As an example of how crucial this influence might be, let us take a brief look at a study of how consulting engineers and public health officials perceive the persons and processes that would be involved in a community decision concerning a specific environmental issue - the use of renovated wastewater.

Because we were interested in identifying the unpremeditated feelings and attitudes of these two groups of professionals as well as their thought-through professional opinions, we used a projective test as a device for initiating discussion of the problem. Respondents were shown a picture in which seven adult men in business dress are grouped in various attitudes around a conference table. They were given these instructions:

> This is a picture of a meeting in a mayor's office which he has called to discuss the possibility of coping with an impending local water shortage through the use of reclaimed wastewater. I would like you to use your imagination and tell me a story about it. Who do you think are the various persons attending the meeting? What is going on at the moment? What are the men thinking and feeling and saying? How do you think this situation will turn out?

The first question we want to ask of the stories the men told is who did they see as attending the meeting? That is, what interests are represented, what professions have members present, and indeed, who has been left out?

Out of 12 ranked categories of persons identified as being present at the meeting, the first 8 are either executive-administrators or professional experts: the mayor, a member of the city council, a consulting engineer, a public health official, a water works superintendent, a member of either the mayor's or the city engineer's staffs, and a legal counsel. Overwhelmingly, the respondents restrict membership in the decision-situation to government officials and their professional consultants. Rarely are non-elected representatives of the public (such as, heads of community organizations) or representatives of business and industry (such as, the chamber of commerce) mentioned. Apparently, there is the conviction that the question of a solution to an environmental problem should be left to them, as experts, and to public officials. The people themselves - both the general public and organized public groups - are left out. This de facto exclusion fits with the disdain and fear of public opinion that Sewell [6] found to be characteristic of professionals.

Now that we know who is involved in the meeting, we can ask what went on? That is, who took what position on the question of using renovated wastewater, and why; who was for and against and what were their reasons?

Both professional groups are in complete agreement in their perceptions of themselves, each other, politicians, and the public. The consulting engineer is seen as the person most favorably disposed toward the reuse project (54 per cent), the public health official as most opposed (58 per cent), and the mayor as most neutral, undecided, or equivocal (76 per cent). These assignments of a preponderant position contrast sharply with the perception of "the public" which is seen as being more evenly distributed between positive (25%), negative (48%), and neutral (24%) attitudes. Clearly, both the engineers and health officials are far more certain of themselves and their professional brothers than of the unknown layman--at least in so far as the initial response to the idea of using renovated wastewater.

We have seen that the majority of both consulting engineers and health officials perceive themselves to be in opposition to one another. But these are general attitudes; what are the specifics, the causes (or rationalizations) of their positions. What are the distinguishing concerns of each professional group?

It is interesting that the professional sample most favorable to the idea of using reclaimed wastewater--the consulting engineers--is, at the same time, the group which finds it personally most repugnant: 46 per cent of them admit to feelings of revulsion, and it is their first-ranked concern. The next problems most frequently seen by engineers are three: unfavorable public reaction (28 per cent), health issues (22 per cent), and technical feasibility (24 per cent). This last figure is surprising; only a fourth of the engineers raise questions concerning their own area of expertise--the technical problems involved in direct potable reuse.

The same logic suggests that public health officials also respond somewhat unexpectedly--health issues involved in the use of renovated wastewater are not their first concern, that rank goes to their worried interest in what the public reaction will be (55 per cent). And indeed, their anticipation that the public may "cause trouble," is shown again in their concern about such a program's possible political consequences, an idea expressed with equal frequency (46 per cent) to that of their concern for health issues (46 per cent).

In sum, the two professional groups contrast greatly in the issues discussed at the meeting in the mayor's office. Engineers have but a single concern of first magnitude--that of expressing (and controlling) their feelings of revulsion to the use of renovated wastewater. While they acknowledge the problems of technical feasibility, public response and health, they do not emphasize them. Public health officials, on the other hand, are primarily concerned with three questions, of which health safeguards is but one; first and foremost is their anxiety over public response and political repercussions. Again, Sewell's research has anticipated these results:

> "The problem of consulting public opinion poses a somewhat different problem for the public health official than it does for the engineer. The effectiveness of the former in performing his tasks depends very much upon the extent to which his recommendations and regulations are understood and accepted by the public, and the extent to which he is able to overcome opposition (real or imaginary) from various groups."

We can now ask a third and final question of the stories: what is the meeting's final accounting? After the positions have been argued, who "votes" which way? The groups' concluding attitudes are much like the initial ones: twice as many consulting engineers (39 per cent) as health officials (18 per cent) favor the idea, and virtually twice as many health officials (68 per cent) as engineers (38 per cent) oppose it. What has happened in the course of the meeting is a shift toward a negative view; originally 54 per cent of the engineers were favorably disposed toward the water reuse proposal and only 58 per cent of the health officials were opposed. This movement is probably best viewed in the light of the professional conservatism--the well-known tendency of the invested professional to avoid the risk of change and to preserve the known and controlled status quo in his area of expertise.

The interprofessional differences that appear here are considerable. More than two-thirds of the health officials (68 per cent) are against the use of renovated water, only 18 per cent of them are for it, and then for the "crisis time only." This contrasts sharply with the final attitudes of the consulting engineers--as many of them are for it (39 per cent) as against it (38 per cent).

These differences are surely best understood from the differing perspectives of the two professions' areas of concern and their correlative differences in training. Consulting engineers are not directly involved with questions of public response or politics; their primary interest and responsibility is with the technical--its possibility and practicality. The public health official, on the other hand, is by definition responsible to the public. He must be concerned about its response. And further, the potential consequences of his approval of a program to use renovated wastewater are far more threatening. The spectre of a possible widespread disaster must loom large in strengthening the health official's resistance to an unfamiliar system. His risks are far greater than those of the engineer.

We see, then, that in telling stories about a hypothetical situation in which city authorities invite experts to consult with them on the possibility of a community program using renovated wastewater, consulting engineers and public health officials reveal their initial attitudes toward such a proposal, their perceptions of what problems might be encountered, their own personal concerns, and finally, their considered professional stance.

The data suggests strongly that when you ask for an expert's opinion, you get far more than you bargained for, far more, that is, than his purely expert judgment. You also get his professional fears and prejudices.

With that general point firmly in mind, and with the specific finding of these professionals' - particularly the public health officials - anticipation of a negative public response to the idea of renovated water also in mind, we can now look at a study that focuses directly on the question of public acceptance [7].

A study of what the general public thinks and feels about water reuse encounters formidable difficulties from the beginning. These are principally of two kinds. First, except in rare instances, people have had no experience with direct recycled water; both the questions and the answers must be hypothetical. The 'if...then' nature of such data suggests that their interpretations be approached with considerable caution. Second, psychological theory, previous research on water reuse, and the checkered history of public response to fluoridation [8], all strongly indicate that the possible reasons for how the layman may react to the idea of using recycled water are both numerous and diverse and that they trespass the confines of sociology, psychology, and political science.

Working within these acknowledged limitations, we had three aims: 1) to identify the nature and frequencies of public responses to the concept of recycled water according to its various uses; 2) to determine how such responses might be related to those standard sociological background characteristics of the sample (age, sex, race, education, social class, and religion) that previous research has indicated to be relevant; and 3) to attempt to break new ground by exploring a number of psychological variables seen as potentially determining acceptance or rejection of recycled water.

We'll discuss the findings relevant to each of these aims. First, 48% of the sample was willing to drink renovated water. It is important to emphasize that this finding reflects a minimal level of acceptance, since all other uses of reclaimed waste water are more acceptable. That is, as was anticipated, acceptance of the idea of renovated water depends in large part upon the particular use intended. Responses to the various uses presented to the sample population display three levels of acceptance that correlate with three levels of closeness to the self. Thus when usage involves internalization of the water, drinking or cooking, acceptance is at its lowest level, 48-51%. Acceptance increases to between 78-81% as one moves to the somewhat less intimate uses involving body contact: swimming, fishing, washing, and irrigation of food products. Finally, acceptance reaches its highest level as usage of renovated waste water is perceived as being most distant from the self; 96% approve of its use for irrigation of golf courses, and 94% approve of its use for industrial cooling. Contrast these figures with the public response anticipated by the professionals in the former study.

Our second aim was to see if we could relate acceptance or rejection of renovated water for potable use to social background factors. A most significant finding in several prior studies is the relationship of a person's attitude toward reuse and his formal education and knowledge of reuse. Generally, the more formal education a person has had, the higher the probability of his receptivity to using renovated waste water. Our study supports this relationship: 26% of the respondents with a grade school education or less approved of renovated waste water for drinking, whereas 63% of those with some college education approved of the idea.

Similarly, our study, in line with others, found a significant relationship between a respondent's knowledge concerning use of renovated waste water and his level of acceptance. Even at a minimum, some knowledge concerning the concept of recycling renovated waste water appears to have significant influence on a respondent's attitude. Of those respondents who could recall having heard about the notion of recycling renovated waste water, 52% were in favor of drinking it, whereas only 24% of those who were unaware of the possibility would accept it as a source of drinking water.

Our findings differed from previous studies however, regarding the connections between accepting renovated water and several other variables. Thus, changes in the price of water do not appear to affect significantly a respondent's willingness to adopt renovated waste water. Increases in the price of water in order to maintain conventional sources of supply did not have any statistically significant effect on public acceptance of renovated waste water. Regardless of the changes in price the vast majority were unwilling to change their attitude. Public acceptance may change, but not under the penalty of price increases.

Another thesis suggests that a respondent's attitude is greatly influenced by his perception of the quantity and/or quality of alternative sources. But our study suggests the absence of a relationship between consumers' perception of the existing source of supply and acceptance of renovated waste water. Respondents were requested to rate their drinking water according to five criteria:

overall quality to drink, cloudy material, taste, color, and odor. No relationship exists between his assessment of the five characteristics of water quality and his attitude toward renovated waste water.

We now turn our attention to the third and final area of the study -- determining what psychological variables might be active in influencing response to possible use of renovated wastewater. How does one examine such an area; the methodological problems are, indeed, formidable. A search of the literature and of test compendiums failed to produce any standard instruments measuring variables of obvious relevance. Consequently, for the pilot study, conceived as a hunting expedition, we developed a sentence completion test consisting of 29 items designed to obtain data on the following six dimensions:

1) Fear of, or disgust at, the incorporation of or contact with the impure. Manifestations would range from exaggerated health concerns to body waste revulsion. A sample item is: If I were eating an apple and dropped it on the floor, I would...

2) Faith in science and accompanying trust in expertise versus suspicion of technology and mistrust of scientific authority. An example is: When there is a problem concerning natural resources, the people to do something about it are...

3) Internal versus an external locus of control. That is, the sense of being autonomous and efficacious in dealing both with the self and with the environment in contrast to a feeling that life is controlled by forces outside the self, such as God, luck, or fate. An example is: Getting ahead in the world results from...

4) Modern, innovative, progressive approach to problem solving versus a traditional, conservative 'holding on' to established methods. A sample item is: In making progress, man has...

5) View of the world in which technology is seen as interfering with nature's or God's ordained system. Thus results a sense of the wrongfulness of manipulation of the environment. An example is: I believe that the practice of seeding clouds in order to make it rain...

6) Deep, essentially aesthetic commitment to the 'natural' as opposed to what is perceived as being artificial. An example is: Given a choice between aerosol whipping cream and the kind that one has to whip oneself, I would buy... because...

But out valiant effort was disappointing. Only two of the sentence stems produced responses that varied significantly according to whether the respondents accepted or rejected the idea of drinking renovated waste water. First, regarding the practice of seeding clouds to induce rain, 52% of those who approved of drinking renovated waste water viewed such technical manipulation of the environment positively; only 29% of those who disapproved of drinking renovated water did so. Second, on the sentence stem concerning fluoridation, 84% of potential drinkers of renovated water responded positively, as against only 70% of the nondrinkers. Both these differences are statistically significant, and both suggest that those respondents who accept the possibility of drinking renovated waste water are also those who possess a greater confidence in the effectiveness of scientific technology in addressing environmental problems.

But the difficulty with negative findings, of course, is that they are ambiguous; one never really knows whether they reflect a true lack of difference or whether they result from an insufficiently sensitive or erroneous instrument. If the researcher refuses to believe his results, he faces the accusation of displaying pigheaded tenacity toward his expectations; if he accepts them, he faces the accusation of using simple-minded and superficial measuring techniques.

Where are we left then, what can we say (and with what level of confidence) about the question of public acceptance to renovated wastewater?

The data I've reported here are consistent on two points. First, they reveal the presence of a relationship between public response to renovated waste water and what may be termed cognitive characteristics of that public knowledge and education. Second, the data show an absence of such a relationship with those variables labeled psychological. In brief, what laymen think and feel about using recycled water appears to depend primarily upon what they know about it and their general educational level rather than on unconscious fears of contamination or general belief and attitudinal systems concerning nature, technology, aesthetics, authority, progress, or destiny.

These findings immediately raise two questions. First, if variation in response to renovated water is related to variation in educational level so that the higher the education, the more positive the response, we would like to know why. What is it about education that would lead to a greater acceptance of renovated waste water? An answer is certainly not obvious, but perhaps it is reasonable to speculate that one relevant result of more education is increased confidence in science and technology as appropriate and effective means of coping with environmental problems. The two attitudinal items that were found to yield significant results support this argument.

The second major question raised by the findings of this study arises from the nagging suspicion left by the negative psychological findings. Can it really be that the public takes so reasonable or at least so intellectual an approach to the intimate use of waste water, to drinking what was once sewage? We worry that the preponderantly positive attitudes that we found might reflect in these days of environmental concerns a desire in our respondents to be ecologically responsible. Might not the reason of the layman when he is asked how he would respond if he were to use renovated water collapse when he is confronted with the actuality of using it? Confidence will require further research that puts the glass to his lips.

But this question and the suspicion that occasions it, allows us to come full circle and end where we began, for it illustrates my own professional bias as a psychologist. That is, my professional training, my socialization, my beliefs and ways of looking at things and assumptions - all dictate the conviction that surely there must be <u>something</u> unconscious at work in determining the layman's response to the use of renovated wastewater. Surely, it can't be as simple or so open a matter as that of knowledge and education. But if I would accuse the engineer and the public health official of projecting their biases when they speculated on the resistance of the public, I must have the grace to acknowledge my own bias in disbelieving what would appear to be the public's sweet reason.

REFERENCES

[1]Sims, John H., "The Federal Civil Service Executive: The Psychodynamics of a Social Role," American Psychological Convention Proceedings, September, 1969.

[2]Sims, John H. and Baumann, Duane D., "Professional Biases and Water Reuse," Economic Geography, 1976, (forthcoming).

[3]Sims, John H. and Baumann, Duane D., "Renovated Waste Water: The Question of Public Acceptance," Water Resources Research, 10, (August, 1974).

[4]Warner, W. Lloyd, et al., The American Federal Executive, New Haven: Yale University Press, 1964.

[5]Murray, Henry A., Thematic Apperception Test: Pictures and Manual, Cambridge: Harvard University Press, 1943.

[6]Sewell, W.R.D., "Environmental Perceptions and Attitudes of Engineers and Public Health Officials," Environment and Behavior, 3, (March, 1971).

[7]Sims, John H. and Baumann, Duane D., 1974, op.cit.

[8]Crain, Robert L., Katz, Elihu and Rosenthal, David B. The Politics of Community Conflict: The Flouridation Decision. Indianapolis: The Bobbs-Merrell Co., Inc, 1969.

CHAPTER VIII

OPPORTUNITIES AND CONSTRAINTS IN THE REUSE OF WASTEWATER

Donald E. Matchske *

This report will cover reuse in all its broad spectrums and will refer to various reuse activities research in the "Chicago-South End Lake Michigan (C-SELM) Wastewater Management Study." The C-SELM study was directed by this author for the Bauer Engineering, Inc. under contract to the Chicago District, U.S. Army Corps of Engineers.

At the onset of the study, we felt one of the best contributions that could be made was to take a look at water reuse and how it could tie into urban and regional planning. Thus, it addresses itself to the idea of regional solutions of wastewater related problems. The region encompasses over 2,600 square miles of area and includes watersheds of four major river sytems (Fig. 1). Politically, the C-SELM study impacts on seven counties located within the two states and also affects a host of other agencies with political powers. Demographically, it impacts on a current population of eleven million by the year 2020. It envisions this population living in densely populated urban centers, suburban areas with lesser density, and loosely populated rural areas. And technically, it involved the study and implementation of a number of types of water reuse.

As I go through the opportunities for reuse and the constraints on reuse, I will refer back to the C-SELM study and show some examples of the work products that came out. I will follow along the outline of Table 1, highlighting opportunities for reuse and also the possible reuse constraints in the following areas: potable supplies, recreation, navigation, irrigation, energy dissipation, industry, and industrial-municipal reuse.

