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SOCIAL, ECONOMIC, ENVIRONMENTAL, AND TECHNICAL FACTORS INFLUENCING WATER REUSE

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FOREWORD

This publication is the final report of a project supported in part with funds provided by the Office of Water Resources Research of the United States Department of the Interior, as authorized under the Water Resources Research Act of 1964, Public Law 88-379. The research plan recognized that a great many factors must be taken into account in order for water salvage and reuse to be a viable source of supply to meet various water demands. To identify and interrelate these factors, the research surveyed literature and current practice from several disciplinary perspectives, including technological, social, legal, economic, and environmental. The primary responsibility for these areas as represented by chapters in the report is as follows: Chapter I (Background)–Bishop; Chapter II (Technological)–Bishop and Pratishthananda; Chapter III (Social)–Colton; Chapter IV (Legal)–Crawford: Chapter V (Economic)–Keith; Chapter VI (Environmental)–Bishop and Pratishthananda. Chapter VII represents the researchers' effort to synthesize the key factors from each disciplinary perspective in providing an integrated consideration of how various factors interrelate in determining possibility of water reuse for municipal, industrial, and agricultural purposes in a particular area.

FOREWORD

This publication is the first report of a project supported in part with funds provided by the Office of Water Resources Research of the United States Department of the Interior, as authorized under the Water Resources Research Act of 1964, Public Law 88-379. The research plan recognized that a great many factors must be taken into account in order for water salvage and reuse to be a viable source of supply to meet further water demands. To identify and interrelate these factors, the research surveyed literature and current practice from several disciplinary perspectives, including technological, social, legal, economic, and environmental. The primary responsibility for these areas as represented by chapters in the report is as follows: Chapter I (Background) Bishop; Chapter II (Technological) Bishop and Pratishthananda; Chapter III (Social) Cellini; Chapter IV (Legal) Crawford; Chapter V (Economic) Keith; Chapter VI (Environmental) Bishop and Pratishthananda. Chapter VII represents the researchers' effort to synthesize the key factors from each disciplinary perspective in providing an integrated consideration of how various factors interrelate in determining possibility of water reuse for municipal, industrial, and agricultural purposes in a particular area.

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CHAPTER I

WATER REUSE IN WATER RESOURCE SYSTEMS

Background and need

A growing population together with rising per capita income has resulted in increased demand for water for virtually all uses. At the same time there has been increased public concern for maintaining the quality of streams for recreation, sight-seeing, and other social uses, and to conserve environmental values. A partial answer to these conflicts in water use and management is more extensive wastewater reclamation and reuse. Heretofore, water salvage and reuse has been mainly practiced in specific operational cases, such as recycling industrial process water, or on an ad hoc basis, such as a series of diversions and subsequent discharges of wastewater along reaches of a stream. However, in areas experiencing growing demand for water for virtually all social, economic, and environmental uses, an integrated region-wide approach to water reuse may be necessary in order to insure adequate supplies.

This requires a more explicit understanding of the systems relations among social and economic water using activities and the environmental and technological aspects of wastewater disposal in order to evaluate the opportunities for as well as the constraints on water salvage and reuse.

The problem setting

The general problems associated with water reuse are illustrated by the simple hydrologic flow system and the related water using activities shown in Figure 1-1. The system components consist of water sources (the reservoir, a reach of the river, and a well field), of basic water using activities (municipal, industrial, agricultural, environmental, viz. a wildlife refuge, and recreational), and of wastewater treatment activities (treatment plant). The flow of water from sources of supply to water using activities is represented by the arrows. As is generally the case the same basic sources may supply several different uses. Also, situations of water reuse may occur naturally as a result of the physiography of the system, such as irrigation return flow supplying the wildlife refuges, or purposely as with the recycle of industrial process water.

This pictorial representation of network flow, can be reduced to the more abstract network diagram of Figure 1-2, which shows the flows of water to and from water using activities. The matrix representation, shown in Figure 1-3, also illustrates the relation between sources, activities, and flows. In particular, Figure 1-3 shows the usual dichotomous approach to water resources planning and management. The allocation of water supply is treated separately from the problem of management and disposal of wastewater, thus overlooking the potential and opportunity for water salvage and reuse. In other words, all of the blank entries in the matrix represent possible opportunities for reuse which are often not included in conventional water planning and management.

However, because of the limited supplies of high quality water and the expanding demands placed on those supplies, treatment and reuse of wastewater has gained increasing recognition as a key element in total water resource management. Metzlev and Russelman (1968) provided a general treatment of direct water reuse and possible applications of reuse, indicating that reuse must be considered as an alternative of the development of new water resources. In analyzing water supply needs of the future in the context of "the total withdrawal concept," Symonds (1970) also arrived at the conclusion that in satisfying total water needs, water reuse should be taken into account in the development of water supplies.

The actual implementation of plans and programs for water salvage and reuse in a water resources system depends on a number of technological, economic, social, and environmental factors. The aim of this report, therefore, is providing a framework for examining the potential for water reuse from a total system perspective, considering both the interrelation of water using activities and the factors which may either constrain or enhance the possibilities of water reuse in the system.

Overview and approach

The full potential for water salvage and reuse is illustrated in the matrix of Figure 1-4. The matrix shows that after initial allocations from supply sources are made, the unconsumed flow from water using activities is available for reuse by the activity itself (i.e. a recycle reuse of the water) or for reuse by another activity (i.e. a sequential water reuse) in the system.

These "water reuse linkages" between the water using activities are operative to the extent that conditions are satisfied to achieve the combination of reuse indicated. Each combination of sequential or recycle reuse, as depicted by the entries in Figure 1-4, has associated technological, economic, social, and environmental factors