*

Figure 1

CHICAGO-SOUTH END LAKE MICHIGAN
WASTEWATER MANAGEMENT STUDY AREA

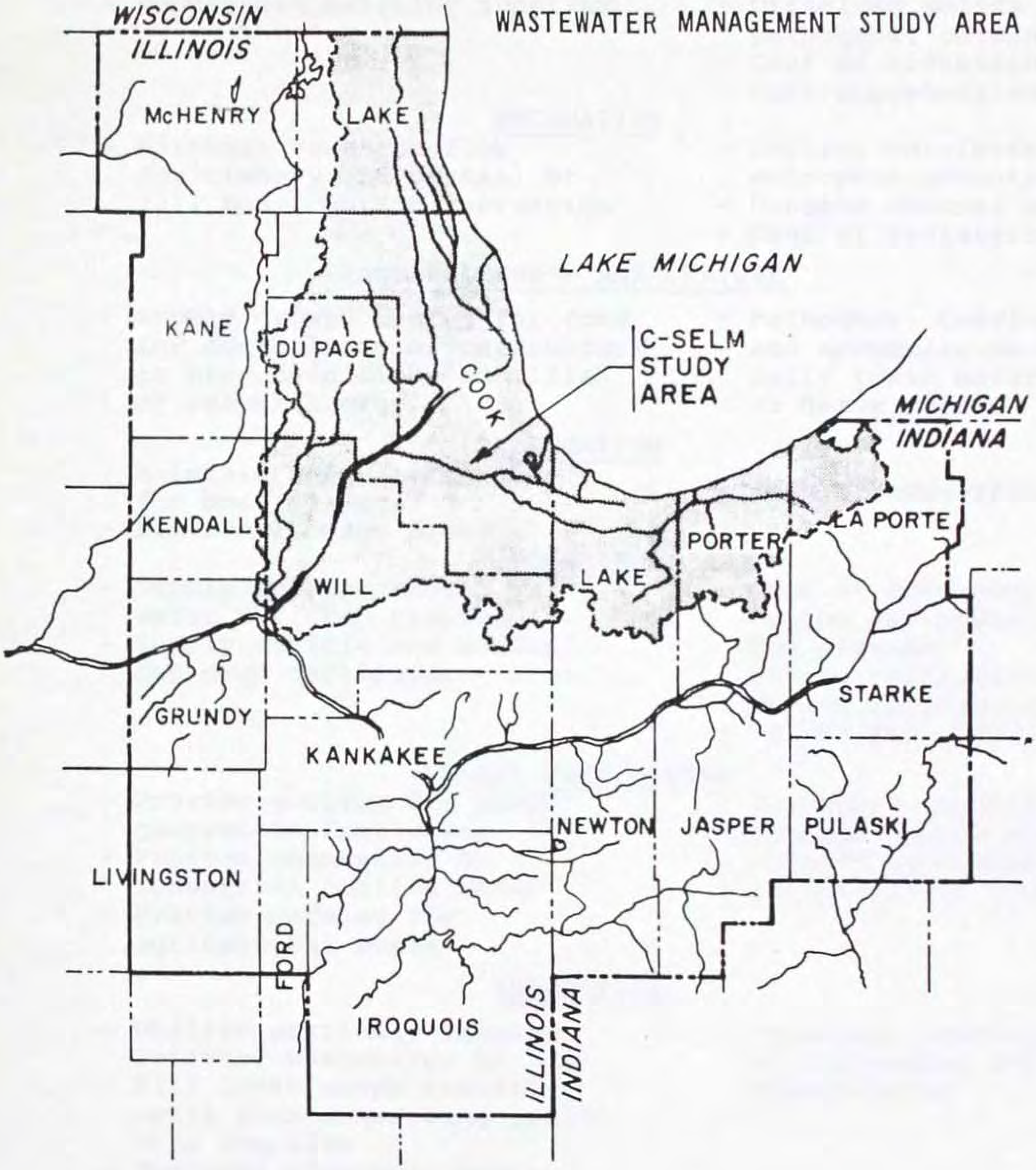


TABLE 1

REUSE OF WASTEWATER

Possible Reuse Opportunities	Possible Reuse Constraints
POTABLE	
- Supplement existing supplies	- Dissolved solids (TDS), pathogens, carcinogens - Cost of redistribution - User apprehension
RECREATION	
- Maintain required flow for fishery and partial or full body contact recreation	- Control nutrients to minimize eutrophic potential - Observe channel erosion limits - Cost of redistribution
AGRICULTURE - MARACULTURE	
- Supply growth medium for food for aquaculture or maraculture to produce a fish, shellfish or crayfish crop	- Pathogens, carcinogens and accumulation of potentially toxic materials such as heavy metals
NAVIGATION	
- Maintain adequate depths for boat passage - Provide lockage flows	- Cost of redistribution
IRRIGATION	
- Supply optimum amount of water for crop growth - Supply vehicle and source for crop fertilizer	- Cost of conveyance distribution and possible drainage systems - Likely restrictions to non-direct food-chain crops - Farmer reluctance
ENERGY DISSIPATION	
- Provide cooling for power generation facilities - Provide commercial or industrial cooling water - Provide warming for agricultural soils	- Increased evaporative loss - Storage lagoon size related to cooling load - Increased TDS concentration
INDUSTRIAL	
- Utilize partially treated internal wastewater to fulfill fresh water requirements thus conserving available supplies - Minimize treatment costs	- Increased concentrations of refractory and TDS constituents
INDUSTRIAL - MUNICIPAL	
- Utilize municipal sewage treatment plant effluent for supply of industrial process and cooling water	- Observe industrial process water quality requirements - Increased TDS concentration

POTABLE SUPPLIES

The necessity of an adequate potable water supply for satisfying all the needs of a community is self-evident. Potable water should be free from turbidity, color, odor and from any objectionable taste, and should be of reasonable temperature. There is also a more exacting set of quality specifications that quantitatively define potable water quality in terms of chemical and biological constituents. Such water is termed potable or "drinkable" meaning that it may be consumed in any desired amount without concern for adverse effect on health. Long-range plans for any community must by necessity include planning for the supply of this high-quality potable water resource at a reasonable price.

Supplementing Existing Supplies

Long-range plans of communities within the C-SELM study area recognize this need and outline possible future sources of supply. The sources are: groundwater, Lake Michigan water, renovated stormwater runoff, and renovated municipal and industrial (M & I) flows.

Groundwater supplies are not being replenished as rapidly as they are being drawn down, and the difference between withdrawal and recharge is growing each year. Probably the most important reuse consideration, however, is the current United States Supreme Court limitation on withdrawals from Lake Michigan by Illinois residents. The Supreme Court limitation of 3200 cfs places a definite restriction on the quantities of water available to the densely populated urban and suburban areas of Northeastern Illinois. However, the State of Illinois can petition to have the diversion limit increased if it can show that all available supplies are being prudently managed and that the inadequacy of the available supply is imminent. Stormwater runoff and M&I flows can be but are not, at present, sufficiently renovated for potable reuse.

The balance between the demand for water and the available supply is already upset in some parts of C-SELM region and will become more pronounced as the C-SELM design target dates of 1990 and 2020 are approached.

In order to supply the increasing demand for potable water, all the available water supply sources will have to be fully developed and appropriately utilized in the future. The most important sources are: (a) Lake Michigan water, (b) groundwater obtained from wells, (c) stormwater renovated via rural stormwater management systems and (d) renovated municipal and industrial flows including suburban and urban stormwater runoff from treatment plants or land treatment sites.

Water Quality

TOTAL DISSOLVED SOLIDS. A water quality concern with respect to the reuse of reclaimed flows for potable supplies is the concentration of total dissolved solids (TDS). TDS also impacts on the possibility of return of reclaimed flows to Lake Michigan.

The values of TDS concentration found in each source of potable supply is different. In order to balance the TDS concentration, a mix of flow supplies was established within the service area. The purpose was to balance the two service areas with respect to TDS concentrations.

The present TDS concentration in Lake Michigan is approximately 160 mg/l. Regional AWT reclaimed water TDS concentrations are in a range between 500 and 535 mg/l, depending on the treatment technology in question. Rural stormwater and groundwater concentrations are projected to be 130 mg/l.

Standards for drinking water quality, as established by the 1961 revision of the Public Health Service Drinking Water Standards, lists a recommended maximum limit for TDS at 500 mg/l. The World Health Organization sets the potable limit for TDS at 750 mg/l. Many areas in the western parts of the United States have 1,000 to 3,000 mg/l of TDS in their potable supplies. A threshold concentration (a value which might normally not be deleterious to fish and other aquatic life) of 2,000 mg/l TDS has been established as an upper bound for healthy aquatic life in fresh water.

It is evident that a great deal of difference exists between the present TDS in Lake Michigan and the higher levels of TDS considered acceptable. Nevertheless, if the total quantity of dissolved solids discharged into Lake Michigan per year remains as at present, and the management of flows into and out of the lake also remains unchanged, a steady rise in the TDS concentration in the water in the lake can be projected such that a concentration of 500 mg/l could be reached in several hundred years.

There are ways in which such an inevitable rise in TDS could be mitigated. For example, Lakes Michigan and Huron are now at all-time highs such that substantial lowerings would be desirable. If all discharges into, for example, lower Lake Michigan could be avoided during such wet periods, some reduction in maximum lake level could be achieved and the average rate of increase in TDS could be substantially reduced.

During periods of low lake level it would be desirable to return treated flows to the lake to mitigate the effects of low lake level. A return of 3,000 MGD to the lake for 10 years adds a volume equivalent to one foot of depth over the approximately 50,000 square miles of Lakes Michigan and Huron. This foot of depth could be useful and beneficial during such dry periods.

In summary the TDS questions are particularly troublesome because, as a result, the C-SELM design must undertake to keep all of Illinois' reclaimed water out of Lake Michigan, while, at the same time, the United States Supreme Court limits the Illinois diversion from Lake Michigan. This also influences the C-SELM design to return all Indiana reclaimed water to Lake Michigan. Not only does this appear to be an inconsistent policy, but it adds materially to the cost of reuse systems envisaged in the study.

TOXIC MATERIALS. Phenol is an example of a potentially toxic ingredient in drinking water. The safe level of phenol concentration in potable water supplies is typical of the water quality questions that arise from time to time. The best knowledge that is available in the literature pertains to a 0.001 mg/l phenol concentration which is based on nuisance and odor and not on human health criteria. If you were to ask a public health official for a safe level for human consumption, he might answer 0.1 milligrams per liter. This writer has made an intensive search for the basis upon which 0.1 mg/l phenol concentration in water is held to be safe. The only studies uncovered to date demonstrate the adequacy of this limit for fish life.

I personally am on the edge of an issue with a group of clients because I have had to inform them of our state of knowledge. They are very concerned people, some of whom have their potable groundwater supplies contaminated with phenol from a spill, who are drinking water or being asked to drink the water, and being told by the state and federal government that water is safe at 0.1 milligrams per liter phenol concentration. My advice to clients has instead been based upon natural background levels of phenol occurring in the area groundwater at up to 0.100 mg/l phenolic substance concentration. Concentrations at levels in the vicinity of or greater than 0.010 mg/l are my recommended level for concern and for reliance upon alternative potable supplies until the problems are identified and rectified. The complete answer to this question, "what is the safe concentration of this or many other potentially toxic materials?" is just not available because scientists have not yet tackled the problems.

<u>Distribution</u>

Another most important constraint is distribution. The trend today is to regionalize, to abandon smaller treatment plants and go to fewer and larger plants with more advanced technologies and further removed from the tributary population. If reuse of water is desired for potable or other uses, I suggest that such regionalization poses a very awkward situation.

After regionalization it is then necessary to build a convenience system that will return the water back to the population. Thus a longer pipe is built both ways. This problem did occur during the C-SELM study. Regardless of the technology being used to treat the water, the feasibility of operation will relate back to the cost of conveyance and redistribution system of reused water. I suggest that when setting down plans for management of the water resources, water reuse and distribution should be incorporated in the future vision.

User Apprehension

User apprehension can be a most important factor in potable reuse. Often the technical merits are not the decisive factor in whether potable reuse of water can become an immediate reality. Personal preferences in some instances can be afforded if other, albeit more costly, water resources are available. Since the C-SELM is not at present a water short area, this remained largely an esoteric issue to be grappled with sometime in the future.

RECREATION

Recreation is another type of reuse that may be developed. One opportunity is maintaining the required flow for fisheries and another is water for partial or full-body contact recreation. If you happen to think that maintaining stream fishery habitates is a well understood subject, or something very easy to arrive at, then I suggest that you ask your fisheries expert. What you would like in the way of stream flow and at what times of the year you want it, and what is required in maintaining a profitable fishery are very difficult questions, apparently, to answer. In the C-SELM study, we had difficulty in arriving at meaningful kinds of criteria. If you're going to use renovated water for recreation, you would like to be able to sustain the fishery and not say you're going to sustain it and find it to be an impossible task.

Recreational flow needs were determined from observations of existing flow regimes in selected streams within the C-SELM area. Supplementary flows were then designed to be supplied to designated streams through pipes to headwater and downstream supply points to provide a year-round base flow.

To meet mimimum flow requirements, flows were supplied to area streams at locations called injection points. These points are selected on the basis of best service for recreational needs within the C-SELM area. Actual flows supplied to injection points are between minimum and maximum desirables and are based on total flow available for reuse. Recreational flows are supplied from reclaimed M & I flows from either treatment plant or land treatment systems.

There can be many constraints in maintaining recreational water areas. One, and I believe one that is often neglected, is the potential for channel erosion. The C-SELM area has significant susceptibility to soil erosion. These problems often arise in new sub-division developments in the areas where local small creeks and drainage ways have been relocated to aid development. Significant levels of sediment erode in Spring and Summer. This is not a manifestation of natural processes but instead due to soil sediments washed out of the newly-excavated areas. Will the fact that you're providing a steady flow of reuse water continue the erosion, stop the erosion, or is the erosion going to create problems with the recreational quality standards?

The fishery managers will perhaps stipulate certain depths of water that should be maintained and that will require higher flows. At the same time, the types of soils in the area may not tolerate the higher flows which will result in major erosion problems. The depths of water you can control for one purpose may cause all kinds of problems for another purpose. For example, in the C-SELM area, there is a naturally slow streamflow, while the optimum range that the fishery managers want is a good deal greater. This raises the question of restructuring nature and perhaps not doing a good job.

Water Quality

Recreational water quality concerns center mainly around the establishment of a viable aquatic community and the creation of an aesthetic visual resource. The aquatic considerations are greatly enhanced through the establishment of permanent flows of high quality reclaimed water in the area streams. The prevention of unregulated and untreated stormwater flows from reaching the stream system helps to insure the quality of the streams established through the injection of recreational reuse flows.

In addition to established flow regimes, it is equally important to consider the quality of the water which is being reused to establish the aquatic community. Any action which might interrupt or overstimulate the natural food chain in the aquatic community at any level is serious to all organisms higher up on the chain. The nutrient or "fertilizer" concentration in the various NDCP (No Discharge of Critical Pollutants) reclaimed waters associated with the treatment technologies presented in the C-SELM study are not so low or so high as to cause this type reaction in the stream system.

Another concern in any aquatic system is the suffocation of aquatic organisms by lowered or completely removed oxygen concentrations. For this reason the Biochemical Oxygen Demand (BOD) and oxygen relationships of the reclaimed water are very important. This is of no concern in the systems envisioned for reuse since, in addition to the extremely high quality of the reclaimed water with respect to these particular parameters, the very action of delivering the waters to the streams enhances their dissolved oxygen content. For example, additional aeration could be accomplished by an injection point mechanism which induces further aeration by passing water over a series of steps, or small rapids as it leaves the injection pipe.

NAVIGATIONAL REUSE

With navigation, we have one obvious need for maintaining sufficient depths for vessel passage. We have a second incentive, to conserve fresh water supplies, which may or may not have some value in the areas in which you may be concerned, for providing renovated water for lockage flows. In a regional area like Chicago, a great deal of water is actually passed through lockages because of the procedures by which locks are manipulated. By markedly introducing reused flows and by using air curtains to make sure that the reused water doesn't diffuse back into the fresh water supply, you can indeed accomplish some very significant conservation of fresh water with the use of reused water. In the case of the C-SELM study, some sixty million gallons per day of fresh water were conserved.

Navigational flows are based upon individual lockage requirements. This is a reflection of the actual number of lockages in any specific period. In addition to the pump-back, closed-lockage system designed for the C-SELM study, an air-bubbler system, designed to prevent any mixing between reuse flows in the streams and Lake Michigan at the lock interface, is provided. This system is provided at each end, or gate area, of the locks. A diffusion system is envisioned. Compressors deliver air to a bubbler manifold located on the bottom of the lock, at a rate sufficient to establish a barrier to intermixing.

Pump-back facilities are designed to empty or fill the standard lock chamber within a period of four to five minutes.

Navigational (and recreational) flows are supplied through a complex distribution system, which may be very costly in some areas and which may be a very important constraint in this type of water reuse development.