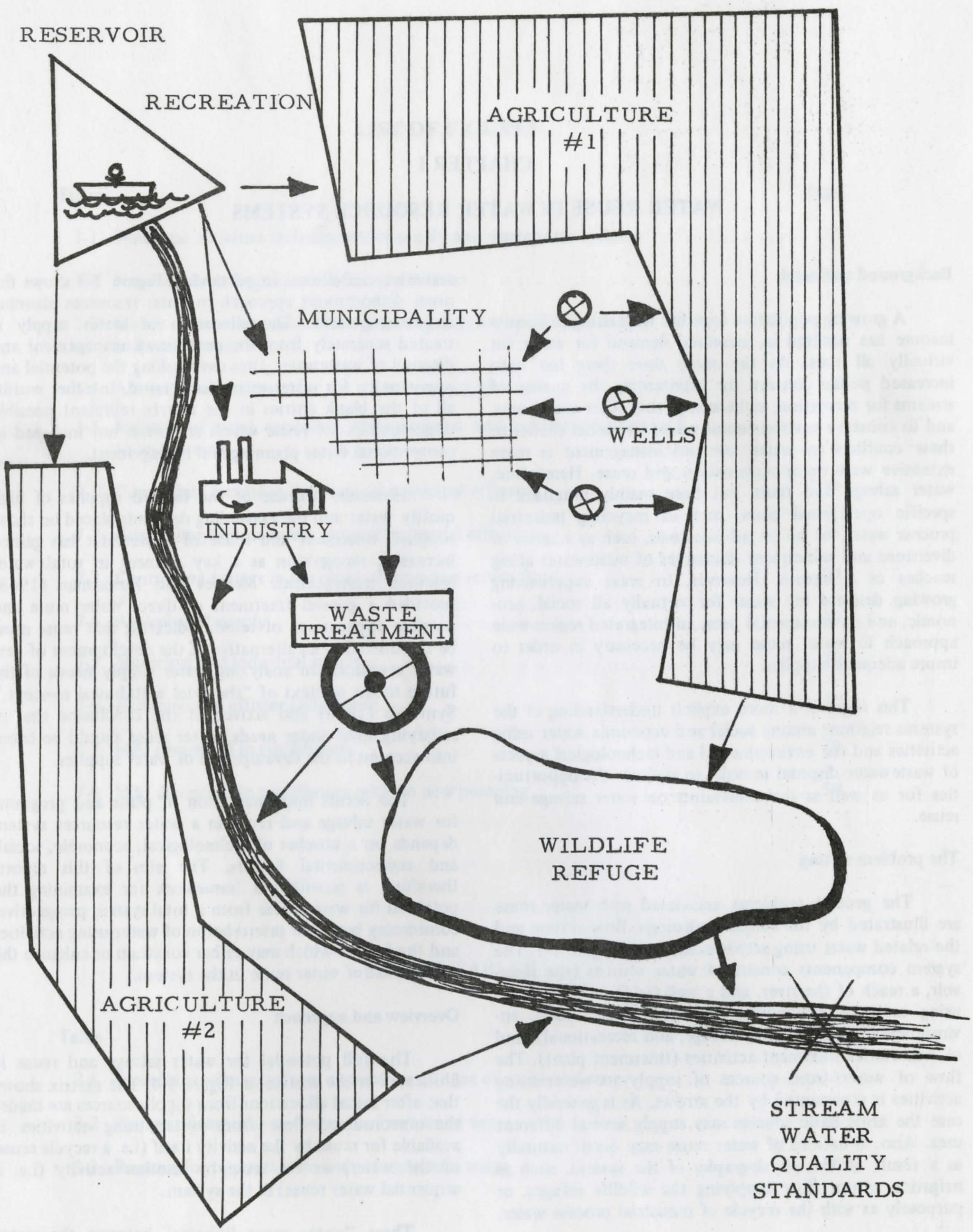

Figure 1-1. Water use activities including water supply and wastewater systems.

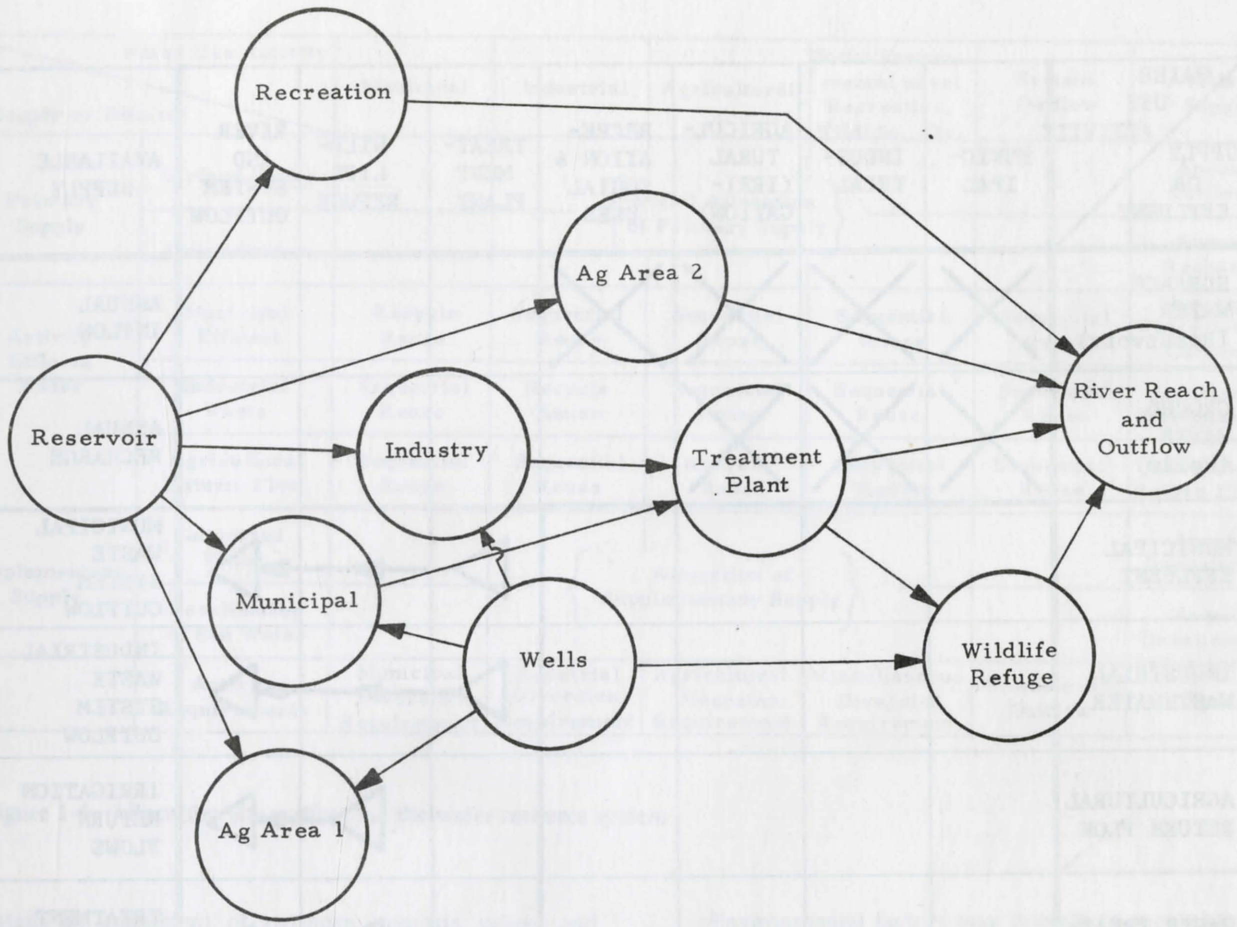

Figure 1-2. Network flow diagram of water use activities.

which will affect water reuse between activities. The effect of interaction of these factors is to control the allocation and flow among water using activities as shown in Figure 1-5. Some of the basic considerations include the activity's functional process, the quality of influent to and effluent from the activity, the economic, social, and environmental controls and constraints which govern the recycle reuse of the water by the activity itself, and the conditions that must be met in order to make water available for sequential reuse by other activities. In this context, this report examines the nature of the controls and incentives. shown at various points in the flow diagram of Figure 1-5, which will influence or regulate the rate of water salvage and reuse.

Technological factors are examined in light of what is needed to return effluents to a quality of influent needed for subsequent sequential or recycle reuse. This includes, among other considerations, treatment processes required to upgrade effluent quality to desired levels, and methods for recycling process water within the using activity in order to describe alternative possibilities for technological treatment and the points of potential application in the system.

Technological and economic constraints may be related to the ability of techniques of recycle or sequential reuse, or methods of treatment, to deliver economically the quality water needed for reuse in a particular activity sector.

The alternative combinations for reuse of water are also examined in terms of economic feasibility and the economic or market mechanisms which may influence their implementation. This includes the analysis and comparison of economic factors for the various potential reuse combinations, considering a variety of economic measures such as incentive payments, taxation, penalties, also including an examination of cost-benefit, market mechanisms, and economic efficiency.

Social and legal factors are evaluated in terms of the effect that they may have on the reuse of water. This

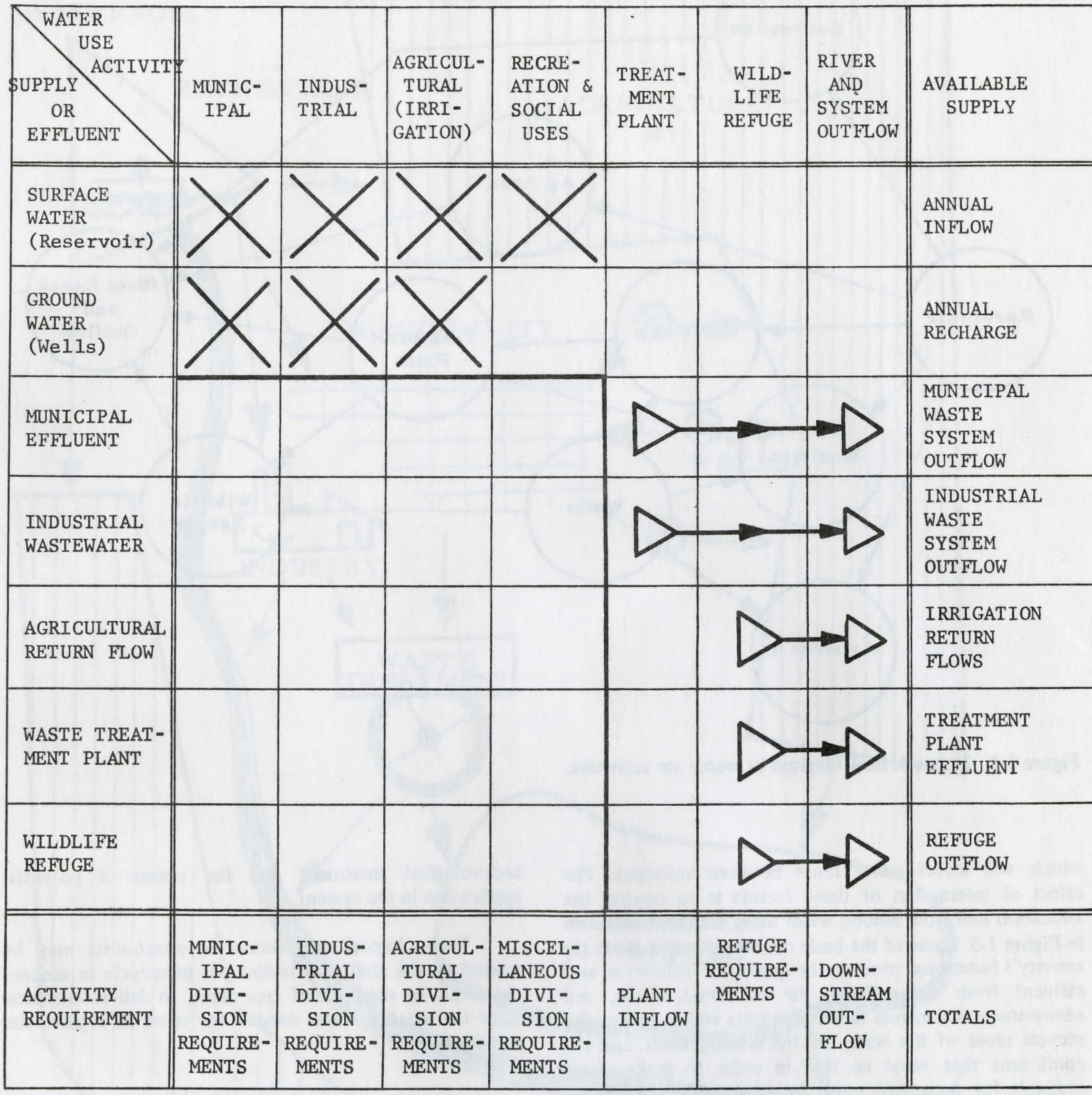

Figure 1-3. Matrix of water use activities illustrating dichotomy of water supply and waste treatment.

Supply or Effluent \ Water Use Activity		Municipal	Industrial	Agricultural	Social/Environmental uses: Recreation, Wildlife, Etc.	System Outflow	Available Supply
Primary Supply	Surface Water			Initial Allocation of Primary Supply			Annual Outflow
	Groundwater						Annual Recharge
Activity Effluent Water	Municipal Effluent	Recycle Reuse	Sequential Reuse	Sequential Reuse	Sequential Reuse	Sequential Reuse	Municipal Waste System Outflow
	Industrial Waste	Sequential Reuse	Recycle Reuse	Sequential Reuse	Sequential Reuse	Sequential Reuse	Industrial Wastewaters
	Agricultural Return Flow	Sequential Reuse	Sequential Reuse	Recycle Reuse	Sequential Reuse	Sequential Reuse	Irrigation Return Flows
Supplementary Supply	Imported Water			Allocation of Supplementary Supply			Annual Importation
	Desalination of Sea Water						Annual Desalination
	Activity Requirements	Municipal Diversion Requirement	Industrial Diversion Requirement	Agricultural Diversion Requirement	Miscellaneous Diversion Requirement	Downstream Outflow	Totals

Figure 1-4. Allocation alternatives for the water resource system.

entails an assessment of attitudes, interests, values, and norms of individuals and groups that may be affected by reuse of water. The social organization which presently exists will be considered in order to determine changes that may be needed to make the reuse of water feasible. The potential resistance to such change and the sources of this resistance in relation to the water reuse for various economic and social activities is discussed. Legal factors include an analysis of the federal laws, the state statutes, and the local ordinances which may inhibit or encourage various types of water reuse. Social and legal factors may be identified as important constraints on particular types of water reuse in relation to various activities sectors. Values, attitudes or norms may be in conflict with various reuse possibilities. In addition the social organization may need to be changed in order to adopt a particular reuse policy, since institutionalized normative patterns of behavior may prove to be constraints that may limit reuse possibilities.

Environmental factors may operate to encourage or restrict the feasibility or magnitude of reuse possibilities. Both the disposal of wastewater and water reuse have physical and biological impacts on the environment that need to be taken into account before water salvage and reuse practices are instituted.

The systems approach serves to integrate the technological, economic, social, legal, and environmental constraints. Since systems are complex a framework is needed for analyzing the interaction among factors that may impose serious constraints on the reuse of water. In this respect the purpose of this report is not to develop a "formula" for reuse but to organize a systems frame for considering water reuse and determining the necessary conditions for removing constraints of all types, technological, economic, social, legal, and environmental, in order to achieve the maximum opportunity for water reuse.