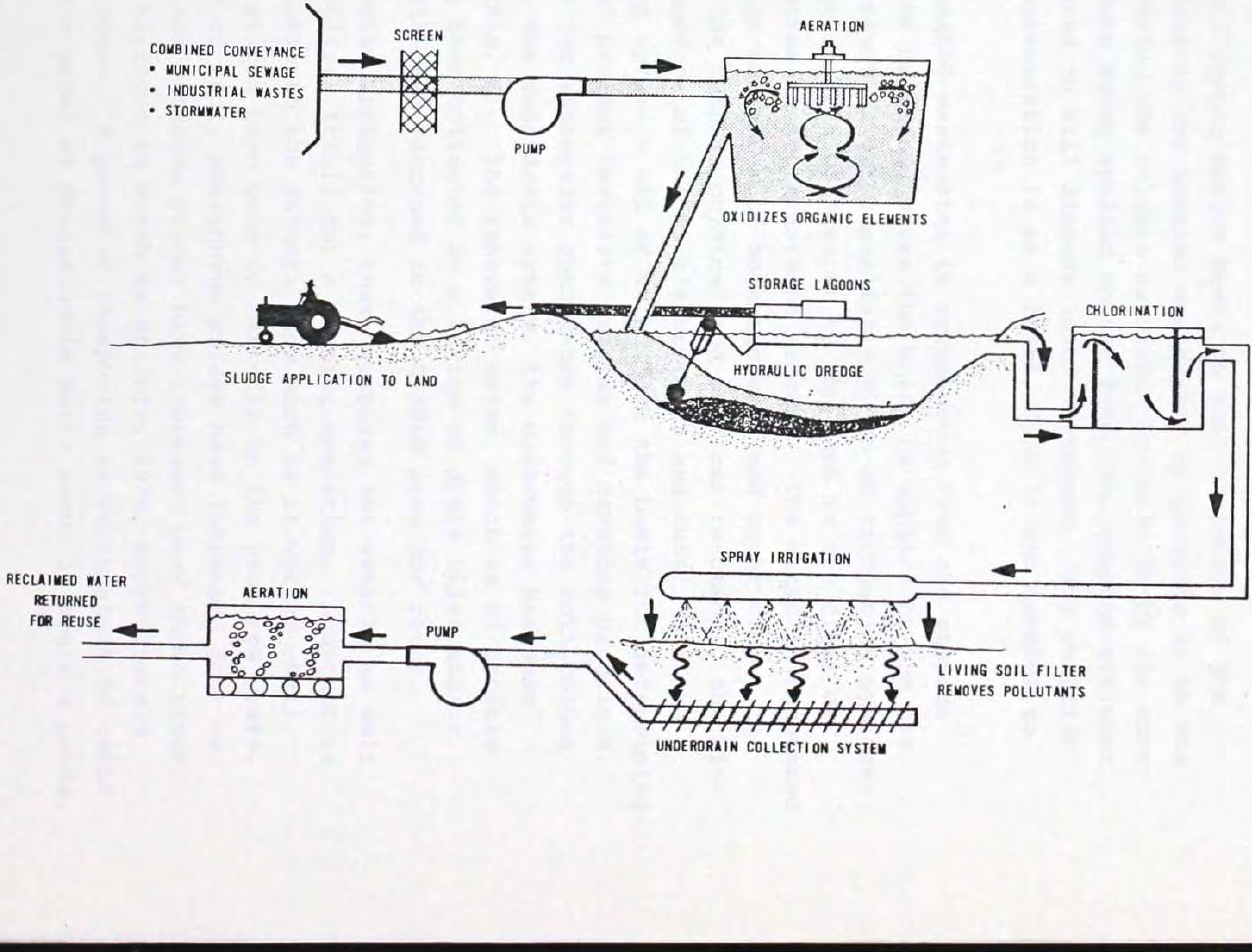
IRRIGATION

The land treatment system can be described in terms of the operational functions of its physical parts (Fig. 2). Aside from the pipeline network transporting the raw wastewater from the metropolitan area to the land treatment site, the first part consists of two types of lagoons connected in series. In the first or aerated lagoon, oxygen is added by mechanical aerators and mixers which constantly aerate, mix, and churn the raw wastewater. The added oxygen provides the necessary environment for microbial organisms living in the water to decompose municipal and industrial wastes, thereby transforming the organic and soluble wastes into suspended solids. The treated wastewater is then transferred to a much larger storage lagoon where the suspended solids settle on the bottom. There the solids or sludge continue to be broken down by further bacterial action until the solids residue is relatively stabilized. The stabilized sludge, which is high in nutrient and organic value, is then removed for subsequent reuse. This sludge can be used either on the adjacent farm lands as a source of fertilizer for agricultural production or transported outside the land site area where it may be used as a source of organic material for improving soils and disturbed areas (e.g., strip mined areas) having low existing productivity.

At this point in the process the wastewater has received the equivalent of primary and secondary treatment. This is the same level of water quality currently being achieved by most of the major sewage treatment plants in the study area. At present the treated wastewater from study area treatment plants is discharged into nearby streams. The wastewater, however, is still rich in the plant nutrients carbon, nitrogen, phosphorus and potassium. If discharged directly into a stream, the carbon, nitrogen and phosphorus would stimulate growth of aquatic plants in the stream. Thus, during the cycle of growth and decomposition of these aquatic plants, dissolved oxygen in

Figure 2

LAND TREATMENT COMPONENTS



the water would be periodically depleted sometimes to the point of causing a fish kill. This phenomenon of abundant aquatic plants coupled with oxygen depletion is commonly called "eutrophication."

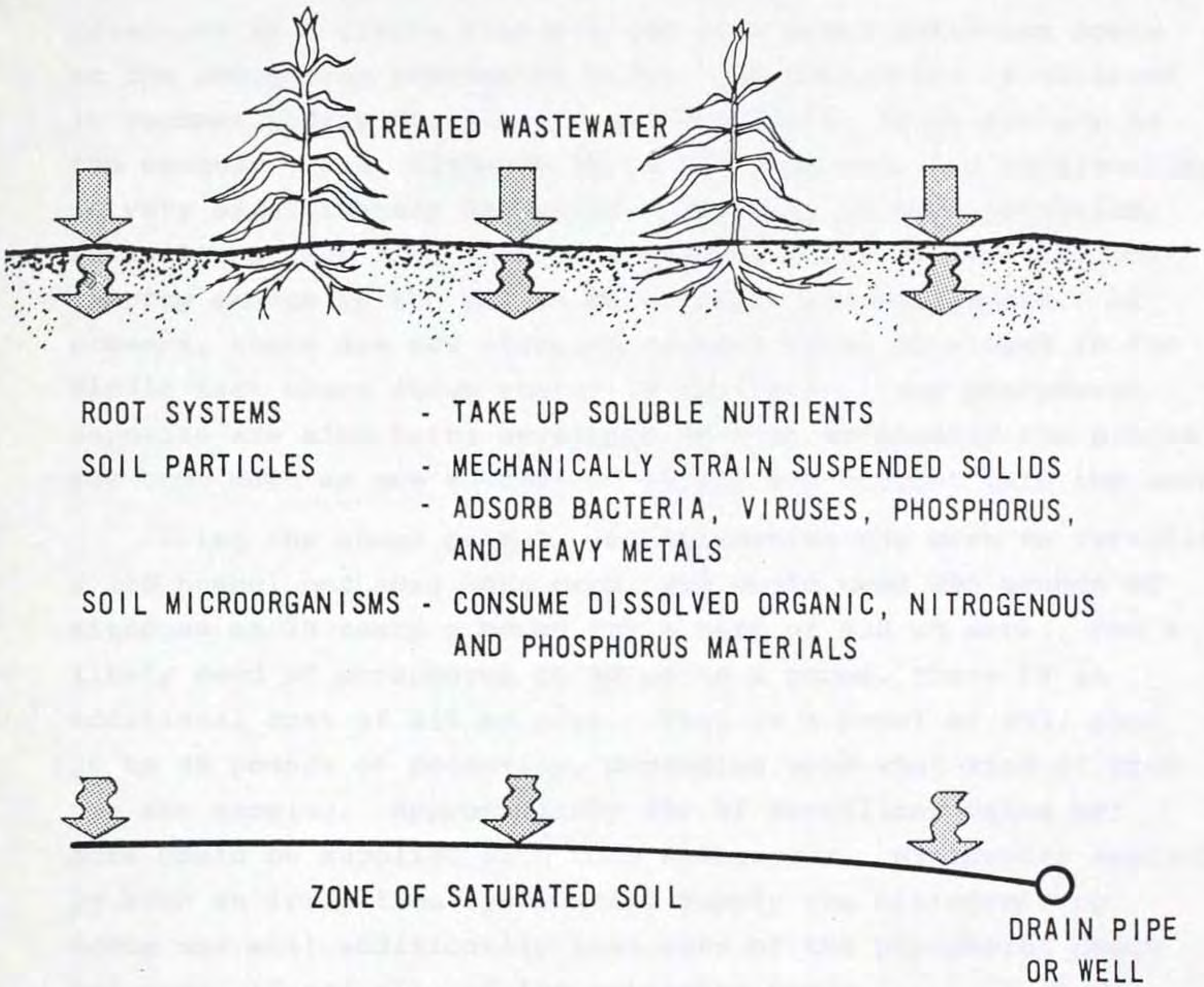
The land system design seeks to take advantage of the nutrient value in the treated wastewater by spraying it on the soil and letting the soluble nutrients be taken up by the crop cover. Before being applied to the land, the treated effluent is chlorinated to kill disease level organisms. The chlorine residual concentration is at a level which is not harmful to the crops.

The treated wastewater is transported from the storage lagoon to the croplands where the water is applied by the use of a centerpivot or other available types of irrigation systems. Applying the treated wastewater to the land is the final or polishing stage in the treatment process. The water is renovated by the entire biosystem of both the soil and cover crop. Involved are the complex physical and chemical reactions, the biological processes of the soil's bacteria and fungi, and the natural crop uptake - all of which form the basis for determining the farmers' present fertility program and cropping practices. By the time the wastewater percolates through the soil column and reaches the underdrain system, the wastewater has been renovated (Fig. 3). The renovated water, which is of potable quality, is then collected by a system of drain tiles and/or drainage wells and returned to the C-SELM area for reuse.

Wastewater irrigation, thus, supplies the vehicle as well as the fertilizer itself for a farming operation. And that is very profitable to the farmer. How much is it worth? Well, fertilizer prices have gone up markedly in the past few years. As a matter of fact, phosphorus prices have increased four or five times and nitrogen prices have increased over three times. A pound of nitrogen is worth as of July, 1975, approximately 15 cents a pound. A pound of phosphorus is worth about 50 cents a pound and a pound of potassium is worth about 10 cents a pound.

Figure 3

LAND TREATMENT PROCESS



Because nitrogen fertilizers are very energy dependent, we are not apt to have a great increase in nitrogen production for some time. Phosphorus is a material that can only be mined and developed as a finite resource and with great pollution costs at the phosphorus processing point. As phosphorus is utilized it becomes widely distributed and eventually finds its way to the oceans. This, although it is not consumed, its availability is very significantly decreased. Thirdly, we have potassium. Potassium prices have been more stable, while we look for continuing change in the prices of nitrogen and phosphorus. At present, there are new nitrogen sources being developed in the Middle East where cheap energy is available. New phosphorus deposits are also being developed so that eventually the prices may come down as new sources of supply are brought into the market.

Using the above prices, and estimating the cost to fertilize a 150 bushel per acre corn crop, you would need 200 pounds of nitrogen at 15 cents a pound for a cost of $30 an acre. For a likely need of phosphorus at 50 cents a pound, there is an additional cost of $15 an acre. That is a total of $45, plus 30 to 60 pounds of potassium, depending upon what kind of crop you are growing. Approximately $50 of fertilizer value per acre could be supplied with this wastewater. Wastewater applied by such an irrigation system will supply the nitrogen crop needs and will additionally take care of the phosphorus needs and most, if not all, of the potassium needs.

The agricultural utilization of sludge employs sludge as a fertilizer or soil conditioner and is applied to the agricultural land at a controlled rate on a yearly basis. Both biological (organic) sludges and physical-chemical (inorganic) sludges can be applied to the land for agricultural utilization. Inorganic sludges are used for their acidity control and soil conditioning values.

Application Rates

An optimum sludge application rate for the agricultural utilization of conventional and land treatment sludges over a 50-year period is 13.5 dry tons/acre/year(Table 2). For advanced biological sludges, the corresponding rate is 28.8 dry tons/acre/year. The sludge application rate is adjusted so that the total nitrogen applied to the land is equal to the nitrogren uptake of crops plus the nitrogen lost through volatilization and soil denitrification. Increasing the organic nitrogen content of the topsoil is ignored as a means of consuming additional nitrogen, as a limit could be reached in this process before the end of the design 50-year period. Thus a maximum crop yield can be expected without a simultaneous groundwater pollution problem. The 50-year accumulations of these sludges is not expected to produce excessive accumulations of the associated heavy metals, based upon existing test experience over periods of years.

The optimum sludge application rate for the agricultural utilization of physical-chemical sludge is a 1.73 dry tons/acre/ year. This application rate is determined by the alkalinity of the sludge.

Land Ownership

What are the constraints on land treatment? The price of land is currently high in many areas. The ideal situation for cities is to provide supplemental wastewater to a farmer who needs more water to grow his crop and who is willing to pay for the wastewater. The city would not buy the land in this case, and there would not be the cost of the land but there would be the cost of conveyance of the water to the farmer. This type of system is possible in arid parts of our country. If, on the other hand, the irrigation system is part of a city wastewater treatment system in a humid part of the country, the first purpose is to treat the wastewater. In this situation, the city or other unit is desirous of acquiring the right to use the

TABLE 2

CHARACTERISTICS OF WASTE SLUDGE AND

LAND APPLICATION RATES

Types of Sludge	Yield Dry Tons/ MG	% Solids for Pipeline Transmission	Agricultural Application Rate Dry Tons/Ac/Yr.	Accumulation in 50 Years Dry Tons/Acre[b]	Land Reclamation Application Rate Dry Tons/Acre	Accumulation in 50 Years Dry Tons/Acre
Advanced Biological	1.64	6	28.8	1,440	213	213
Chemical-Physical	1.13	10	1.73	86.5	-	-
Conventional Biological	0.77	6	13.5	675	100	100
Land Treatment	0.77	6	13.5	675	100	100

[a]These sludges are all amenable to greater dewatering. This would be appropriate for alternative transportation systems such as unit train or barge transport.

[b]The amounts are believed to be acceptable from the point of view of accumulations of heavy metals which accompany all sewage sludges. These metals are kept largely insoluble by maintaining a pH of about 7.

land for irrigation of the treated wastewater by paying the owner a lease or rental price which is mutually agreeable to both parties and which encourages the farmer, whoever he might be, to continue to farm the land. I strongly urge that you consider the rental of the land, because it allows the farmer to continue his association with the land and to continue as a farmer. There are many ways in which you can design a system that is compatible and encouraging for the farmers to accept.

Distribution

The cost of conveyance to and from an irrigation site can be very great. It is advantageous to have the irrigation and treatment site as close as possible to the sources of the raw wastewater. The closer it is the least costly it is. To be right on the periphery of a town area is ideal because there is a short conveyance and a short return distance.

Restricted Use

There may exist local institutional restrictions for the use of wastewater irrigation on some varieties of crops. Likely it may only be applied to non-direct food chain crops. I include the word likely because it depends upon the state. In Illinois and Michigan and other Midwest states, they will not allow you to apply chlorinated or non-chlorinated secondary wastewater to anything other than crops that are used for animal feed such as grass or feed grains. These will consider application, however, to sugar beets or some other product that undergoes a processing step prior to direct human ingestion. Other states have different restrictions. In California, for example, wastewater is being used to irrigate nut trees and tomato crops. I personally feel this can be a problem if abused, but I also feel that you can apply directly to most crops, if, in fact, you follow reasonable precautions of washing prior to use. Individuals at present, however, do not have the freedom to decide on that issue; instead it either will be, or has been decided for you at the state level.

Soil Quality

VIRUS AND PATHOGENS. These are removed by the same mechanisms that remove suspended solids since they are, indeed, microscopic suspended solids. Various investigations have determined that once these constituents have been captured in the soil mantle, they do not long persist. Apparently, the soil environment is not conducive to their survival, perhaps because the indigenous solid microorganisms are too acclimated and competitive to permit a less than indigenous species to survive. A properly designed soil process irrigation system is capable of doing a 100 percent effective job of disinfection for the reclaimed water.

HEAVY METALS. Heavy metals are ion exchanged/adsorbed by the clay constituents of soils and are chelated by the organic constituents of the soils. Once captured by the soil, they are held irreversibly in the normal soil experience, requiring varying degrees of acidic leaching to effect their release. Within certain limitations prescribed by agricultural experience, small residual concentrations of most metals are compatible with soils and can be almost completely removed by soils. As the organic concentration of soils decompose, new and more stable soil organic matter is being formed with continuing heavy metal holding power, so that in a "living filter" type of soil system there appears to exist an unlimited life sink for controlled amounts of heavy metals.

CHLORINATED HYDROCARBONS, PESTICIDES AND PHENOL. These substances are captured in the soil by adsorption mechanisms much like other dissolved organics and subsequently converted to new cell material and gaseous carbon dioxide by aerobic microorganisms. The acceptable concentration of these constituents in the solid and wastewater system must be substantially controlled and regulated by pre-treatment, however, much like the limitation on heavy metals. These organic species are largely inimical to the soil microorganisms, and to abuse the soil system with an overload would eliminate the very micro-organisms that accomplish the adsorption and ultimate disposal. The pre-treatment afforded by the municipal biological system in producing a secondary effluent is sufficient guarantee against excessive concentrations of these species.

TOTAL DISSOLVED SOLIDS. Exclusive of the species heretofore discussed, TDS pass through the soil process unaltered. Typical of constituents in this category are sodium, sulfate, and chloride. Potassium is largely extracted by the crop root system for crop growth.

Farming Implications

The implications of adapting the land treatment system to the farmer's needs and life style are the concerns of the designer and certainly the farmer himself. Similar to any irrigation system, there are specific operational controls which have to be maintained if the treatment process is to function properly. Consequently, an interest in the farmer's land would have to be acquired for an extended period of time. This limited interest would require the farmer to agree to the following: (1) to accept a certain amount of treated wastewater within a specific time framework; and (2) to grow and manage those crops suitable to the system's needs. In all cases, the major objectives are to insure proper utilization of the nutrients, particularly nitrogen, and to insure that maximum crop yields are attainable.

In return for participating in this system the farmer can expect to obtain a yearly gain in net income. Presently the average harvested yield, for corn on well managed farms in the counties where the C-SELM study land sites were located, is 135 pushels per acre. With the installation of the proposed system and application of the equivalent nitrogen, phosphorus, and potassium budgets for 200 bushels per acre corn; and assuming a 15 to 20 percent field loss, it is anticipated that an average yearly yield of 165 bushels should be harvested from each acre. Based on an average market value of $1.06 per bushel, the farmer's net income should increase by $31.80 per acre. Furthermore, there should be a net savings in out-of-pocket field operational costs. This is only part of the total savings in production costs and does not include equipment depreciation and other allied operational and overhead factors. The anticipated savings in field production cost is estimated to range from $11.05 to $11.55 per acre, depending upon the type of tillage method employed. The basis and derivation of these net savings is shown in Table 3. Not included is the net labor saving of 1 day or at least 10 hours per 10 acres that can be achieved using the no-tillage system. This labor saving estimate obtained from a local farmer actually utilizing both tillage methods on his 700-acre farm, correlates very well with other time saving estimates prepared by various University and Extensive Service studies.