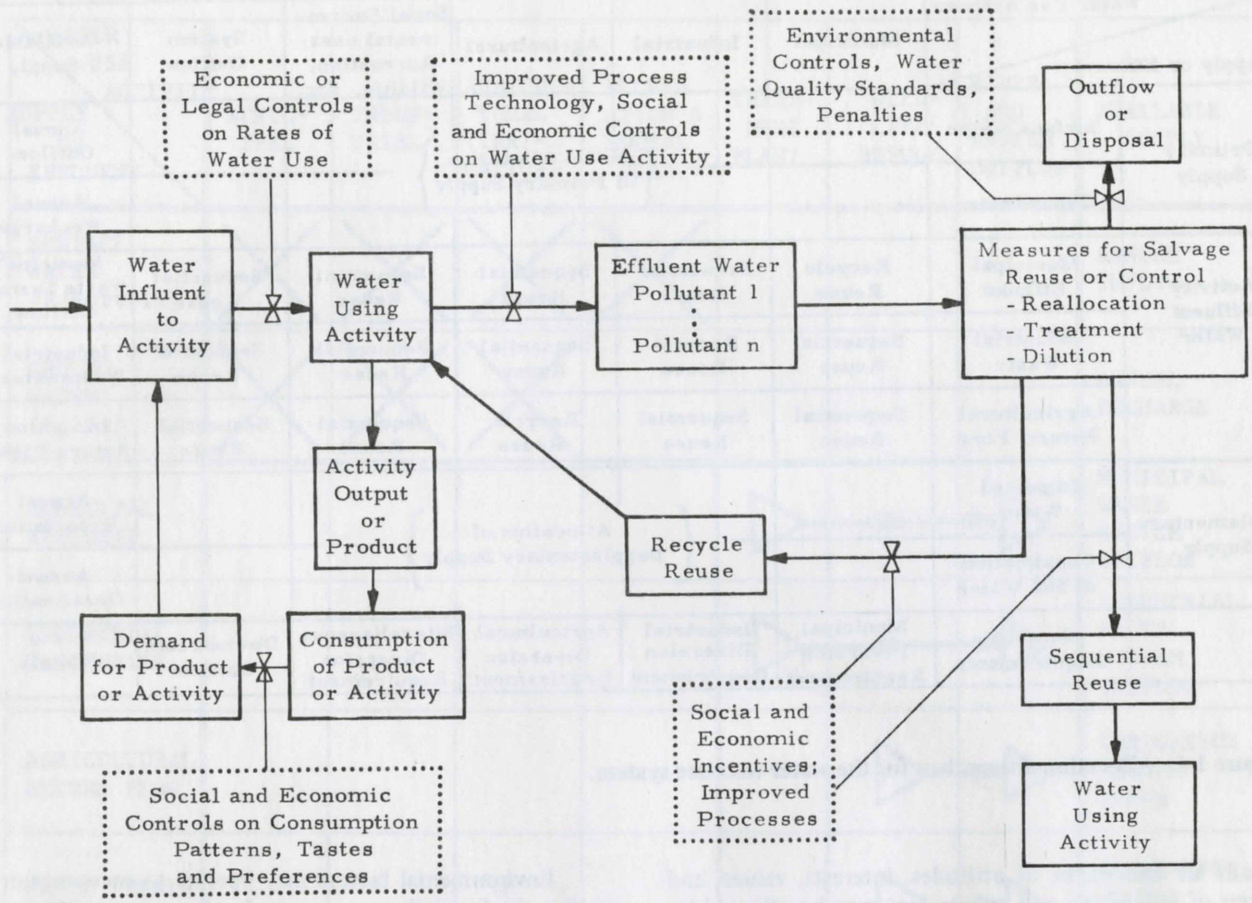

Figure 1-5. Relation of social, economic, environmental, and technological factors to water reuse.

CHAPTER II

TECHNOLOGICAL ASPECTS OF WATER REUSE: CURRENT PRACTICE

Water salvage and reuse, now being practiced in specific operational cases, provide excellent illustrations of technological aspects of water reuse in two areas. First, they demonstrate the kinds of processes and procedures that are presently implementable from the standpoint of technology, and second they illustrate the setting and situation under which such processes are operated.

The discussion in this section is organized to correspond to blocks in the matrix of Figure 1-4. The current practice for salvage of municipal wastewater effluents for reuse in municipal, industrial, and agricultural systems are each discussed in turn; likewise, discussions are developed for industrial and agricultural effluents. Finally, a brief review of treatment processes and plant technology is described as a vital link and necessary step in water reuse or wastewater disposal.

Reuse of municipal effluents

Indirect wastewater reclamation by subsurface injection for municipal reuse has long been practiced. Ammany (1968) reported the recharge activities in California and Israel. In the Dam River project near Tel Aviv, Israel, where municipal waste treatment plant effluent from the town of Ashqelon was used, the quality of reclaimed water after percolation through the ground met standards for potability. In Los Angeles County, the effluent from the Whittier Narrows Water Reclamation Plant was pumped underground for eventual unrestricted use. Parkhurst (1970), in describing the changes in the quality of the water mined from the subsurface strata, noted that the increment of salt added to the reclaimed wastewater was less than that obtained by importation from the Colorado River Basin. In Orange County Water District (Baier and Wesner, 1971) trickling filter effluent was used for injection through wells into confined aquifers. The reclaimed water was acceptable for domestic use after travel through 500 feet of a confined aquifer in that bacteria, virus, and toxic material were consistently absent. However, odors and tastes, as well as high concentrations of dissolved organics, were found to persist in the reclaimed waters.

Municipal recycle. The Windhoek, South-West Africa, became the first city in the world to reclaim wastewater on a regular basis for domestic reuse (Stephan and Schaffer, 1970). Here, 1 mgd of municipal wastewater is reclaimed and added directly back to the municipal water system. A physical-chemical process is used to reclaim water. The reclamation facilities consisted of provisions for flotation, ammonia stripping, recarbonation-stabilization, sand filtration, foam fractionation, chlorination, and activated carbon filtration. The potable water obtained from this process makes up 30 percent of the city supply, and was acceptable in terms of the World Health Organization Drinking Water Standards (Stander and Funke, 1969).

Municipal to industrial. Fuhrman (1969) discussed the criteria involved in making the decision for reuse as an alternative for developing fresh water sources. Several examples in which industrial water reuse achieved desirable economies were cited.

In Monterrey, Mexico, Gomez (1969) reported the use of reclaimed wastewater for subsequent utilization as source of water for 30 different industries. The wastewater was treated by conventional primary and secondary methods and was then lagooned and chlorinated. Water treated in this manner then could be used for gardens, cleaning, fire system, and cooling. Before such water could be used for manufacturing processes, however, further treatment was required. Softening by precipitation and demineralization by use of ion-exchange resins provided the additional treatment.

Another use of renovated municipal effluent is in the steam-electric power industry which requires make-up water for cooling towers (McKee, 1971). At San Diego, California, a reverse osmosis pilot plant was constructed for the purpose of providing reclaimed water for boiler water feed and for cooling towers (Dodson, 1971). At the refinery of the Standard Oil Company in Lima, Ohio, municipal wastewater treatment plant effluent was used as a boiler feed water when the city's treated water supply became inadequate (Elliot and Duff, 1971). The additional treatment required consisted of a high-rate solid-contact softener, filters, and a continuous, countercurrent ion-exchange softening system.

Municipal to agriculture. The amount of nutrient available in treated municipal effluent provides a good source of fertilizer in growing crops. Hirsch (1969) reviewed irrigation practice with reclaimed wastewater and assessed the effects of certain constituents in wastewater on the growth of various plants. Use of oxidation pond effluent for irrigation of forage crop in Mississippi was reported by Allen and McWhorter (1970). It was concluded that considerable increase in yield could be expected under normal growing conditions. A spray irrigation system is employed by Muskegon County in Michigan (Chaiken, 1973) as means of wastewater management. The effluent furnishes water for growing crops on sandy soil normally classified as non-agricultural land. The method is not only providing irrigation water but it also reduces amount of discharge nutrients to Lake Michigan.

Municipal to recreation and aesthetics. Parness (1968) reported on uses of trickling filter plant effluent to form artificial lakes and to irrigate the golf course and airport in Livermore, California. The creation of artificial lakes on the golf course with reclaimed water not only contributes to the aesthetic appeal of the course, but also acts as storage for irrigation water and as the location for groundwater recharge.

At Santee, California, a physical chemical process was used to reclaim wastewater. The renovated water is used to create artificial lakes for recreation purposes and to irrigate a golf course (Honser, 1970). Viral and bacterialogical content of the water has been studied and to date no public health problems have been encountered (Merrell and Ward, 1968).

Reuse of industrial effluents

General aspects of industrial wastewater reclamation and closed-loop recycle are discussed by Rey et al. (1971). With the current industrial trends, it was concluded that closed-cycle systems were generally feasible. However, industry in general has avoided implementation of reuse practices because the quantity and quality of its water supply has been assumed constant in time and space and because of the general fear of waste treatment (Dairs and Irisne, 1970).

Recycle reuse. The pulp and paper industry appears to have adapted water reuse to its needs rather extensively. Smith and Berger (1968) showed that pulp and paper mill wastewater may be treated stepwise to produce a water which is completely reusable in the manufacturing process. The process consisted of settling solid removal, massive lime precipitation, biological stabilization, activated carbon adsorption, and demineralization. Pulp-mill condensates have been successfully used in a conventional cooling tower (Esteridge et al., 1971). The pulp-mill condensates, decker filtrates, and condenser water were passed through a cooling tower and removal efficiency of 60 to 85 percent for pulp-mill condensates, and approximately 40 to 50 percent for combinations of decker filtrate and pulp-mill condensates, could be obtained. Recycling of reclaimed water resulted in the reduction of the mill's water requirement by 8 to 10 mgd. Reverse osmosis as well as electrodialysis and ultrafiltration also have been applied to the renovation of wastewater derived from the pulp and paper industry (Anon, 1969). The reverse osmosis and ultrafiltration is used to treat pulp-mill wash waters which generally contain approximately 1 percent dissolved solids. Nelson and Walraven (1969) reported a wastewater treatment by reverse osmosis in a neutral sulfite semi-chemical hard wood pulp process. The results indicated that a feed containing 0.5 percent dissolved solids could be concentrated to the 8 and 10 percent range at 600 psi pressure to produce a product water of suitable quality for direct mill reuse. A similar successful treatment of neutral sulfite semi-chemical pulp and paperboard mill wastes was reported by Morris et al. (1971).

Direct reuse of reclaimed wastewater is becoming a trend throughout the steel industry because of limited water supply. In some cases reclaimed water is more suitable for use than river water (Anon, 1968). Baker and Pettit (1968) detailed the process used to renovate water at Armco Steel Works, Middletown, Ohio. The treatment process consisted of sedimentation, coagulation, flocculation, and clarification. After clarification the water is cooled and put back into use. In the production of cast iron for Chrysler Corporation's Indianapolis, Indiana, foundary (Balden and Erickson, 1971), the wastewater containing oils, phenols and iron particles was renovated using chemical coagulation and separation of the resulting destabilized suspension in a solid contact clarifier. McMichael et al. (1971) discussed the problems associated with recycling of water derived from the gas cleaning system of blast furnaces. An extensive mathematical model that described the dynamics of recycle operation was developed and various limitations to recycling operations, particularly those relating to the stability of the water were described.

A method for reclaiming textile wastes that contain dyes. wetting and scouring agents, caustic soda, and other chemicals is detailed by Pangle (1969). The method consists of the addition of lime to absorb impurities which settles out as a sludge, and aeration which produced a foam that was removed, collapsed and recycled to the wastewater. Phipps (1970) described a textile wastewater renovation system at the Hollytext Carpet Mills in Southampton, Pennsylvania. The treatment, consisting of an activated carbon absorber, consistently reclaimed 80 percent of the wastewater flow. The renovated water has been used for making up new dyed solutions and for rinsing dyed carpeting. An air-flotation system, used for the purification of wastewater derived from latex polymer, is described by Lundgren (1969). This approach was necessary because of the variable characteristics of the waste stream. The renovation method was accomplished by coagulation with alum and subsequent scalping of the excess solids. Additional removals were achieved by pH adjustment with lime and precipitant removal by air flotation. The reclaimed waters were sufficient for subsequent recycle.

Sequential reuse. Smythe (1971) described the treatment system used at El Paso Product Company to reclaim city's wastewater for its cooling purposes. The renovated water, after the cooling cycle, is clarified, filtered, and then sold to an oil-producing company for secondary oil recovery.

Reuse of agriculture irrigation return flow

Irrigation is the largest single water user in the United States. However, methods of irrigation are improving efficiency of water use, and thus reducing return flow. In border and furrow irrigation, a system to collect tailwater and pump back for reuse was presented by Bondurant (1969). The method presented formula to compute pump size to be able to collect desired amounts of tailwater. Irrigation return flow is usually discharged downstream with minimal treatment. The practice is prevalent since the cost of pollution is not directly reflected on the water users (farmers) themselves. Ponding is used for retention of return flow before discharge in some cases.

Wastewater treatment processes as reuse links

Wastewater treatment methods can be divided roughly into two categories, the physical and chemical processes and biological processes. Relative merits of physical and chemical process versus biological process was reviewed by Barth (1971). The conclusion was that the basic techniques for wastewater treatment are generally biological systems combined with specific physical or chemical processes.

The physical and chemical processes

(1) Physical-chemical processes. Physical-chemical treatment usually consists of chemical clarification, dual or multimedia filtration for solid and phosphorus removal, and granular or powdered carbon absorption to remove the dissolved organics. In domestic raw wastewaters, however, most of the soluble nitrogen exists as ammonia or its predecessor, urea, and is not removed by clarification or adsorption. Three physical-chemical processes are available for ammonia removal: Air stripping of water above pH 10.5 (O'Farrell et al., 1972), breakpoint chlorination (Pressley and Bishop, 1970), and selective ion-exchange (Mercer et al., 1970). The clarification process, on either primary effluent or raw wastewater, uses lime precipitation or metallic salts, such as $FeCl_3$ or alum. In lime precipitation, two treatment options are available: The two-stage, high-pH lime process (Bishop et al., 1972), usually above pH 11.5, with intermediate recarbonation to remove excess calcium ion from the first stage, and the single-stage precipitation (Villiers et al., 1971) at pH as low as 9.5. In water with moderate alkalinities, the low pH lime process required supplemental flocculants, such as polymers of $FeCl_3$, to produce efficient clarification. Filtration can be achieved using conventional sand bed, or moving bed filter (Bell et al., 1970). A key property of activated carbon is its absorption of organics and color. Either packed or expanded carbon bed was equivalent in removal of soluble organics (Hopkins et al., 1970). The effluent from physical-chemical treatment was successfully direct reuse in municipal water supply (Stephan and Schaffer, 1970). The process can also be used to treat various municipal or industrial waste for direct or indirect reuse (Honser, 1970; Baker and Pettit, 1968; Balden and Erickson, 1971; Pangle, 1969; and Phipps, 1970).

(2) Reverse osmosis. Reverse osmosis can be considered as another physical treatment method. Although reverse osmosis originally developed for the conversion of brackish water to fresh water, recent research results have indicated that this process is also effective and economically feasible for wastewater renovation. Feuerstien and Bursztynsky (1969) evaluated reverse osmosis for treatment of municipal wastewater at all stages of conventional treatment. The wastewater was subject to chemical treatment before reverse osmosis. In all cases, excellent removal of all pollutants was obtained with varying degrees of membrane fouling. To overcome fouling problems, porous glass membranes were investigated as an alternative (Ballou et al., 1971). Kraus (1970) investigated a system in which membranes were dynamically formed from polyelectrolytes and the constituents of wastewater. While this system did not preclude fouling, it made membrane replacement extremely economical. Application of the process for municipal reclamation is still limited (Dodson, 1971). In industry, however, the process was extensively used especially in reclamation of pulp and paper-mill wastewater (Anon, 1969; Nelson and Walraven, 1969; and Morris et al., 1971).