Based on the foregoing it is estimated that the farmer should be able to increase his net income anywhere from $42.85 to $43.35 per acre. No income allowance gained from the marketing of a rye forage second crop has been included; the value was assumed at this point in time to offset the cost of harvesting. The cost of aerial inter-seeding and installation, operation and maintenance of both the irrigation and drainage systems was expected to be borne by the legally-designed operating entity, not the farmer.

The option of using the spray rigs for applying herbicides to the irrigated areas can be made available to the farmer at no cost other than material costs themselves. This may prove to be the most efficient application technique both from a cost and use standpoint. This latter factor can have significant meaning in light of the current concern over the use of insecticides and herbicides.

TABLE 3

PRODUCTION COST COMPARISON[1]
($ per acre)
Field Corn Only

Field Operation	No Irrigation	With Irrigation	
	Conventional Tillage	No Tillage	Conventional Tillage
Fertilize (excludes material cost)	1.10	1.10	1.10
Plow (moldboard)	4.85	--	4.85
Disk and Drag	2.50	--	2.50
Plant	2.60	5.00	2.60
Spray herbicide	1.50	1.50	1.50
Cultivate	1.70	--	1.70
Harvest	8.10	8.10	8.10
Materials: Fertilizer & Insecticide[2]	28.00	12.00[3]	12.00[3]
Herbicide	4.00 (band)	12.00 (broad-cast)	5.00 (broad-cast)
Seed	10.80	13.20	12.55
Hauling, Storage & Drying	5.40	6.60	6.60
Total	70.55	59.50	59.00

[1] Based on average custom rates for the North Central Region as published in Doane's Agricultural Report dated 3/17/72 and/or actual costs incurred on farms within the land site(s) areas.

[2] A cost of $4/ac included as a constant for insecticides.

[3] Includes soil amendments such as dolomitic limestone to maintain soil pH and balanced plant nutrition.

ENERGY DISSIPATION

Some of the facilities of the land treatment and irrigation system can be used jointly for water resource management and electric power generation. Wastewater can be used in these associated areas, which I term "Energy Dissipation."

Predictions of future energy requirements have been given in a number of studies, and in most cases these energy forecasts have been based on the assumption that the large increases in energy needed in the next 50 years would be substantially provided by the generation of electric power.

One such forecast is the Federal Power Commission's (FPC) National Power Study compiled in 1966-68. This study forecasts that the minimum energy demands would require a doubling of installed capacity every ten years for the next 30 years. This prediction was based on a projection of the energy demands experienced over the past 20 years, including an allowance for decreasing population growth rates. Using this projection the minimum commitment for generating facilities in the year 2000 would be approximately seven times the 1973 levels.

In another study, Professor Earl Cook, professor of geography and geology at Texas A & M University, pointed out the possible need to conserve resources to minimize the associated pollution problems and to maintain adequate reserves for future generations. This reasoning leads to a leveling-off of power consumption at about the year 2010 and 2020 at a level of about four times the present 1973 level. To achieve the result envisaged by Professor Cook would require unprecedented public policy changes, as it would call for an arbitrary limitation of consumption of resources.

The C-SELM estimate for this study area assumes it would be wise to make a minimum commitment for generating facilities at about seven times 1970 levels for the year 2020, or 65,000 MW as compared to 12 times present levels as predicted by local power companies. This estimate falls between the two projections listed above, although it does seem to fit more nearly with the conservative projection of Professor Cook.

Cooling for Power Facilities

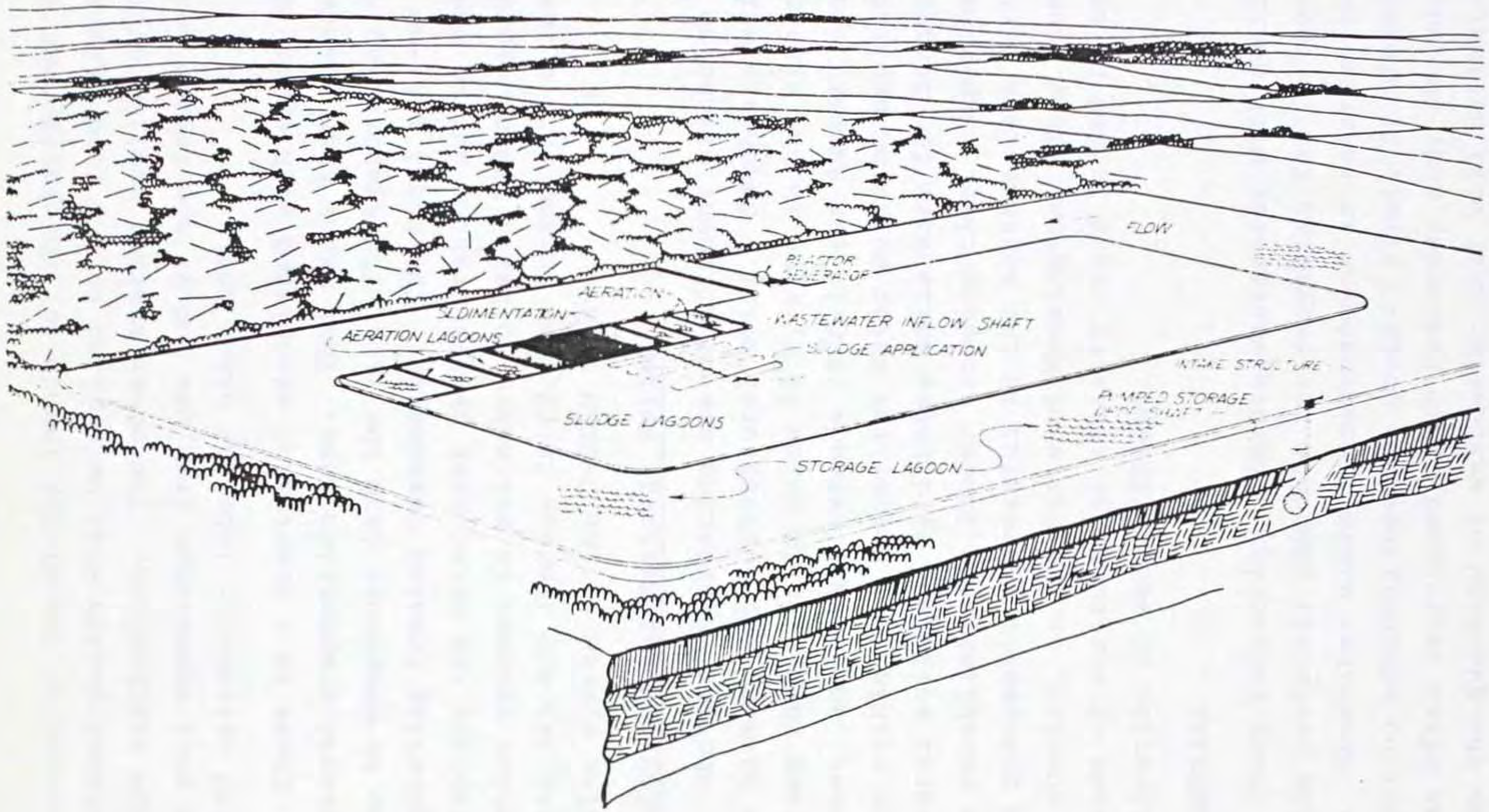
The utilization of land treatment storage lagoons for the dissipation of the waste heat generated during the production of electric energy had been investigated for the C-SELM study. In making this investigation, certain basic assumptions and design criteria were established.

The first and primary assumption made is that a nuclear power generating station located near the land treatment sites would provide the additional power needed to meet the energy requirements of the C-SELM study area through the year 2020. An additional 55,000 MW of electric generating capacity would be required to supplement the existing or 1970 installed capacity of 10,000 MW in order to meet the 65,000 MW projected requirement in 2020 according to the energy forecast of the previous section. The waste heat to be dissipated from the generation of this much power amounts to 8,780 billion BTU's per day. The cooling pond surface area required for dissipating this heat is approximately 70,000 acres, provided that the temperature of the cooling pond is allowed to exceed $80^{o}F$ during the summer. This surface area requirement for heat dissipation is on the same order as the surface area provided by the land treatment storage lagoons in the year 2020. Thus, the storage lagoons provided by the land treatment alternative could be fully utilized as part of the waste heat dissipation system for the generation of power at the projected 2020 levels.

Figure 4 shows the general arrangement of a modular land treatment system in combination with a nuclear power generating system. The wastewater being pumped into the treatment system through the inflow shaft will be distributed to the aerated lagoons for biological treatment. The effluent from the aerated lagoons will be directed to the sedimentation lagoons where most of the suspended solids will be removed. The effluent will then be directed in to the storage lagoon and the sludge will

Figure 4

CONCEPTUAL VIEW OF LAND TREATMENT SYSTEM ASSOCIATED WITH POWER STATION



be stored in the sludge lagoon for thickening and storage. The thickened sludge will be applied to the land allocated for sludge application. The power station cooling system would pump cool wastewater from one end of the lagoon and discharge heated wastewater into the other end.

There is a constraint associated with energy dissipation -- increased evaporation loss. That means that pounds of water are going to evaporate into the air. The evaporating network is evaporating treated wastewater. The total make-up water required to replace the water lost by evaporation during the heat dissipation process is estimated to be 43 MGD or approximately 16% of the 265 MGD average daily flow coming into a land treatment modular system in the C-SELM study.

Warming for Agricultural Soils

Another interesting use of effluent discharge is to provide warming for agricultural soils. Secondary effluent temperature rarely falls below 55°F, even in the winter in the Midwest, and rarely exceeds 70°F in the summer. Because it stays within that range, the water could be applied to agricultural soils and hold these soils warm for longer periods, thus establishing a longer cropping time. Experiments have been reasonably successful in the northwestern portions of the country, in the State of Washington. They found that periods of agricultural activity could indeed be extended by application of warm effluent.

INDUSTRIAL

Many industries generate wastewater with quality characteristics perfectly adequate for recycling for further industrial use. Sometimes minimal pretreatment is required for recycling. Recycling accomplishes two goals: first, it minimizes demands on an often over-taxed water resource; and, second, it minimizes the quantity of wastewater that will ultimately be rejected or blowndown for treatment prior to discharge to a receiving water. As treatment requirements, and thus treatment costs, become more demanding with increasing water and effluent quality goals, it is advantageous to minimize the final flows requiring ultimate treatment.

The power industry is an example of an industry that commonly employs recycling of its cooling water via a cooling lake or cooling tower. In the relatively water-abundant C-SELM area, power industry recycling is motivated by a desire to minimize discharge of waste heat to natural waters in order to control the effects of thermal pollution.

There are existing federal and state standards that specify the conditions under which cooling water discharges are acceptable to receiving waters. Those standards apply not only to the power industry but also to any other potential discharger of waste heat. The C-SELM evaluation of impact of existing and NDCP future standards considers the impact of thermal recycling on the critical industries.

Recycled, blowndown flows from industrial cooling systems are considered acceptable to the C-SELM waterways for the purpose of this study. No deleterious effects are ascribed to the increased total dissolved solids concentrations associated with these blowndown flows.

The steel industry is a critical industry discharger in the C-SELM area. The water needs of the steel industry per unit of production have increased slightly in recent years reflecting the requirements of new, high-volume production technology. At present the water requirements of advanced-technology, integrated steel mills will be approximately 40,000 gallons per ton of steel, of which 19,000 gallons per ton, or 47%, is required for indirect cooling; 7,000 gallons per ton, or 18%, is required for direct cooling; and 14,000 gallons per ton, or 35%, is required for process use.

A generalized maximum recycle strategy for the integrated steel industry is as follows:

1) All cooling flows and the sinter plant, steelmaking processes, and hot and cold rolling mill process flows are reclaimed and recycled repeatedly until the total dissolved solids concentration approaches inhibitory levels.
2) Blowdown from the recycling flow, described above, is successively used for the by-product coke plant cooling and process requirement followed by the blast furnace process requirement.
3) Pickling wastes are regenerated with a hydrochloric acid-thermal-recovery system; tinplating and galvanizing wastes are essentially stripped of their heavy metal contents by adsorption recovery systems and discharged to local or remote, and, as required, advanced waste treatment.
4) Reclaimed iron solids are recycled to either blast furnaces or steelmaking processes via sintering, as required; reclaimed oil is classified and reused or sold for further reclaiming; recovered zinc, tin and chromium are selectively reclaimed, as economically feasible, and reused.
5) Sanitary flows are transmitted to local or remote primary, secondary, and as required, advanced waste treatment.

Utilizing this strategy, the make-up water required per ton of steel can be reduced by approximately 92.5%, inasmuch as only the make-up water equipment passes to final and advanced treatment. The increased unit cost for treatment is offset by the reduced flows requiring treatment. The net result is NDCP or advanced treatment with little if any increased cost to the steel industry.

Another critical industry discharger in the C-SELM area is the petroleum industry. In the past fifteen years, the potential make-up water requirement for crude oil for both processing and cooling has decreased from 440 to 60 gallons per barrel. This has been possible largely through recycle of cooling water. Further reduction in wastewater production per barrel of crude is still possible. An ultimate make-up water requirement of approximately 40 gallons per barrel was projected in the C-SELM study.

The wastewater parameters of the various petroleum production sub-processes are compatible with conventional primary, secondary and advanced waste treatment, as required. Pretreatment for oils and sulfides is frequently required.

A review of large (greater than 5 MGD effluent discharges) petroleum refineries in the C-SELM study area reveals that recycle of cooling water is not intensively practiced and that most potential reductions have not been achieved. With an ultimate recycle strategy in the petroleum industry within the C-SELM area, it is possible to hypothesize a major reduction in petroleum industry wastewater requiring treatment. Again, as in the steel industry, this is not estimated to result in significant additional costs to industry over costs currently being met to treat to present standards.

INDUSTRIAL - MUNICIPAL

The opportunity for the reuse of secondary effluent from municipal treatment plants for industrial process waters is great. The quality of intake waters for a number of C-SELM industries is not significantly different from secondary municipal effluent. At present a number of industries operate raw water pretreatment facilities to properly condition their process water. The incremental cost of pretreating municipal effluent versus present pretreatment operations may prove to be feasible when viewed as a water-conserving technique. Table 4 presents selected industrial reuse opportunities. The municipal treatment plant should be in close proximity to the particular industry. Industrial reuse of such water may not be feasible in areas where there exists an abundant water supply or where industrial water consumption is much larger than nearby municipal wastewater flows.

TABLE 4

INDUSTRIAL REUSE POTENTIAL OF MUNICIPAL EFFLUENT

Industry	Reuse Potential
Steel	For coke and slag quenching, gas cleaning and hot rolling operations, secondary effluent quality would be acceptable. For cold rolling and reduction mill waters, secondary effluent would have to be pre-treated (coagulation, sedimentation, filtration) mainly to reduce suspended solid content. Pickling and cleansing rinse waters require a softened or demineralized water.
Petroleum	Pre-treatment of effluent for suspended solids and turbidity removal is necessary to enable use as process water for desalting, washing, and product transportation operations. Utilization of wastewater for brine removal from crude oil produces synergistic effects through wastewater renovation of certain pollutants such as phenols.
Food Processing and Pharmaceutical	The reuse of secondary effluent for process water is not acceptable since all water for washing, transport and blanching operations must be of potable quality.
Explosives and Soap	The reuse of secondary effluent for process water would require pre-treatment including coagulation, sedimentation and filtration. Further treatment may include softening and demineralization for the particular desired water quality.
Power and Boiler Feed and Cooing Operations	The reuse of secondary effluent for cooling and coiler feed operations may have limited use. Cooling water use in the steel and petroleum industries far exceeds the process water use in these industries. Pre-treatment will be dependent on specific installations. Generally pre-treatment for boiler feel will be necessary for solids and hardness control.

CHAPTER IX

WATER REUSE IN AGRICULTURE, INDUSTRY AND RECREATION

James E. Bertram

The multiple reuse of water in Lubbock, Texas is evolving as one solution to a growing demand for a depleting resource. Many cities in arid or semi-arid regions of the United States have, or will probably, consider similar courses of action in the near future.

The city of Lubbock is situated on the southern portion of the high plains of west Texas. The only noticeable variations in topography are from numerous playa lakes (shallow depressions) varying in size from 10 acres to a square mile and from small canyons eroded by occasional surface runoff. Average annual rainfall is approximately 18 inches. Most rainfall runoff is trapped in playa lakes where considerable surface water is lost through evaporation, averaging 73 inches per year.[1]

The high plains of Texas has a rich agricultural economy. It is underlaid by a large acquifer referred to as the Ogallala formation. Many cities, using water from the acquifer for domestic water supplies and numerous irrigated farms, are lowering the water table from one to three feet per year, while recharge averages only an inch or less per year.[2] The City of Lubbock, until 1968, took its entire water supply from the Ogallala. Recent engineering studies indicate that based on Lubbock's estimated growth rate, peak daily domestic water demands will reach 141.3 million gallons per day by 1995, while maximum development of existing water sources will produce only 137.3 million gallons per day by 1995.[3]

RECLAIMED WATER AS A PROBLEM AND RESOURCE

Like most cities, the early history of sewage effluent disposal in Lubbock reflected a growing "problem" of what to do with the "waste" water. Early solutions in Lubbock involved large man-made tanks near the reclamation plant.[4] By 1974, Lubbock's average daily use of potable water was 31.3 million gallons per day (MGD) of which an average of 16.3 MGD, or 52% of the water used, flowed into the sewage treatment plants. It is estimated that the amount of effluent could increase to 22 MGD by 1990. Currently, most of the effluent is received by the southeast treatment plant (activated sludge process) which has a design capacity of 25 MGD.

HISTORICAL REUSE APPLICATIONS

Crop Irrigation

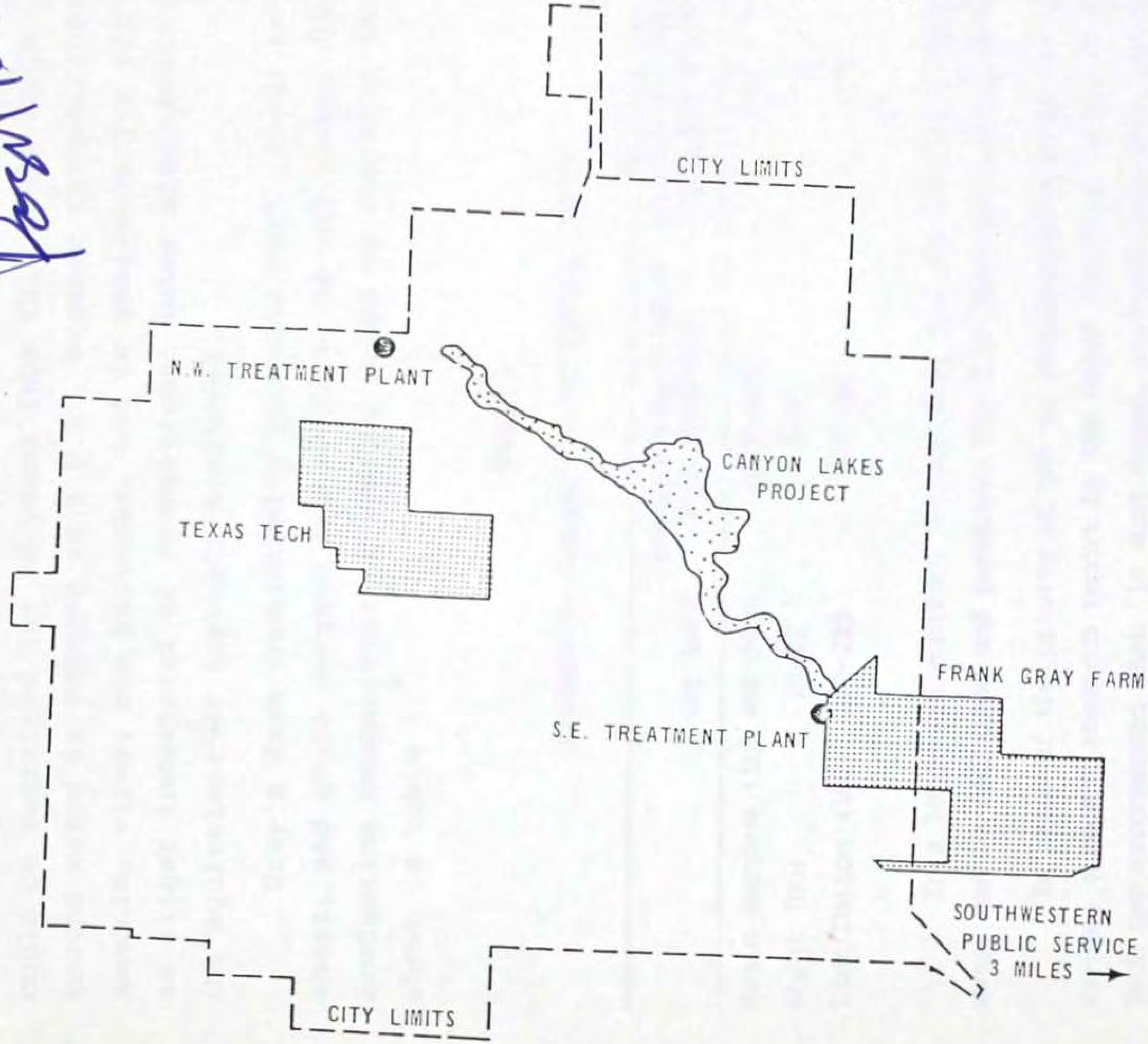
The first change in attitude in Lubbock from effluent being "wastewater" to that of a "resource" came with the decision in 1937 to irrigate cropland near the southeast reclamation plant. Frank Gray, a farmer, through a series of long-term contracts with the City, began spreading a million to a million and a half gallons per day on 200 acres.[5] By 1974, he applied 14 to 15 MGD to 5000 acres (Fig. 1). Occasionally, Gray supplies water to an additional 200 acres adjacent to his farm.[6] During many times of the year, effluent ponds are formed in lower areas of the farm, where grazing cattle drink from them. In addition, Mr. Gray's domestic water supply comes from wells in the groundwater table beneath the farm. No adverse effects are known to have occurred from such ranching and domestic use.

In addition to the profits derived by Mr. Gray from his farming operation, several benefits have accrued to the City of Lubbock: 1) Near-by crop irrigation is a convenient method of disposing of the effluent while avoiding releasing water into the adjacent Yellowhouse Canyon stream bed;
the nitrogen-rich effluent removes much of the nitrogen that cannot be totally removed by percolation throught the soil; and 3) The constant percolation of water through the soil has created an "artificially" recharged water table which has been raised to within a few feet of the surface under the Gray farm.

Position

Figure 1.

APPLICATIONS OF WATER REUSE IN LUBBOCK COUNTY



It is estimated that annual withdrawals of as much as 6 MGD could be sustained for 20 years from this water table.[7] This ground water is reduced in B.O.D., organic carbon, phosphorous, ammonia, virus, and bacteria, and is available for reclamation as either industrial or recreational water after having undergone the equivalent of tertiary treatment.

Gray's farm consistently produces high yields of cotton, wheat, and grain sorghum and requires no additional fertilization. Production comparisons of typical crops on the Gray farm are shown in Table 1.[8]

TABLE 1

Production Comparisons of Typical Crops

	Dry Land	Irrigation With Water From Ogallala	Irrigation With Effluent Without Fertilizing
Grain Sorghum (lb)	800-1000	4000-5000	6500
Wheat (bu)	10-12	30-40	80
Lint Cotton (lb)	150-225	600-800	1250

In a long-term contract between Gray and the City of Lubbock, this water can be reclaimed and purchased for 1.5 cents per 1000 gallons.

In terms of the priorty of use or recommended sequence of multiple re-use, a recent research report by the Water Resource Center at Texas Tech has recommended that "in most cases, irrigation be employed as mandatory first use."[9]

Texas Tech University

In terms of historical sequence, Texas Tech was the second user and began receiving all of the effluent from Lubbock's northwest treatment plant in 1965. Currently, this water (1 MGD) is used exclusively to irrigate farmland on the Tech campus. Long-range planning is underway to consider recharge of the water table under the Tech campus for future domestic re-use and also to water turf areas of the campus entirely with reclaimed water (Fig. 1)

Southwestern Public Service Company

In May 1968, the City of Lubbock contracted with Southwestern Public Service Company (an electric utility) to provide treated effluent to be used as cooling water at the generating plant, southeast of the city. Southwestern Public Service could initially take 3.5 MGD with two options to increase to 7.7 MGD in June 1977, and ultimately to 12.35 MGD by June 1986.[10] The water is piped directly to the electric production plant after secondary treatment at the southeast treatment plant. The water is purchased from Mr. Gray at 1¢ per thousand gallons.

Canyon Lakes Projects

The most distinctive topographic feature in Lubbock is the Yellowhouse Canyon, extending approximately 8 miles from northwest to southeast Lubbock (Fig. 1). It ranges in depth from 40 feet at the northern end to approximately 75 feet at the southern end, and ranges in width from a few hundred feet to approximately one half mile.[11]

Historically the canyon had become an eyesore, being used for dumping building debris, junk yards, caliche mining, wrecking yards, and even a sanitary landfill for the City of Lubbock. In 1967, during an update of the Lubbock Land Use Plan by the City Planning Department, it was recommended that the Yellowhouse Canyon be reclaimed as an open space greenbelt and used to store reclaimed water in a series of recreational lakes. The Santee, California project was used as an example of recreational applications of reclaimed water. Through a series of reports and a color slide presentation, numerous civic clubs and interested citizens were exposed to the proposal. Widespread acceptance of the proposal resulted in the project becoming the No. 1 recreational goal in "Lubbock's Goals For The Seventies." Numerous citizens and civic clubs requested the City Council to pursue an investigation of the project.

In 1968, the engineering firm of Freese, Nichols, and Endress was commissioned to complete a feasibility study on the project. In November, 1969, the feasibility report concluded that "there is enough water available to support the proposed lakes and that, with proper monitoring and control, they can be kept safe and attractive for public use".[12] Conclusions of the report, relating to the first six lakes, include the following: 1) make-up water should be obtained from wells beneath the Frank Gray farm; 2) lakes 1 through 6 would be suitable for secondary contact activities; centrations of plant nutrients in the lakes would be substantial, and while algae and aquatic weeds could be expected, they could be adequately controlled; 4) all surface drainage from cattle feed lots must be abated; 5) induced aeration of the water should be employed; and 6) a continuous water quality monitoring program should be established. The estimated capital cost of the first six lakes was set at $6,063,100.

Following a massive tornado on May 11, 1960, which damaged over 7 square miles in the central and northeastern sectors of the city, a tornado-recovery bond election was held. It included $2.8 million for the Canyon Lakes Project, which was approved by approximately a 2 to 1 margin. Subsequently, in 1971, $3.4 million from the State Parks and Wildlife Department and the Bureau of Outdoor Recreation (BOR) and $832,828 from the Department of Housing and Urban Development were tentatively committed to the project. BOR funding was conditional upon the water meeting State water quality standards. This requirement initiated a second report on make-up water by the firm of Freese, Nichols, and Endress.[13] After investigating three alternatives (a) Well water from beneath the Gray farm, b) effluent from the activated sludge plant, and c) in-plant tertiary treatment of effluent), the report concluded that ground water from the Gray farm should be used. By cost comparison, it was estimated that annual operations costs for 5 MGD would be $229,000 (12.55¢/1000 gal.) for ground water, $425,900 (23.33¢/1000 gal.) for activated sludge effluent, and \$854,400 (46.81¢/1000 gal.) for in-plant tertiary treatment. The report concluded that ground water is superior to other alternatives and that it is relatively free of virus and bacteria. A subsequent report by the Water Resource Center at Texas Tech University supported the conclusions about virus and bacteria control; however, it raised concern over urban storm runoff which would be "Considerably poorer in quality than treated domestic sewage."[14] The Water Resource Center at Texas Tech is currently under contract to the City as the project's "water quality monitoring agent." Water quality monitoring equipment is being constructed with the Canyon Lakes dams and an active program is underway to clean up the urban water shed. In the initial phase of the project, four lakes of an eventual eight-lake system will be constructed. Rainfall will fill the lakes and approximately 4 MGD of reclaimed water will be used to offset evaporation and percolation.

To date, all of the necessary land for the project (555.29 acres) has been purchased, and when combined with existing local and state parks along the canyon, creates a 1344 acres continuous greenbelt through the city. In 1973, the City Parks Department acquired a bulldozer, front-end loader, maintainer, and three dump trucks with general revenue sharing funds and initiated a concentrated clean-up of the canyon. A local manufacturing firm, Clark Equipment Company, has donated large earth scrapers to be tested in excavation of lake areas. The transformation in the canyon has been remarkable. Four dams are currently under construction and approximately 19 acres of park development has been completed. Future plans include over 20 miles of bicycle trails, picnicking areas, and various forms of water recreation. Initially all water sports in the four lakes will be limited to secondary contact; however, future monitoring and testing of the water may allow primary contact.

FUTURE WATER REUSE APPLICATIONS

Future applications are uncertain. In all probability they will consist of variations of existing agricultural, public use, industrial, or recreational applications. Because of Lubbock's limited sources of new domestic water, multiple re-use of water will continue to be a necessity, rather than a discretionary alternative.

The Lubbock experience seems to be a fulfillment of a forward-looking prediction in an early publication on water re-use in 1965: "re-use of water through many cycles will be routine practice in fifty years."[15]

REFERENCES

[1]Freese, Nichols and Endress, Consulting Engineers, Feasibility Report on the Canyon Lakes Project, Lubbock, Texas, 1969.

[2]Sweazy, R.M. and Whetstone, G.A., "Case History of Effluent Reuse at Lubbock, Texas," presented at Spray Irrigation Seminar, Harrison Hot Springs, British Columbia, April, 1975.

[3]Freese, Nichols and Endress Consulting Engineers, Report on Makeup Water for the Upper Canyon Lakes, Lubbock, Texas, 1971.

[4]City of Lubbock Planning Department, "Methods of Storing and Using Renovated Waste Water for Lubbock, Texas," An Expanding Lubbock. . . Reclaimed Water For A Growing City, April 1968.

[5]Sweazy, R.M. and Whetstone, G.A., op. cit.

[6]Sweazy, R.M., "Multiple Reuse of Municipal Wastewater," presented to An International Symposium -- RONTIERS OF THE SEMI-ARID WORLD, International Center for Arid and Semi-Arid Land Studies, October, 1974.

[7]Freese, Nichols and Endress, Consulting Engineers, 1969, op. cit.

[8]Sweazy, R.M. and Whetstone, G.A., op. cit.

[9]Sweazy, R.M., op. cit.

[10]Freese, Nichols and Endress, Consulting Engineers, 1969, op. cit.

[11]Headstream, Marcia, et al., "The Canyon Lakes Project," Journal American Water Works Association, March, 1975.

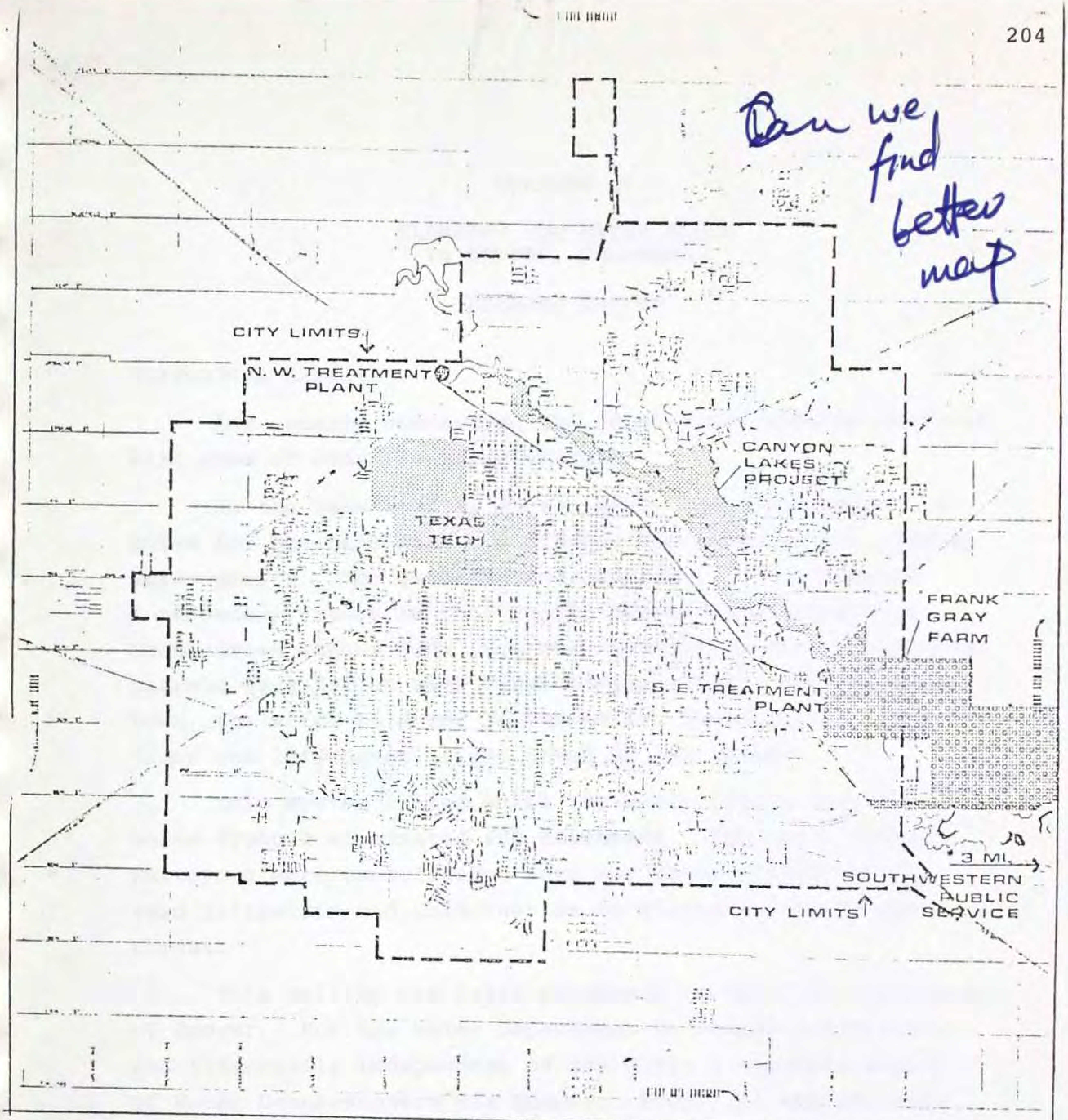
[12]Freese, Nichols and Endress, Consulting Engineers, 1969, op. cit.

[13]Freese and Nichols Consulting Engineers, Recommended Plan of Action for Development of Additional Surface Water Supply for Lubbock, Texas, Fort Worth, Texas, 1975.

[14]Thompson, G.B., et al., Variation of Urban Runoff Quality and Quantity with Duration and Intensity of Storms -- Phase III, Office of Water Resources Research, Department of the Interior, Washington, D.C., August 1974.

[15]Whetstone, G.A., Re-Use of Effluent in the Future with an Annotated Bibligraphy, Texas Water Development Board Report 8, Austin, Texas, 1965.

Can we find better map



APPLICATIONS OF WATER REUSE IN LUBBOCK COUNTY

1/2 1 MILE 2

FIG. 1

CHAPTER X

PLANNING FOR WATER REUSE IN DENVER, COLORADO

Richard Heaton

HISTORICAL ASPECTS

Any remarks concerning the reuse field must be prefaced with some of Denver's water history.