(3) Groundwater recharge. Groundwater recharge can be accomplished either by injection through wells into confined aquifer or spreading over the surface into unconfined aquifer. In either method the aquifer acts as a natural filtration plant. Subsurface injection as a means of reclaiming wastewater was conducted by the Orange County Water District (Baier and Wesner, 1971), Nassau County, New York (Rose, 1970), and other water short areas. The surface spreading method is used both as irrigation and groundwater recharge (Sopper, 1971).

(4) Other methods. Ozonization of wastewater was claimed to be competitive with activated carbon for removal of refractory organics. In process, ozone will also disinfect. However, due to low half life of ozone in clean water, an effective contacting process has to be used (Huibers et al., 1970). Ozone in usages of 20 to 40 mg/l was found to be effective in decolorizing, deodorizing, and disinfecting the water (Kul'skii et al., 1970). Use of atomic radiation was reported (Spragg and Curtin, 1968; Ballantine et al., 1969; and Compton et al., 1970). While the treatment induced some desirable effect, the method is still uneconomical. Use of selective hollow fibers to remove carbonates from water, described by Cole and Genetelli (1970), obtained removals as high as several

hundred milligrams per liter. High quality effluents can be obtained by electrodialysis method (Brummer, 1967). However, membrane fouling and high electricity requirements per unit of heated effluent excluded the method from being an economically feasible wastewater treatment method, at least for the time being. Ion exchange is also used to reduce salt concentration before some industrial reuse of the effluents.

Biological processes

Biological processes have long been conventional methods for domestic wastewater treatment. The process utilizes biological activity to degrade wastes and reclaim the water.

(1) Biological filters. The function and design of trickling filter and the role of microorganisms in their efficiency is discussed by Bruce (1969) in general review of the process. Several mathematical formulations model the activities of the trickling filter (Lofy, 1969a and b; Ross, 1970; and Lamb and Owen, 1970). Improvement of efficiency of trickling filters could be achieved by new palling design or by mixing of the liquid film (Maier, 1968). Recirculation of treated waste improves trickling filter performance (Hanumanulu, 1969), the effect was more pronounced with deep filters and with increased wastewater strength. Various media as an alternative to normal mineral media have been proposed; most of them are plastic palling (Brendish and Perry, 1969; Seyfried, 1970; and Born, 1971). Comparison of the performance of stone-packed and plastic-packed was given by Wing and Steinfeldt (1970). An interesting use of redwood slat as media was reported by Schaumburg and Losswell (1970). The process produced a high quality effluent. The applications of trickling filter to specific industry wastes are reported for a number of cases. Tannery effluents and their treatment are discussed by Bailey (1970). The performance of a pilot-scale trickling filter, containing plastic media, in the treatment of wastewater from a Kraft mill was studied by Middlebrooks and Coogan (1969). Mohanrao et al. (1970) investigated the treatability of wastes from the manufacturing of synthetic drugs. Based on their studies, the factory installed two-stage, high-rate trickling filters for treatment of their waste. Trickling filter was also successfully used to treat brewery wastewater (Uhl and Hancke. 1970), gas works wastes (Sobkowiak, 1971), potato wastes (Filbert, 1971), 3-4-dichloroaniline production waste (Sotnikova and Udod, 1971), nitrilotriacetic acid (Bouveng et al., 1970), and meat packing waste (Baker and White, 1971).

(2) Activated sludge. In activated sludge units, zoogleal microbic growths, or flocs that are produced within the wastewater are systematically retained in suspension and kept aerobic through circulation by mechanical or pneumatic stirring. The oxygen requirements of activated sludge flocs are supplied by absorption from air originating either in the overlying atmosphere or in compressed air injected into the circulating wastewater. Use of high purity oxygen was found to be an efficient technique for aeration process in activated sludge units (Shvetsov, 1970). Chemical coagulation of biomass in conjunction with aerobic generation has been frequently used in activated sludge units. Ideally, the complementary biological and chemical processes can be designed to proceed in sequence at optimum rates by suitable pH control and power dissipation (Fair et al., 1971). Phosphate removal may be a primary or secondary consideration. To obtain good removals of phosphate in addition to BOD and nitrate, operation of aeration tank should be at pH range of 9.2 to 9.5 (McGriff and McKinney, 1971). Levin et al. (1971) reported that the addition of powdered coal to aeration tank had beneficial effects on sludge setting, BOD, and phosphate removal.

(3) Stabilization ponds. Stabilization ponds are one of the popular treatment methods in the semi-arid area where there is an abundance of sunshine and land. The principles of aerobic ponds design are outlined by Barnhart (1968), in which organic removal rates, oxygen requirements and transfer efficiency, solid production, nutrient, temperature, and pH requirements are discussed. Design and performance of an anaerobic-aerobic pond system is described by Wymore and White (1968). The design of facultative ponds based on the Wehner and Wilhelm equation for nonidle mixing for first order kinetics was proposed by Thirumurthi (1969). Sudweeks (1970) presented a detailed description of current facultative pond design standards in Utah. A mathematical simulation of facultative ponds was presented by Roesler and Preul (1970) by analyzing both aerobic and anaerobic sections. Three kinetic models were presented by Marais (1970) for the prediction of performance of facultative ponds. Current design criteria established by state agencies for anaerobic ponds and loading characteristics of existing ponds were outlined by White (1970), and design of two-stage and three-stage ponds are discussed (Kormauik, 1972; and Goswami, 1972) which increase efficiency and reduce retention time. The efficient operation of stabilization ponds is related to the use of certain types of algae (McGarry and Tongkasame, 1971; Culley and Epps, 1973). The algae is used to accelerate degradation process and later harvested for animal feed. The method, probably the most extensively used in treating wastewater, is generally the last stage of the treatment process before effluent is discharged or reused for other purposes. Use of oxidation ponds as pretreatment of petrochemical wastes was reported by Hovious et al. (1973).

(4) Landsurface disposal. The method utilizes soil-plant complex as treatment plant. The quality of reclaimed water depends on the method of application, application rate, and soil-plant complex type. Spreading, furrowing, and spraying are the usual methods of application. The method has long been used on a small scale, often in concurrence with irrigation. The renewed interest in application of this method emerges after a report of

successful application of spray irrigation by a Pennsylvania State University Project (Sopper, 1971), coupled with the requirements of the Federal Water Pollution Control Act Amendments of 1972 designed to reduce pollution discharge. A massive project is now undertaking at Muskeon County (Chaiken et al., 1973) to study full implication of the method.

Disinfection processes

The reuse of reclaimed water in many areas is restricted due to public health concerns. Methods for effective disinfection and rapid detection of harmful pathogens can enhance the scope of reuse. The primary objective of wastewater disinfection is the inactivation of pathogenic microorganisms including bacteria and viruses. The usual criteria used to determine the effectiveness of such disinfection measures is the concentration of coliform bacteria or more recently fecal coliforms in the treated wastewater or receiving stream.

Common disinfecting agents can be divided into five categories (Chang, 1971; Lothrop, 1969): (1) Oxidizing agents, (2) cations of heavy metals, (3) quaternary ammonia and pyridinium compounds, (4) gaseous agents, and (5) physical agents. In light of the trends in reuse of reclaimed waters, establishment of bacteriological standards for effluents is a necessity to protect public health. The disinfection of wastewater effluents is becoming a paramount issue. Thus it is appropriate to consider the efficiency of methods of wastewater disinfection.

(1) Chlorination. Various forms of chlorine have been widely used as disinfectants. The most effective form of chloride, as an antiviral agent, was found to be the undissociated hypochlorous acid (HOCl). A residual chlorination in a pH range yielding a substantial HOCl is essential for adequate disinfection of water subject to viral contamination.