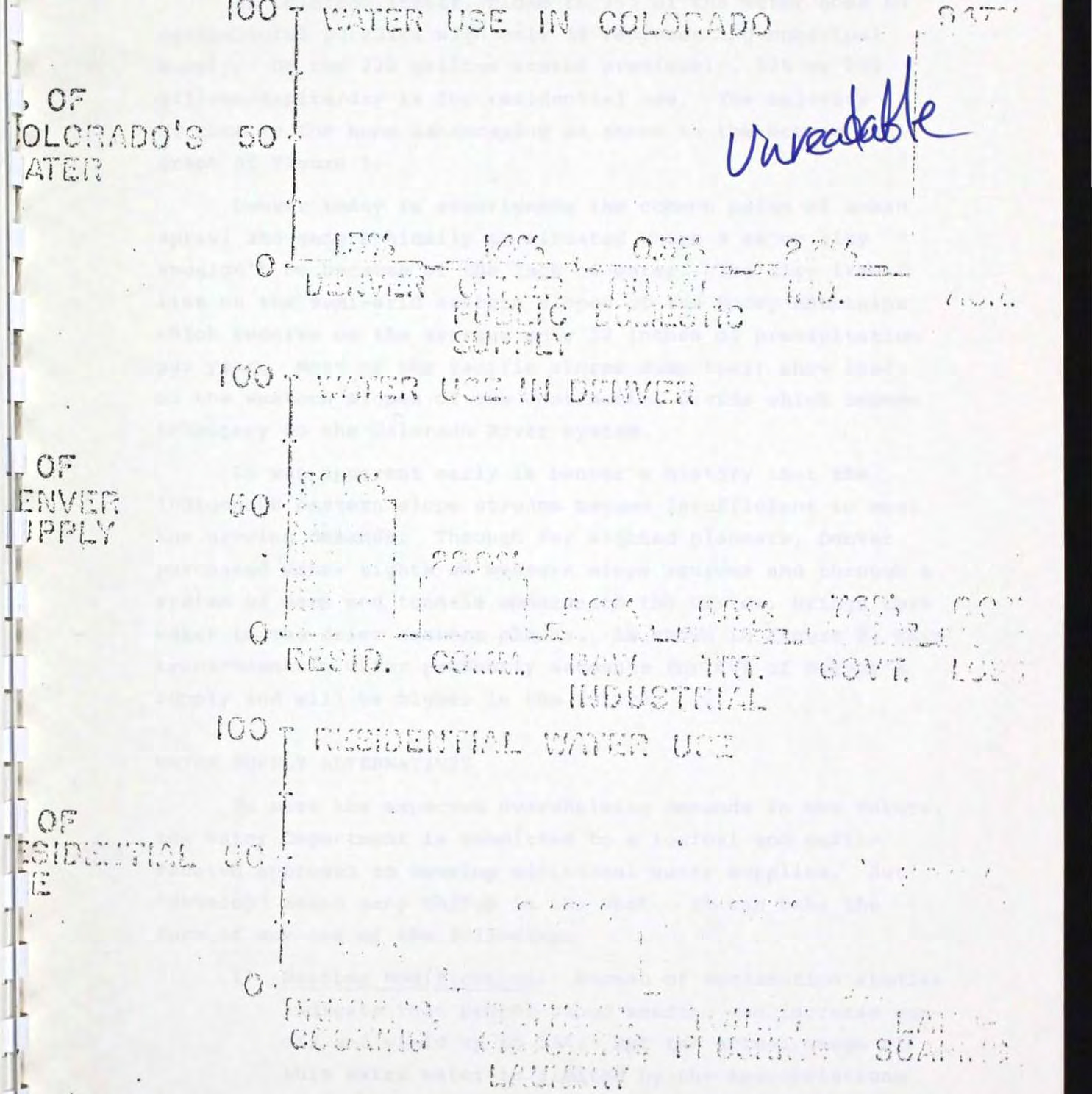
In the late 1800's, eleven small water companies competed for business with the six-gun and force as the primary sales gimics. The quantity and quality of water were of a secondary nature in that highly competitive atmosphere. Horse-drawn wagons went into the mountains where the numerous barrels were filled with clear stream water. Returning to town, the water sold for 5¢/bucket for those on the first floor and 10¢/bucket if you lived on the second.

This system lasted until the early 1900's when water-borne typhoid eliminated 600 customers. The small water purveyors were consolidated into one water utility which used filtration and chlorination to eliminate the disease threat.

This utility was later purchased by the City and County of Denver. For the Water Department to remain politically and financially independent of the City, a separate Board of Water Commissioners was formed. Thus, all the revenues from water sales go into the Water Department treasury and not the city's. No tax monies are used for support.

The water utility today serves close to one million people with a service area of 300 square miles. In 1974, 72.0 billion gallons of water was served to customers. This equates to a yearly average consumption of 220 gallons/capita/day, one of the highest in the country. Figure 1 provides more details of the actual water use.

FIGURE I
TYPICAL WATER USE



In Colorado itself, close to 95% of the water goes to agricultural pursuits with only 3% representing municipal supply. Of the 220 gallons stated previously, 52% or 115 gallons/capita/day is for residential use. The majority of that is for home landscaping as shown in the bottom bar graph of Figure 1.

Denver today is experiencng the common pains of urban sprawl and geographically is situated where a major city shouldn't be because of the lack of water. The city itself lies on the semi-arid eastern slopes of the Rocky Mountains which receive on the average only 12 inches of precipitation per year. Most of the Pacific storms dump their snow loads on the western slopes of the Continental Divide which become tributary to the Colorado River system.

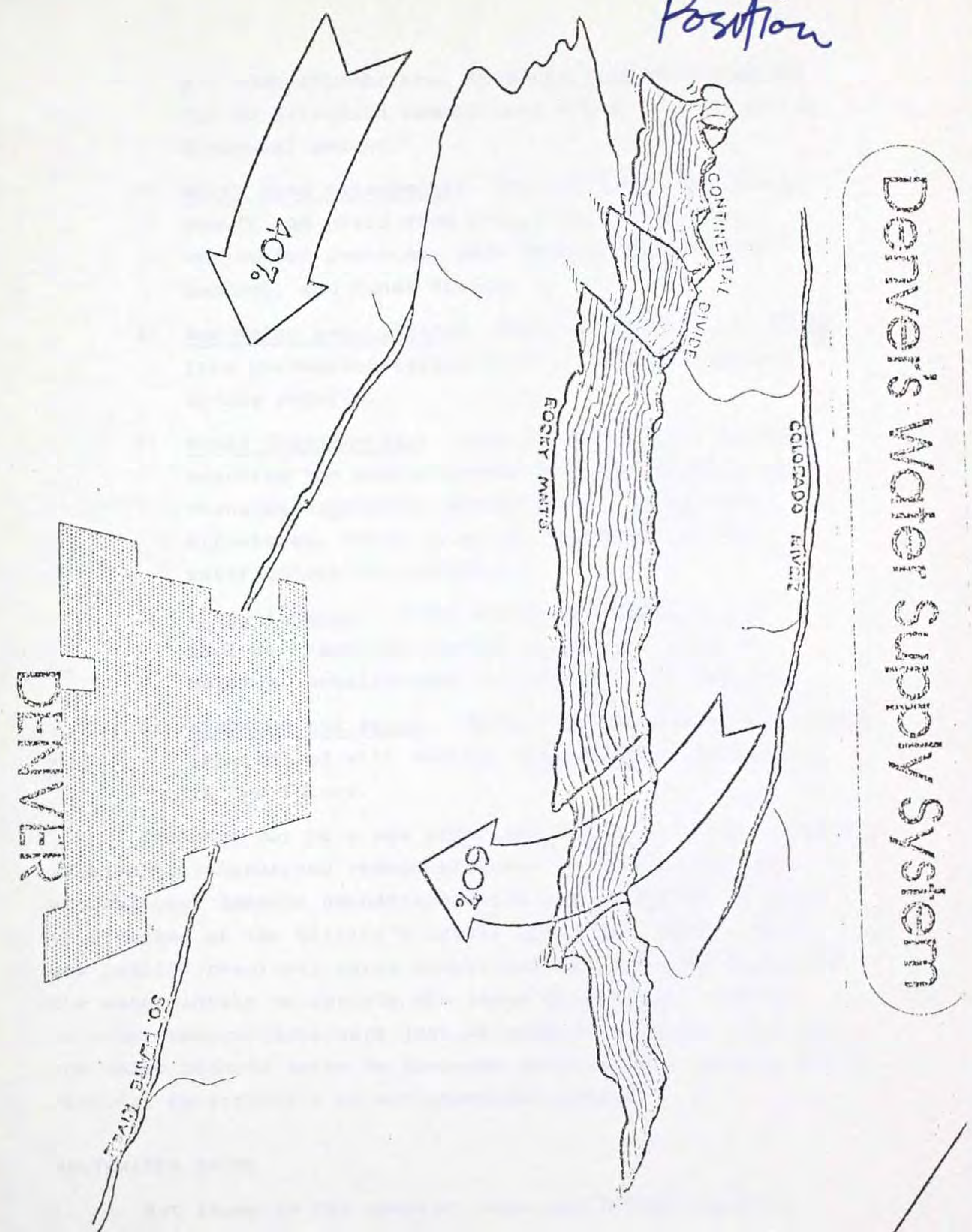
It was apparent early in Denver's history that the indigenous eastern slope streams became insufficient to meet the growing demands. Through far sighted planners, Denver purchased water rights on western slope sources and through a system of dams and tunnels underneath the Divide, brings this water to the drier eastern plains. As shown in Figure 2, this trans-mountain water presently accounts for 60% of Denver's supply and will be higher in the future.

WATER SUPPLY ALTERNATIVES

To meet the expected overwhelming demands in the future, the Water Department is committed to a logical and multi-faceted approach to develop additional water supplies. But "develop" means many things in the west. It can take the form of any one of the following:

1) Weather Modification: Bureau of Reclamation studies indicate that proper cloud seeding can increase run-off and yield up to 15%. But the actual usage of this extra water is limited by the Appropriations Doctrine in western water law. Where the rivers are

Position


Denver's Water System
40%
60%
CONTINENTAL DIVIDE
COLORADO RIVER
ROCKY MNTS.
DENVER
SO. PLATTE RIVER

all over-appropriate, it means that more demands can be satisfied rather than one entity receiving a greater amount.

2) Water shed management: This includes optimizing runoff and yield from proper forest cutting, vegetation patterns, snow fences, evaporation control, and canal lining.

3) Raw water acquisition: This alternative can range from purchasing agricultural rights or capturing spring runoffs.

4) Water Conservation: This fourth method involves teaching the public proper watering methods and changing vegetation patterns to inverse rate structures, total metering, or rationing and restrictions if necessary.

5) Miscellaneous: Other areas of investigation include trans-continental pipelines, glacier melting, desalination and groundwater studies.

6) Exchange and Reuse: These last two areas are closely related and will receive considerable attention in the future.

Exchange may be a new principle to eastern water ideology. In essence, discharged sewage effluent is used to satisfy agricultural demands downstream while a like amount of water is diverted at the utility's intake upstream. Before this was legally resolved, large quantities of water had to bypass the water intake to satisfy the usage downstream. Sewage or other return flows were just an unmeasured bonus. All of the above methods serve to increase water supply, many without physical construction or environmental damage.

WASTEWATER REUSE

But reuse is the seminar theme and Denver views it as one of the more viable means of supplementing future supply. The words "reuse, recycle and reclaim" are interesting. They all sound good and recycling of resources appears at first to be a logical and efficiant conservation process. But reclaiming wastewater poses a unique set of problems.

For the last ten years, Denver has been evaluating all of the reuse potential in the area. In every reuse scheme, save direct potable reuse, a dual distribution system is required: one line to convey potable water and the other a lesser quality product.

Industrial Reuse

Industrial reuse was the first of several alternatives evaluated. If a city is fortunate enough to have its heavy water-using industries near the sewage source, the most logical approach would be to offer those industries reclaimed water and thus conserve the potable supply. Industry, however is not centralized in Denver, nor is it always located adjacent to a sewage treatment plant. This form of reuse then requires an expensive additional pipeline and pumping facility which may or may not be justified by economics or water shortages.

Other factors require consideration as well. Industrial reuse may be the most logical but not necessarily the most efficient method. There does exist in Denver a large coal burning power plant within 2000 ft. of the municipal wastewater treatment plant, an ideal situation georgraphically. The plant uses in excess of 10 mgd of water for cooling and stack scrubber purposes. Existing sources of water include shallow wells and diverted ditch water purchased from the Water Department. The cost approaches 6¢/1000 gal. To provide the plant with an equal amount and equal quality of reclaimed effluent would cost 30-40¢/1000 gal. which is five to six times the present rate.

The industry cannot realistically be expected to convert to a more expensive source even for public relations benefits. Secondary effluent, available at no charge, is of insufficient quality to serve the plant needs. Tertiary treatment would be required to remove scale forming phosphates and corrosive ammonia. Faced with an EPA discharge permit which limits TDS, the power plant must exert careful control over concentration cycles. Using reclaimed water with an initially higher TDS content would limit tower concentrations, thus, requiring purchase of even more of the expensive product.

The Water Department also receives $100,000/year from sale of the ditch water. Substituting another source automatically eliminates that revenue as no other market is available. Exchanging the water right to another diversion point practically eliminates the quantities involved. Forcing use of the more expensive reclaimed water in a drought situation is impractical as the plant's wells could suffice. It is difficult to compete economically with a mere pumping charge especially when the power is inherently owned.

Industrial reuse is an acceptable plan and is being sucessfully implemented countrywide, but it's not the panacea for all communities. When properly planned, sewage effluent can readily serve new industries or those which can adapt to a different quality of water. Some thought has been given to establishing a new industrial park where the businesses were amenable to secondary effluent. As to the creation of a new water market, questions, as growth encouragement, etc., arose which did not comply with the initial conservation theory in Denver.

Municipal Reuse

A second alternative for reuse involves municipal application. This plan calls for an extensive dual distribution system to serve parks, golf courses, recreational lakes or perhaps individual home needs (lawn watering and toilet flushing).

A major year long study was undertaken in Denver to evaluate a dual pipe system in a new and completely planned community of 10,000 population. A secondary pipeline of highly treated wastewater would have served the needs of a recreational lake, golf course and many private homes. Several combinations of reuse were evaluated. All costs being considered, the resultant price of the reclaimed source was more than the potable water in neighboring communities.

But who would subsidize the cost differential?

1) The Water Utility for demonstration purposes? A losing economic venture was not needed as the future didn't look that promising.

2) The developers themselves? Adding the increased price onto the home would jeopardize an already sensitive market.

3) The Recreation Association? Its mandatory monthly fees were already prohibitive.

4) The Homeowners through higher rates? Why should he pay extra just for the privilege of living in an experimental conservation minded community? He expected a rate reduction.

The high system costs were due strictly to:

1) Intensive treatment requirements since the recycled water was expected to be at least biologically safe in case of short-termed accidental ingestion.

2) The dual piping system, dual meters, home plumbing modification, and resultant increased O & M costs.

3) The lack of a winter market for the product in Denver's climate.

4) The storage, holding, and flow equalization necessity. Large summer irrigation demands would have caused undesirable water level fluctuations in the recreation

reservoir. Control measures and costly sizing were necessary for a successful operation.

In addition, proper training in the use of the dual system would have required a definite change in individual life style. For these reasons the project was deemed infeasible. In other situations, a dual system may be practical and advantageous due to its inherent water conservation. Utilities have been trying for years to instruct the populace in wise water usage with very little success among adults. The real results have been among children who are more ecologically minded. The impact of their water savings won't be felt for 15-20 years. Recycling in essence performs the water conservation and moves the responsibility from the customer to the utility.

Agricultural Reuse

The use of sewage effluents directly or indirectly in agriculture is widely practiced. It is often the only source of water and relieves some demand on rivers or well systems.

Unfortunately, knowledge is insufficient regarding any deleterious health effects in the food chain from uptake of toxic substances. In addition, highly polluted agricultural return flows are even more concentrated if sewage effluents are the feed source.

In the Denver region, major agricultural reuse is simply prohibited by certain water rights decrees. This particular legal condition will become more apparent as municipal demands increase along the eastern slopes of the Rockies.

Groundwater Recharge

Where extensive underground aquifers exist or salt water intrusion is evident, ground water recharge with highly treated sewage effluents is a viable means of increasing supply or detering a problem.

With respect to the Denver situation again, the underlying geology is simply not amenable to recharge. And with complicated western water law, it is not clear whether injection of x gallons of water at one point in an aquifer justifies the same x withdrawal at another. Ownership is highly questioned once control through injection is lost.

Potable Reuse

Each city considering the reuse alternative should evaluate each mode before a decision can be made. Denver has looked in depth at all of the potentials and has concluded that the most efficient and logical reuse of wastewater is in the potable system, or the reclaiming of sewage effluent to a product suitable for human use and consumption.

As legally determined in the State Supreme Court, the only water available for reuse is the 60% trans-mountain flows. In terms of volume, however, it represents close to 100 mgd available for reuse by 1985. The total of all the industry's and park's water usage in the area doesn't approach this tremendous usable resource. Using only a part means wasting, wasting something which was purchased once and represents millions in potential revenue if sold again.

Potable reuse eliminates the dual distribution concept. But the same arguments against the other alternatives can be used against potable reuse. It too is expensive, from the sophisticated treatment which guarantees reliability to the years of health effects research which insures safety.

PUBLIC ATTITUDES

When the decision has been reached to approach potable reuse, several attitudes become prevalent. The first of these can be properly titled the "Yuk syndrome". This is the "no, never, not at any cost" attitude: "I'll move first, truck in bottled water, steal it, whatever, but not me, brother." The second is toned down a bit and says, "Yes, go to potable reuse but only as a last alternative. Exhaust every means first. Wait until the farms are dry and my grass is dead. Even if it's cheaper, hold off as long as possible." The third attitude is a positive one which views potable reuse as a viable means of supplementing future water supply. "When it becomes economical and safe to apply, do it."

The last attitude is, of couse, the one Denver is pursuing and encouraging. The decision is sound and no shame need be implied in its admittance.

The public relations studies conducted thus far are in fact very positive in terms of acceptance. An original premise was that no program could succeed without the approval of an informed public. Thus every effort has been made to publicize the program.

A first survey in 1971 covered 500 people. When first confronted with a reuse question, the response was most definitely negative as shown in Table 1. A short reuse information paragraph was read to the participants and the question rephrased. A slightly positive response is noted in Table 2. With even more discussion and the question given as indicated in Table 3, 85% of those surveyed would be willing to drink reclaimed water if the quality were as good as or better than existing supplies.

Two important facts were learned from the initial survey. Education of people is important; The more which is known concerning potable reuse, the more positive is the response. The second but rather formidable task is how to produce a snow-melt equivalent water from secondary effluent.

A second survey was conducted by a professional organization in March of 1975. A random group of 452 persons was selected by age, sex, income, ethnic background and geographic location. In conjunction with other statements on growth and water supply, the question as shown in Figure 3 was asked. The graph indicates that 63% of the respondents were in favor with about 25% against and 12% having no idea.

FIGURE 3
PUBLIC REACTION TO POTABLE REUSE

QUESTION 16: WATER REUSE IS THE TREATMENT OF SEWAGE WATER, PURIFIED TO THE SAME QUALITY AS OUR PRESENT SUPPLY, SO THAT IT CAN BE INTRODUCED INTO THE DRINKING WATER SUPPLY. WOULD YOU FAVOR OR OPPOSE A WATER REUSE SYSTEM FOR DENVER ?

TABLE 1

REUSE ATTITUDE SURVEY

Question: "HOW WOULD YOU FEEL ABOUT USING TREATED AND PURIFIED SEWAGE WATER FOR DRINKING. . . . TO TAKE CARE OF FUTURE WATER SUPPLY PROBLEMS?"

STRONGLY APPROVE	17%
SLIGHTLY APPROVE	21%
	38%
SLIGHTLY DISAPPROVE	19%
STRONGLY DISAPPROVE	41%
	60%

TABLE 2

REUSE ATTITUDE SURVEY

Question After Reading Short Reuse Information Statement: "IF DENVER ANNOUNCED THAT IT WAS CONSIDERING THE USE OF RENOVATED WASTEWATER AS A PART OF ITS DRINKING WATER SYSTEM, WHAT WOULD BE YOUR PERSONAL REACTION?"

STRONGLY APPROVE	23%
SLIGHTLY APPROVE	27%
	50%
SLIGHTLY DISAPPROVE	19%
STRONGLY DISAPPROVE	29%
	48%

TABLE 3

REUSE ATTITUDE SURVEY

Question: "WOULD YOU DRINK RENOVATED WASTEWATER IF ITS QUALITY WERE THE SAME AS YOUR PRESENT HOUSE WATER?"

YES, DEFINITELY	53%
PROBABLY SO	24%
NOT SURE, TEND TO THINK SO	8%
	85%
NOT SURE, TEND TO THINK NOT	5%
PROBABLY NOT	4%
DEFINITELY NOT	6%
	15%

Variations in response pattern were found to be statistically significant. By age, people in the two youngest groups (18-24 and 25-44 years) were considerably more in favor than older groups (up to 75%). This age-response difference appears significant in terms of ecological awareness. The popularity of a recycling scheme is a great selling point at this time. It was the surveyor's opinion that more public education is all that is necessary for an even higher favorable response.

A third survey is in the process of being evaluated from recent questionnaires. Favorable response is running two to one over those against.

All of these results may differ somewhat from studies conducted elsewhere and this may be attributable to the attitude of the interviewers or to Denver's extensive public information program. The important point is that, while a national public information program would be helpful, it is the response of Denver citizens that is important to Denver. Acceptance must remain a local function.

INDIRECT VS. DIRECT REUSE

Once the potable reuse decision has been made, two modes of operation become available--the direct or indirect system. The possibility exists in Denver to let secondary effluent flow downstream a few miles before being picked up at the reclamation plant. This, according to many, allows nature's magic mile of stream to dilute or purify the sewage. Perhaps it is more aesthetically pleasing to see water being withdrawn from a river rather than from an outfall.

However, many problems exist with the indirect mode of operation. For some months of the year with low stream flow, sewage effluent is the basis of the South Platte River. There is practically zero dilution. When there is flow, the quality is highly questionable with storm runoff, industrial discharges, upstream sewage plants, and the more consistent than not, accidental spills.

As the discharge standards become more stringent and the quality of sewage effluent improves, it is a shame to put it in a dirty receiving stream.

Some European rivers used for water supply purposes are close to 100% returned sewage flow. This concentration has essentially been ignored and conventional water treatment cannot safely handle the source. The percentage of sewage in U.S. streams is increasing as well, with some figures as high as 50% noted.

Direct reuse, where the sewage outfall is connected to the reclamation plant intake and this plant's product taken directly to the distribution system, is safer than indirect methods. The main reason is that the source is acknowledged. The treatment, monitoring and control of product will be much more sophisticated than conventional water treament because of the inherent dangers.

Quality Aspects

Product quality and standards are going to be very important in potable reuse because it's a whole new ball game. In all probability, more stringent standards will have to be developed for recycled water.

The 1962 U.S. Public Health Service Drinking Water Standards listed 20 chemical parameters, only 9 of which serve as absolute grounds for rejecting a supply as unsafe. The new EPA and World Health Organization Standards contain only a few more. None of these standards list more than a few synthetic organic and inorganic compounds despite the fact that hundreds of such chemicals find their way into wastewater.

Conventional drinking water standards were originally based on the premise that water for human consumption would generally be drawn from groundwater sources or from protected uncontaminated surface water supplies. Although the assumption is rarely true for most surface supplies today, it definitely doesn't apply to sewage effluent.

Two alternatives are then open to an agency considering potable reuse. One is to wait a number of years until the research work is done, until the in-depth toxicological and epidemiological studies are complete. The other method is to adequately monitor, with available equipment, the reclaimed water and attempt what is termed "use-increment" removal or the renovation of secondary effluent to its original pristine state. With monitoring sophistication, this would alleviate many questions concerning possible deleterious effects.

The latter approach has been chosen by the Denver Water Department and offers side benefits of considerable merit. First, "use-increment removal" offers a hedge against future standards. It is the move severe standard and guessing at the future is not required. Second, the idea of "as good as or better than the original source" has a tremendous public relations benefit and satisfies the attitude surveys mentioned earlier.

With current technology, it is not possible to monitor pollutants below certain concentrations and the health danger of every sewage constituent is not known. For this reason, the only logical approach for this highest order of reuse is a combination of "use increment removal" and medical health effects studies. Both are needed. The latter then assumes a secondary or fail-safe role.

Table 4 indicates what is required to achieve "use-increment removal" on Denver's water. The first column represents the existing drinking water and the second Denver's secondary effluent. The third column indicates what must be removed to restore the water to its original quality.

TABLE 4

USE INCREMENT REMOVALS

PARAMETERS	DENVER WATER COMPOSITE	SECONDARY EFFLUENT	REMOVAL INCREMENT
COLIFORM/100 ML	0.0	160,000	160.000
COD-MG/L	<5	62	57
TOC-MG/L	<2	25	23
PHOSPHATE-MG/L	0.04	8.7	8.6
TKN-MG/L	0.1	28.2	28.1
LEAD-MG/L	0.030	0.082	0.052
IRON-MG/L	0.273	3.000	2.7
TDS-MG/L	124	480	356
SUSPENDED SOLIDS-MG/L	0.0	98	98

Treatment Requirements

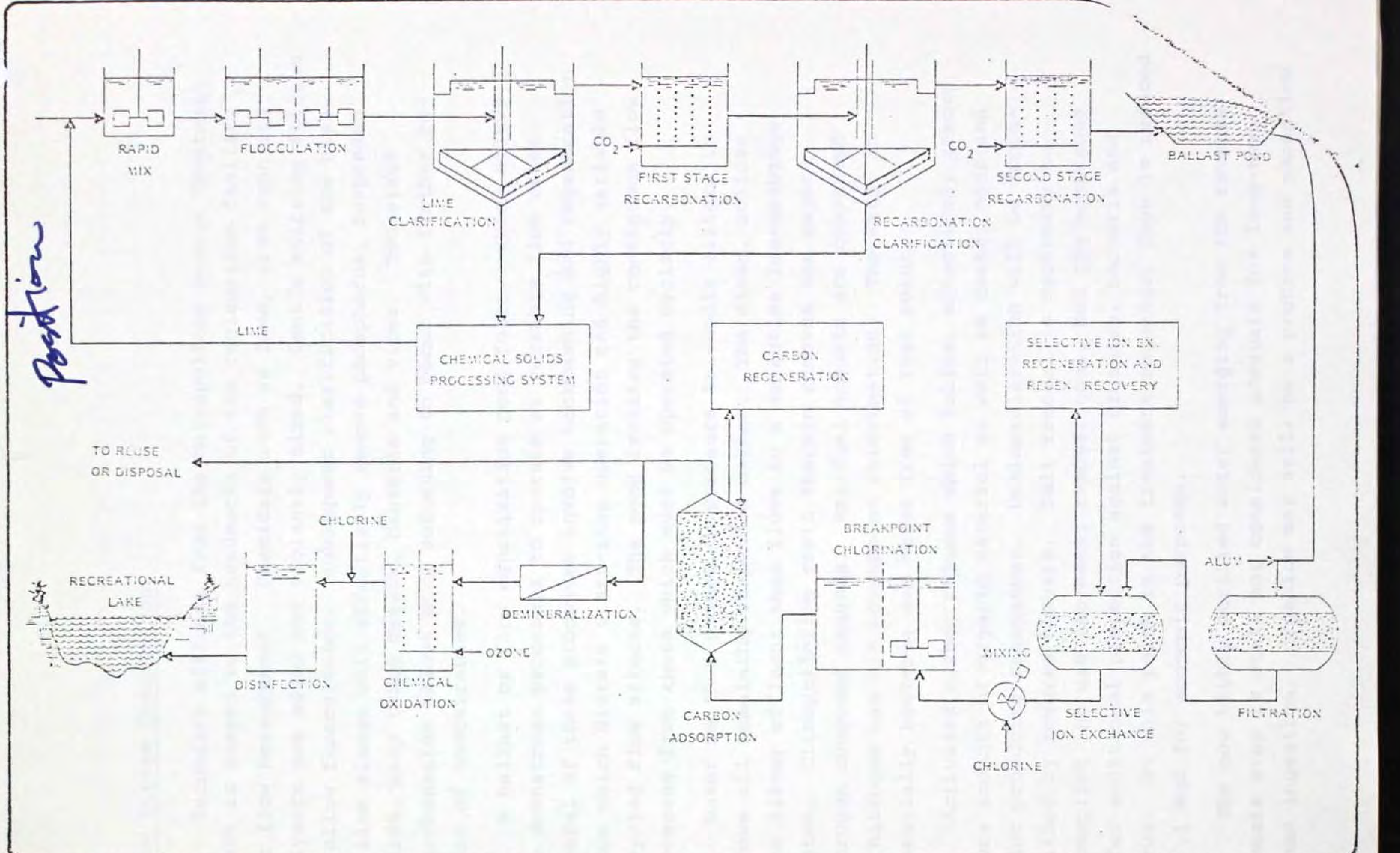
How is the concept of producing a snow-melt equivalent water achieved? This has been the subject of one year's work to conceptually design a potable reuse plant. The first attempt was to collect the opinion from a number of experts in the A.W.T. field in the fall of 1974 on what treatment scheme would accomplish the goal. This information plus subsequent technical input has resulted in a pre-design report as published in August of 1975 by CH_2M-Hill Engineers.

Figure 4 is the selected treatment sequence to produce a drinkable product. Many design objectives are incorporated into the proposal. First and foremost, the plant had to represent the best currently available technology and must incorporate within its design unit processes capable of reducing to acceptable levels all harmful or undersirable substances. Additionally, the facility must be of sufficient size to utilize equipment similar in nature to what would be used in a fullscale facility. It must further contain sufficient flexibility to allow uninterrupted operation and new technology input. It must be as self-sufficient as prudent use of funds will allow-which dictates that all known problems be faced today, not left for later solution. It must finally be visible and accessible to the public.

Because the plant must essentially be a fail-safe operation, two types of redundancy have been stressed: In-kind redundancy with backup duplicate tanks, dual pipes, stand-by equipment and process redundancy where one or more unit operations may perform the same function as another.

Taking all of these factors into consideration has resulted in the Figure 4 flow sequence. The selected size is 1 mgd which takes the plant out of the pilot plant category and into the demonstration plant terminology.

Position



Process Flow Diagram FIG. 4

Flow Stream Description

Secondary effluent from the Metropolitan Sewage Treatment plant is pumped to the headworks of the reclamation facility for flow measurement. Chemicals such as lime, alum iron and polymers are added and violently mixed. Gentle stirring follows to allow flocculation. Subsequent clarification of the high pH lime sludge will effectively remove phosphorus, suspended solids, many trace metals, bacteria and virus. Two-stage recarbonation allows more softening to occur with further removal of undesirables.

A ballast or flow equalization pond follows which allows the downstream processes to operate at variable flow rates. Several of these processes involve backwashing and regeneration steps which dictate start-stop operation and highly variable recycled flow streams. The pond isolates the continuous flow processes from those which must be operated cyclicly.

Water is then pumped to pressure tri-media filters to remove all remaining suspended matter. The clear, solids-free filter effluent then flows to a selective ion-exchange system. Clinoptilolite resin therein removes the major nitrogen compound ammonia. Residual amounts are converted to nitrogen gas via breakpoint chlorination. The water is essentially bacteria and virus free at that point.

Activated carbon columns which follow, effectively remove trace amounts of organic material as well as taste, odor and color producing substances. Demineralization will be accomplished by reverse osmosis. Salt removal is necessary to accomplish the use increment removal goal, but the membranes offer additional protection against organics, bacteria and virus. At this point in the treatment sequence, flow is reduced to .1 mgd for economic purposes.

The now highly purified water emerging from the reverse osmosis step is still not considered adequate for long-term human ingestion. Organics may still be a problem and ozonation perhaps coupled with ultra-violet light as a catalyst will follow. A synergistic effect occurs with almost complete destruction of organics.

Product water leaving the chemical oxidation system will receive a small chlorine dose for residual disinfection before entering a small recreational lake on site. Here the public will have access to fully reclaimed water for touching, feeling and the experience.

Although the treatment scheme has been chosen, many side streams will be researched in light of new discoveries. Some of these may include polymeric adsorption, ion-exchange, or different sequencing.

Expected plant quality is shown in Table 5. This is comparable to those values shown in the Use-Increment Table.

TABLE 5

QUALITY GOALS
1 MGD POTABLE DEMONSTRATION PLANT

PARAMETER	EXPECTED PRODUCT QUALITY
TURBIDITY	0.5
SUSPENDED SOLIDS (MG/L)	0.0
T.D.S. (MG/L)	150
TOTAL NITROGEN (MG/L)	0.05
TOTAL PHOSPHATE (MG/L)	0.07
HARDNESS (MG/L)	88.0
ALKALINITY (MG/L)	60.0
BACTERIA	0.0
VIRUS	0.0
TOXIC METALS (MG/L)	0.01
GROSS ORGANICS (MG/L)	<1

Solids Handling and Regeneration

With respect to solids handling, Figure 5 indicates some of the steps involved. No biological solids will be generated but there will be 7000 lb/day of lime sludge.

Clarifier underflows at 1% solids will first go to gravity thickeners and reach a 4% consistency. Classification and dewatering centrifuges will separate the phosphorus-rich stream from the reclaimable lime solids. Dewatered lime sludge will be fed to a calcining furnace for recovery of the product. The CO_2 generated is used in the recarbonation process. Approximately 20% makeup lime is required.

Lime recovery at the 1 mgd scale is very uneconomical but for demonstration purposes it is necessary.

Carbon will be regenerated in furnaces as well, then recycled. Again the process is not justified at 1 mgd, but any recycled chemical or stream which can affect quality will have to be tested.

The brine solution from the demineralization process will be disposed of at the sewage plant. Ultimate disposal will be by solar evaporation.