Chlorine and chlorine compounds are by far the most widely used disinfectants, accounting for more than 95 percent of all disinfectant treatments. However, its effectiveness in inhibition of bacteria and virus growth is now under question. Furthermore, some of its compound residuals have proven to be toxic to useful aquatic species in the receiving stream (Zillich, 1972). On the other hand insufficient chlorine residual can cause significant bacterial aftergrowth (Shuval, 1973).

Important factors involved in the chlorination of wastewater were presented by Collins et al. (1971). Initial mixing of the chlorine solution and the wastewater has a profound effect on process efficiency as measured by the reduction in coliform bacteria. The results of disinfection of wastewater with chlorine were reported by Kott (1971). Coliform counts were reduced to less than 100/100 ml in some cases by chlorine doses of 8 ml/l. No algae were observed with two hours of contact in oxidation pond effluent.

In a study of effects of chlorination on oxidation ponds effluent (Hom, 1972), it was found that control of time of reaction and chlorine concentration affected process effectiveness. Excessive chlorine resulted in degradation of algae which caused increase in BOD.

(2) Ozonation. The use of ozone as alternative disinfection received added interest in recent years. Loss of economic breakpoint for ozonation using oxygen or air as the ozonation feed gas was presented by Harris (1972). The use of ozone at over 100 water supply installations in France was discussed by Gomella (1972). Lowndes (1972) outlined the conclusions that have been drawn from results obtained from full scale ozonation plants. The effectiveness of bactericidae efficiency was beyond doubt as long as the threshold value had been exceeded, and taste and odor reduction were cited as advantages of ozonation. Pavoni et al. (1972) discussed virus inactivation by ozone and wastewater characteristics. Contact time was reported to have been of greater importance than dosage level.

(3) Other methods. Other types of disinfection agents have yet to prove their commercial value in large scale treatment of effluents. In reuse of effluent as coolant, added heat can, after certain temperatures, inactivate bacteria and viruses in the circulatory water.

(4) Detection methods. There are two major pathogenic agents in effluents, bacteria, and viruses. Because of the difference in relative size of these two agents, different methods are used to detect and isolate each agent.

In most cases, detection of pathogenic bacteria, particularly enteric pathogens, requires at least 48 hours or longer for accurate results. Generally, pre-enrichment procedures are necessary, followed by culture in selective and/or inhibitory media then incubated at specific temperatures. In virus detection, filtration systems continue to be intensively explored in the search for more sensitive and quantitative methods for recovering viruses from wastewater. A quick, reliable method of pathogen detection is yet to be perfected. Many existing methods hold promising prospects. Since the effectiveness of disinfection has to be varified by detection until both can be developed to acceptable standards, reuse of reclaimed water still has to face existing restrictions.

CHAPTER III

SOCIAL FACTORS AFFECTING WATER REUSE

A variety of social factors could potentially affect the reuse of water by individuals living in a community. These include social behavior characteristics and norms related to the use of reclaimed water, reference groups, persons with whom an individual interacts, opinion leaders, and advocates of the use of reclaimed water. Factors related to the acceptance and adoption of social change could also affect the use of reclaimed water. In addition, public awareness of the environment, water as a resource, and pollution problems have increased in recent years and could have an impact on water use, discharge, and reuse or reclamation. Implementation of programs or policies for social characteristics related to water reuse are discussed in the following from two aspects: First, studies on individual attitudes towards acceptance of salvaged water for various uses and second, case studies which demonstrate processes of social change in adoption of reclaimed water for reuse as potable water supplies.

Attitudes and behavior toward water reuse

Attitudes are generally seen today by social psychologists as being composed of three components: The cognitive or belief component, the affective or feeling component, and the behavioral component. Bruvold (1972, p. 133) indicated in an examination of attitudes, beliefs, and behavior related to reclaimed water and water reuse that "... while specific attitude-belief and attitude-behavior consistencies were not always statistically significant, there was evidence for such consistency when more than one belief, or more than one type of behavior, were considered combinatorially." In another publication, Bruvold and Ward (1972) provided some summarizations of attitudes of selected individuals living in towns in California where reclaimed water is being used. Measurements included examination of the three components of attitudes, in analyzing the behavior patterns toward reclaimed water used for boating, golfing, swimming, and lakes and parks. The findings noted that a large percentage of the households interviewed did not have any participation during the previous year. In verbalized reasons for nonuse, most of those who did not participate stated that their reason for nonuse was that they did not participate in the particular activity. In the case of swimming where intimate contact with the water is made, over 46 percent of those who had nonuse stated only that another facility was used and not that the water was from a reclaimed source.

However, Table 3-1 (Bruvold and Ward, 1972) indicates that as the intimacy of the contact with the water increases, the stated opposition by those interviewed also increases. For example, over 56 percent of the respondents opposed the use of drinking water having reclaimed water as a source. In addition, over half of those interviewed also opposed food preparation in restaurants, cooking in the home, and preparation of canned vegetables using reclaimed water. By contrast, the percentage of respondents who opposed less intimate uses such as irrigation dropped to around 10 percent.

Table 3-2 (Bruvold and Ward, 1972) divides possible uses for reclaimed water into five categories–general, commercial, domestic, recreational, and food preparation–and indicates the pattern of response for the sample survey for opposing or not opposing uses designated within each category. The reasons for opposition to uses of reclaimed water are summarized in Table 3-3. An examination of these reasons shows that both the cognative and affective components could be included therein. Measured attitudes and behaviors are related to attitudinal and behavioral norms. It is believed that this may be the case to a large extent with the use of reclaimed water, especially in an area where a high quality supply has existed in abundant quantity.

As mentioned earlier, a variety of factors can affect those attitudes. Interaction and socialization by the individuals with whom one interacts helps develop existing attitudes of the individuals. However, these factors are extremely complex and adequate data did not appear to be available on the relationship of them to attitude toward water reuse. Therefore, no detailed discussion will be made here.

Maslow (1954) indicated that man has a hierarchy of needs. Most basic of these is the satisfaction of physiological needs including the need for water and food for survival. In addition, water could be used in the satisfaction of the other needs mentioned by Maslow: Safety, belongingness and love, esteem and status, and self-actualization.

Metzler et al. (1958) demonstrated that reclaimed water can be used as a source of potable water in the case of emergency. Their article discusses the use of reclaimed water in Chanute, Kansas, during the 1950's. At this particular time, a drought indicated by the authors to be

Table 3-1. **Percentage of respondents opposed to 25 uses of reclaimed water.**

Source of variation	Northern % (N = 386)	Southern % (N = 586)	Total % (N = 972)
1 Drinking Water	55.0	57.3	56.4
2 Food Preparation in Restaurants	53.4	57.7	56.0
3 Cooking in the Home	52.5	55.8	54.5
4 Preparation of Canned Vegetables	52.5	55.1	54.1
5 Bathing in the Home	37.8	39.2	38.7
6 Swimming	24.8	23.0	23.7
7 Pumping Down Special Wells	26.1	21.4	23.2
8 Home Laundry	21.1	23.9	22.8
9 Commercial Laundry	19.4	23.5	21.9
10 Irrigation of Dairy Pasture	15.6	13.1	14.1
11 Irrigation of Vegetable Crops	15.6	13.0	14.0
12 Spreading on Sandy Areas	13.2	13.3	13.3
13 Vineyard Irrigation	14.0	12.1	12.9
14 Orchard Irrigation	10.7	9.7	10.1
15 Hay or Alfalfa Irrigation	8.3	7.0	7.5
16 Pleasure Boating	9.1	6.1	7.3
17 Commercial Air Conditioning	7.8	5.6	6.5
18 Electronic Plant Process Water	6.0	4.1	4.9
19 Home Toilet Flushing	3.9	3.7	3.8
20 Golf Course Hazard Lakes	4.4	2.2	3.1
21 Residential Lawn Irrigation	2.3	2.9	2.7
22 Irrigation of Recreation Parks	2.8	2.4	2.6
23 Golf Course Irrigation	1.8	1.5	1.6
24 Irrigation of Freeway Greenbelts	1.8	0.9	1.2
25 Road Construction	1.6	0.3	0.8

"the most severe in Kansas history" was occurring. The city of Chanute was periodically plagued by water shortages from 1952 to 1956.