Nitrogen removal and recovery is perhaps the only new or undemonstrated process in the plant (Fig. 6). When the clinoptilolite resin is exhausted, a brine solution of NaCl is run through the beds which re-exchanges sodium ions for ammonium ions. The beds are then ready to use again. The ammonia laden stream reaches a clarifier where NaOH is added to raise the pH. $Mg(OH)_2$ is precipitated out because of its interference with the selective resins. From the clarifier, the liquid enters the ammonia removal and recovery process (ARRP) for closed loop stripping. As the water trickles down over open media, ammonia gas is stripped out with blowers. As the gas enters a second tower, H_2SO_4 acid is added and the product is fully recovered as a fertilizer

FIG 5

CHEMICAL SOLIDS HANDLING

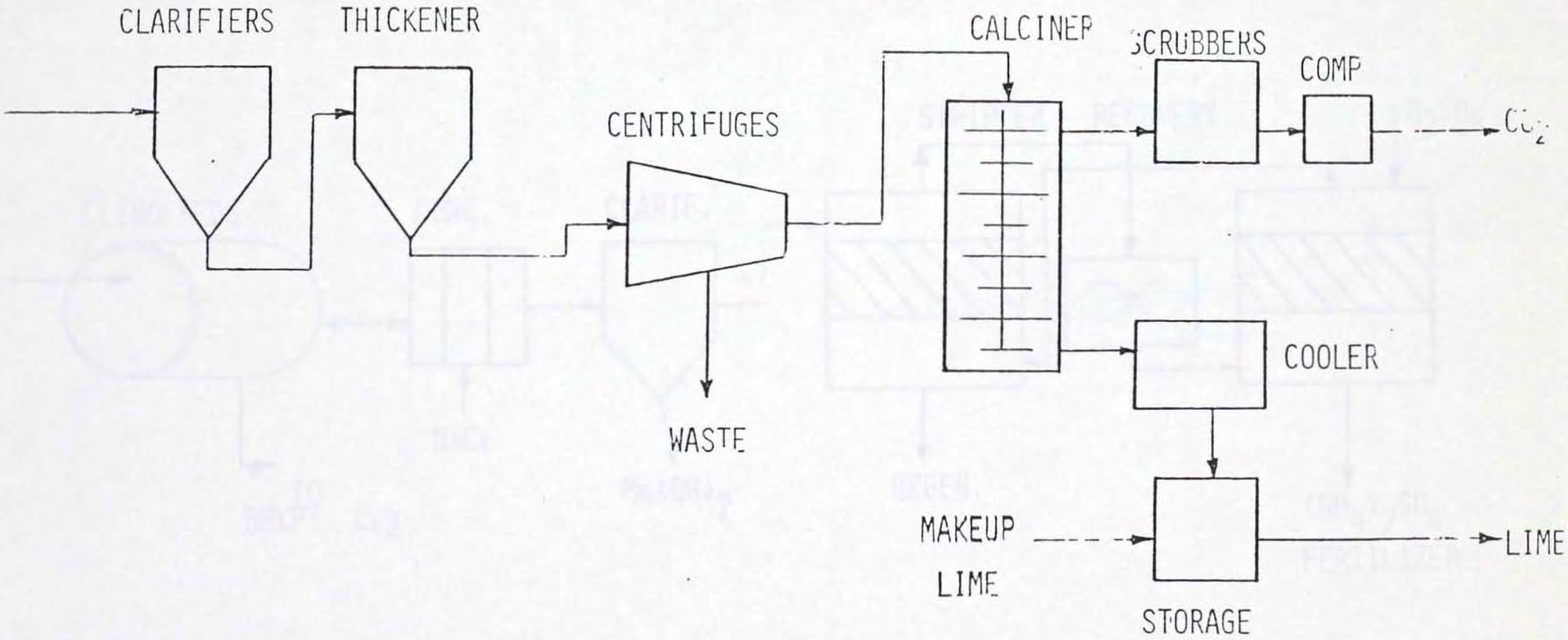
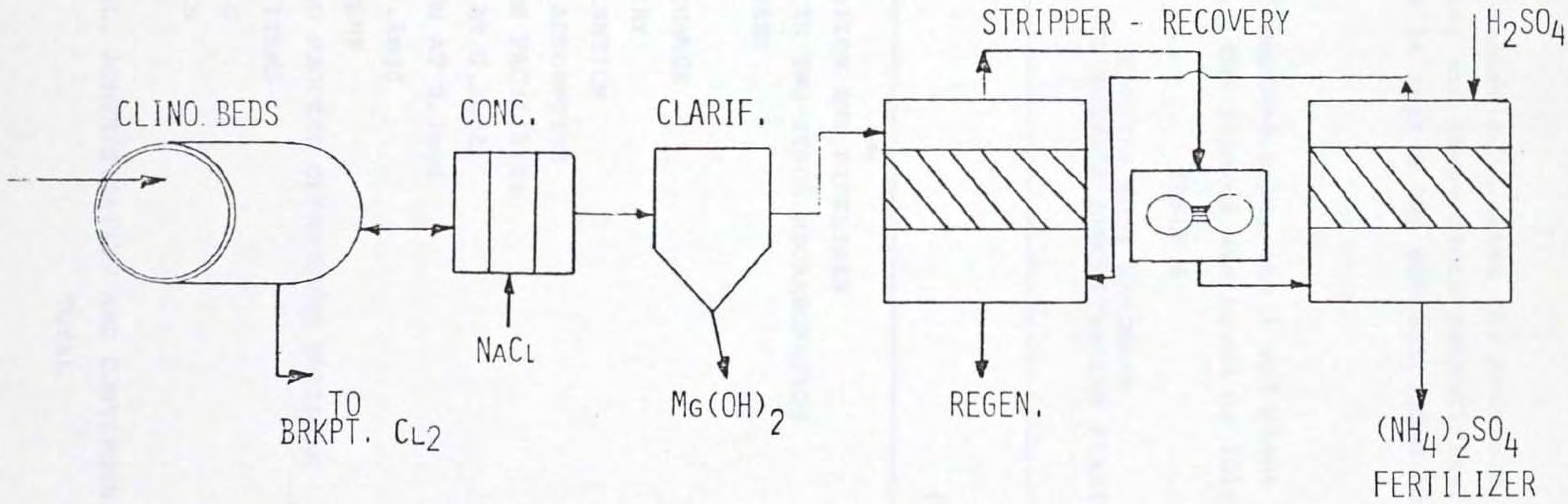


FIG. 6

NITROGEN REMOVAL AND RECOVERY SYSTEM



$(NH_4)_2SO_4$. This method eliminates the previous stripping problems of scaling and temperature sensitivity. The recovered product is near a 50% concentration and is highly marketable.

Economics

In terms of capital cost, the 1 mgd plant will run as shown in Table 6. The figures are based on July 1975 dollars.

TABLE 6

CAPITAL COST ESTIMATE
1 MGD POTABLE DEMONSTRATION PLANT

ITEM	COST ($ MILLIONS)
INFLUENT PUMP STATION AND PIPELINES	0.31
LIME TREATMENT WITH TWO-STAGE RECARBONATION	0.50
LIME SLUDGE RECOVERY	1.40
FILTRATION	0.40
SELECTIVE ION EXCHANGE	0.40
ARRP RECOVERY	0.30
BREAKPOINT CHLORINATION	0.12
ACTIVATED CARBON ADSORPTION	0.37
REGENERATION FACILITIES	0.68
DEMINERALIZATION AT 0.1mgd	0.15
CHEMICAL OXIDATION AT 0.1mgd	0.06
DISINFECTION AT 0.1mgd	0.02
LABORATORY EQUIPMENT	0.10
ADMINISTRATIVE AND PROCESS OPERATIONS BUILDING	0.68
PUBLIC RELATIONS ITEMS	0.15
SPECIAL MONITORING	0.25
LAND AND UTILITIES	0.17
YARDWORK	0.30
ENGINEERING, LEGAL, ADMINISTRATIVE AND CONTINGENCIES	1.79
TOTAL	7.75

O & M costs as indicated in Table 7 will approach \$460,000. At the 1 mgd scale, the final product will cost \$3/1000 gallons. But in the future, economies of scale will apply and the projected cost will range from 70-80¢ per 1000 gallons in the 100 mgd range.

Although this cost appears high, it is highly competitive to some of the other raw water projects now being contemplated.

TABLE 7

ANNUAL OPERATION AND MAINTENANCE COSTS
1 MGD POTABLE DEMONSTRATION PLANT

ITEM		ANNUAL COST
LABOR		\$297,400
POWER		21,300
FUEL		6,700
CHEMICALS		76,700
PARTS		57,800
	TOTAL	\$459,900

CAPITALIZED O & M = \$1,20/1000 Gallons

RESEARCH NEEDS

What is needed for the success of a potable reuse endeavor? First, of course, is a plant to produce the reclaimed water. Second is the need for many years of health effects research.

It is encouraging to see the increased federal interest in the potable reuse field. Indicative of this interest are provisions in the new Safe Drinking Water Act authorizing reuse funds. The EPA Office of Research and Development for a number of years has devoted effort to the demonstration of wastewater treatment processes capable of producing high quality effluents. The goal, however, was primarily pollution abatement and not reuse. Therefore, a reassessment of EPA priorities is necessary to place potable reuse in the proper perspective.

A unified health-effects program nationwide is needed because the problems are not unique to Denver. In fact, many areas are faced with water shortages where the reuse alternative is attractive. The public health aspects of questionable potable water derived from approved sources like New Orleans should be reviewed in the same light as potable reuse. In many instances, the public health aspects are the same.

Answering the health effects questions in potable reuse essentially answers those in all other reuse alternatives. The socio-economic aspects of potable reuse have not paralleled treatment technology as well.

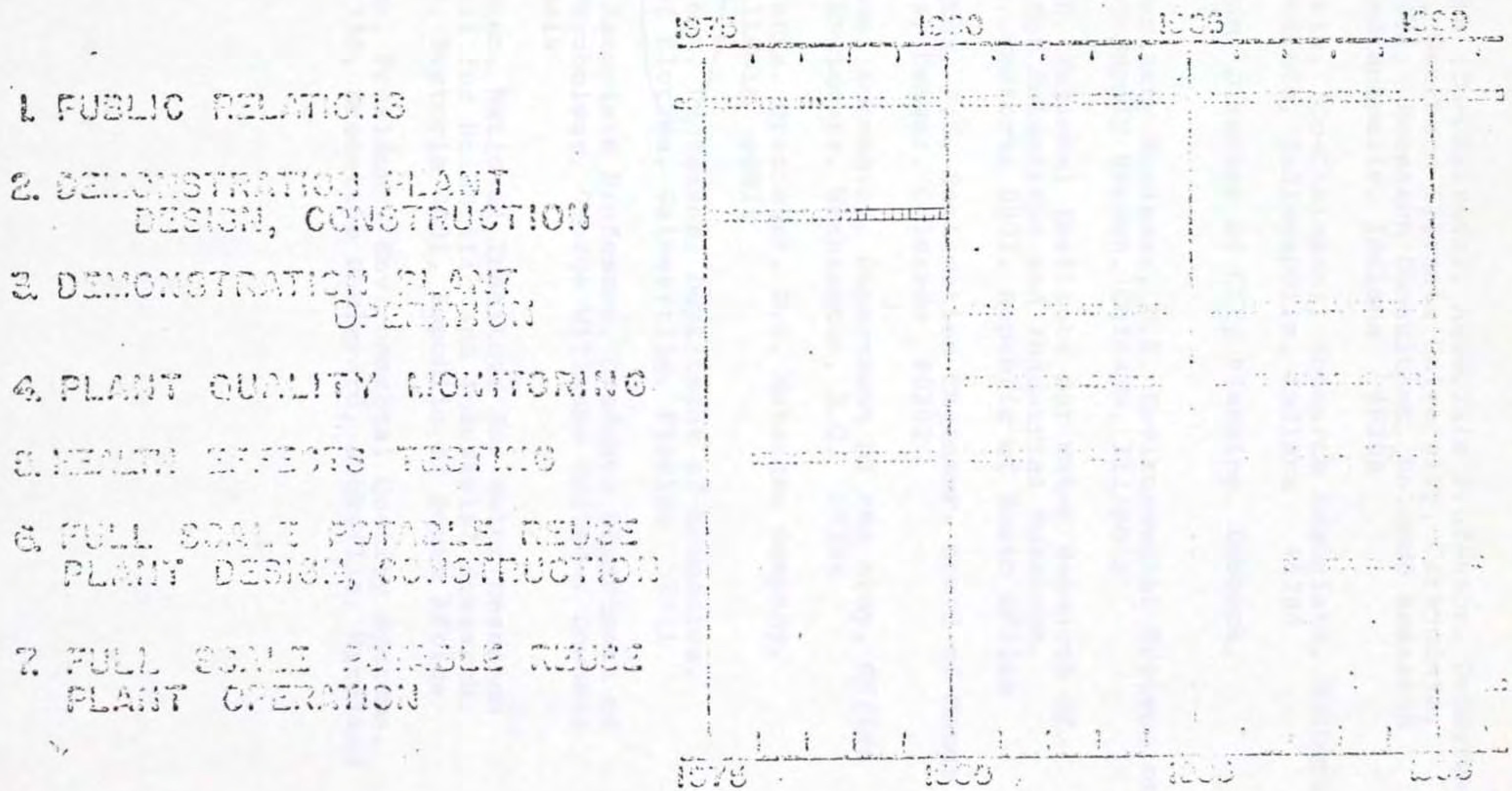
PROGRAM SCHEDULE

In terms of planning, the Denver program is graphically shown in Figure 7. It is designed to incorporate at each step lessons learned in previous steps and to answer all questions as the program progresses. The 1 mgd potable reuse demonstration plant is expected to be on line in 1980.

While potable reuse may not be an attractive, economically feasible resource for all cities, Denver believes it will be a valuable addition to its ongoing water development program. Fears of the unknown are not needed and should not be allowed to negate beneficial research. The potential benefits in water supply are too great.

FIGURE 7

DENVER REUSE PROGRAM



CONTRIBUTORS

Duane B. Baumann (Co-Chairman), Associate Professor, Department of Geography, Southern Illinois University, Carbondale, Illinois 62901; Research Consultant, Holcomb Research Institute, Indianapolis, Indiana 46208

Daniel M. Dworkin, (Co-Chairman), Research Associate, Holcomb Research Institute, Indianapolis, Indiana 46208

James E. Bertram, Director of City Planning, Lubbock, Texas 79457

Paul Durand, Sanitary Engineer, U.S. Environmental Protection Agency, Water Supply Branch, Chicago, Illinois

W.H.J. Hattingh, National Institute for Water Research of the Council for Scientific and Industrial Research, P.O. Box 395, Pretoria 0001, Republic of South Africa

Richard D. Heaton, P.E. Reclamation Engineer, Board of Water Commissioners, Denver, Colorado 80202

James F. Johnson, Economist, Department of the Army, Office of Chief of Engineers, Washington, D.C. 20314

Donald E. Matschke, President, D.E. Matschke Company, Hinsdale, Illinois 60521

James W. Milliman, Professor, Department of Economics, University of Florida, Gainesville, Florida 32611

John H. Sims, Associate Professor, Graduate Department of Counseling Psychology, George Williams College, Downers Grove, Illinois

L.R.J. Van Vuuren, National Institute for Water Research of the Council for Scientific and Industrial Research, P.O. Box 395, Pretoria 0001, Republic of South Africa

Leon Weinberger, President, Environmental Quality Systems, Inc., Suite 750, Executive Boulevard, Rockville, Maryland 20852

PARTICIPANTS

Corps of Engineers Personnel

Kang Wing Chan, Department of the Army, New York District, Corps of Engineers, 26 Federal Plaza, New York, New York 10007

Williams J. Chase, Jr., Los Angeles Corps of Engineers, Phoenix Urban Study, 2721 North Central Avenue, Phoenix, Arizona 85004

John J. Copeland, Corps of Engineers, Clock Tower Building, Rock Island, Illinois 61201

Thomas D. Hendrix, Department of the Army, Tulsa District, Corps of Engineers, P. O. Box 61, Tulsa, Oklahoma 74102

Thomas R. Kincheloe, Department of the Army, Southwestern Division, Corps of Engineers, Main Tower Building, 1200 Main Street, Dallas, Texas 75202

John J. Kranda, Department of the Army, Portland District, Corps of Engineers, P. O. Box 2946, Portland, Oregon 97208

Edgar Lawson, Department of the Army, North Atlantic Division, Corps of Engineers, 90 Church Street, New York, New York 10007

David Mann, Water Resource Planner, Board of Engineers for Rivers and Harbors, Fort Belvoir, Virginia

Robert E. Martin, Jr., Department of the Army, Corps, P. O. Box 2288, Mobile, Alabama 36628

Carl E. Miller, Jr., Department of the Army, Corps of Engineers, Huntington, West Virginia 25721

Howard Olson, Department of the Army, Corps of Engineers, Institute for Water Resources, Kingman Building, Fort Belvoir, Virginia 22060

Scott Sollers, U.S. Army Engineer District, San Francisco, 100 McAllister Street, San Francisco, California 94102

PARTICIPANTS

Corps of Engineers Personnel (continued)

George Steinrock, Department of the Army, Philadelphia District, Customs House, 2nd and Chestnut Streets, Philadelphia, Pennsylvania 19106

Chester E. Sutterlin, Department of the Army, Portland District, Corps of Engineers, P. O. Box 2946, Portland, Oregon 97208

James Tang, Army Engineer, Institute for Water Resources, Kingman Building, Fort Belvoir, Virginia 22060

Rodney L. Woods, Department of the Army, Corps of Engineers, Huntington, West Virginia 27521

PARTICIPANTS

Other Than Corps of Engineer Personnel

Philip R. Allgood, Indianapolis Water Company, 1220 Waterway Boulevard, Indianapolis, Indiana 46202

R. J. Becker, Indianapolis Water Company, 1220 Waterway Boulevard, Indianapolis, Indiana 46202

Richard D. Bertolotti, Henry B. Steeg and Associates, 4930 North Pennsylvania Street, Indianapolis, Indiana 46205

Floyd Bosley, R.P.S. Hendrick County Health Department, P. O. Box 306, Court House, Danville, Indiana 46122

William R. Gammel, Indiana Central University, Indianapolis, Indiana

Mike Graham, Water Resources Research Center, Geology Building, Indiana University, Bloomington, Indiana

David Gries, R.P.S. Hendrick County Health Department, P. O. Box 306, Court House, Danville, Indiana 46122

Steven Price, State of Indiana, State Board of Health, 1330 West Michigan Street, Indianapolis, Indiana 46206

Donald H. Schnepper, Illinois State Water Survey, Water Quality Section, Peoria, Illinois 61601

M.C. Stout, Indianapolis Water Company, 1220 Waterway Boulevard, Indianapolis, Indiana 46202

Nick Teliha, Indiana State Board of Health, Division of Water Pollution Control, 1330 West Michigan Street, Indianapolis, Indiana 46206

Randy Thorne, Indiana Heartland Coordinating Commission, 7212 North Shadeland, Suite 217, Indianapolis, Indiana 46250

Ken White, Indiana Department of Natural Resources, State Office Building, Room 605, Indianapolis, Indiana 46206