> The situation became progressively worse, however, and in the summer of 1956 the Neosho River ceased to flow thus removing the normal supply of water for the town. A variety of solutions were considered and rejected.
>
> On October 14. 1956 without fanfare, the city opened the valve which permitted mixing of treated sewage with water stored in the river channel behind the water treatment plant dam ..." (Metzler, 1958, p. 1025)
>
> Aside from the additional operating chores which were involved in chlorinating the plant effluent and continuously recirculating within the plant to secure more complete treatment, there were no appreciable effects on operation of the sewage treatment plant. There was an unprecedented awareness on the part of local residents and their neighbors in nearby communities of the innovation of Chanute and spectators from near and far visited the plant to observe its operation. (Metzler, 1958, p. 1027)
>
> There were no known cases of water-borne disease or other adverse affects upon health resulting from the use of the recirculated water. The evidence supporting this conclusion is only presumptive, however, since no systematic morbidity studies were carried out. Because of the sensitive public relations and public opinion problems involved, it was decided that a subsequent study rather than one carried on during the recirculation period would be preferable.
>
> On January 29, 1958, representatives of the state board of health met with the local medical society. The results of the special study were reported to the physicians and their comments solicited. They were specifically questioned about their clinical observations during the period of water reuse. The general conclusion was that no illness could be traced to the reclaimed water supply. They reported that stomach and intestinal disturbances were much more prevalent and widespread in the fall and winter of 1957-58 than during the same period the previous year when water reuse was practiced. The physicians were, of course, fully aware of the possibilities and alert for any indication of trouble. Patients were also cognizant of the situation and there was a general tendency to blame almost any kind of sickness–particularly stomach or intestinal disorders–on the water. One physician reported that his patients had complained of dermatitus from bathing in the water.
>
> The clinical observations by local physician and laboratory data are in agreement as to the safety of the water. The tap water met the Drinking Water Standards (Hirsch, 1969) for bacteriological quality during the entire period, and the special biological

Table 3-2. Pattern of response to five uses of reclaimed water.

Scale Content	Number of Uses Opposed						Totals	
	0	1	2	3	4	5	N	%
1. Food Production								
Preparation of Canned Vegetables	0	1	1	1	1	1		
Irrigation of Dairy Pasture	0	0	1	1	1	1		
Irrigation of Vegetable Crops	0	0	0	1	1	1		
Vineyard Irrigation	0	0	0	0	1	1		
Orchard Irrigation	0	0	0	0	0	1		
Number fitting pattern	440	339	23	12	11	69	894	92.0
Number not fitting pattern	0	3	32	17	23	0	78	8.0
2. Recreation								
Swimming	0	1	1	1	1	1		
Pleasure Boating	0	0	1	1	1	1		
Golf Course Hazard Lakes	0	0	0	1	1	1		
Irrigation of Recreational Parks	0	0	0	0	1	1		
Golf Course Irrigation	0	0	0	0	0	1		
Number fitting pattern	721	164	31	8	3	8	935	96.2
Number not fitting pattern	0	15	7	7	5	0	37	3.8
3. Domestic Use								
Cooking in the Home	0	1	1	1	1	1		
Bathing in the Home	0	0	1	1	1	1		
Home Laundry	0	0	0	1	1	1		
Home Toilet Flushing	0	0	0	0	1	1		
Residential Lawn Irrigation	0	0	0	0	0	1		
Number fitting pattern	437	144	157	167	20	13	938	96.5
Number not fitting pattern	0	1	14	4	10	0	34	3.5
4. Commercial Use								
Food Preparation in Restaurants	0	1	1	1	1	1		
Commercial Laundry	0	0	1	1	1	1		
Commercial Air Conditioning	0	0	0	1	1	1		
Electronic Plant Process Water	0	0	0	0	1	1		
Road Construction	0	0	0	0	0	1		
Number fitting pattern	422	310	138	38	9	6	923	95.0
Number not fitting pattern	0	2	21	13	0	0	49	5.0
5. General Use								
Drinking Water	0	1	1	1	1	1		
Pumping Down Special Wells	0	0	1	1	1	1		
Spreading on Sandy Areas	0	0	0	1	1	1		
Hay or Alfalfa Irrigation	0	0	0	0	1	1		
Irrigation of Freeway Greenbelts	0	0	0	0	0	1		
Number fitting pattern	408	290	84	83	19	7	891	91.7
Number not fitting pattern	0	8	43	17	2	0	81	8.3

Note: 0 means would not oppose; 1 would oppose; and total for number not fitting pattern includes missing data.

Table 3-3. Reasons for opposition to uses of reclaimed water.

Reason	Percent Stating Reasons Northern % (N = 386)	Southern % (N = 586)	Total % (N = 972)
1 Psychologically Repungnant	29.0	29.4	29.2
2 Lack of Purity	27.2	17.7	21.5
3 Can Cause Disease	9.3	10.1	9.8
4 Bodily Contact Undesirable	9.8	6.8	8.0
5 Undesirable Chemicals Added	6.2	4.4	5.1
6 Taste and Odor Problems	3.1	4.4	3.9
7 Cost of Treatment Unreasonable	1.6	0.3	0.8

X^2 not computed due to nonindependence of coding categories.

tests did not reveal the presence of pathogenic organisms. In evaluating the laboratory evidence, however, it is well to keep in mind the limitations of the techniques available at present, the difficulties involved in the isolation of specific disease-producing organisms, and the possible limitations of the coliform test under the prevailing conditions...

Initial public acceptance of the water was good, probably because the citizens knew that their supply normally received diluted treated sewage from seven upstream communities. No public mention of the move was made until after recirculation had been started. Public reaction became more adverse when stories appeared in the local newspapers. Bottle-water sales flourished and virtually all grocery stores carried a large stock. Exact figures on the total of bottled water sold are not available, but one of the two major distributors reported a sale of 40,000 gal in 5-gal containers at 20 cents per gallon plus $1.50–unrefunded–for the bottle.

More than 70 private wells were drilled, but most of the water pumped from them was too highly mineralized for domestic purposes and was used primarily for car washing, sprinkling, and other purposes for which use of city water was prohibited. Water was hauled from neighboring towns and farm wells by some people. The city and the Santa Fe Railroad hauled a total of 150,000 gal of water into the city and made it available–at a central location–free to the public for drinking purposes. One cement plant which could not use high-chloride water hauled 20 mil gal of water in a 9-day period at a cost of $100,000. (Metzler et al., 1958, pp. 1053-1054)

Several important social factors related to water reuse can be deduced from the above quotations. As previously noted the physiological needs of man need to be met, and as the supply of higher quality water decreased, supplemental supplies from reclaimed water could be introduced into the culinary system and still have acceptance by the public. Some opposition could develop and some additional supplies such as bottle water would be found. However, if no other supply besides reclaimed water were available, an assumption can be made that the reclaimed water would be used.

If reclaiming techniques were adequate and water of a quality comparable to that which has been previously used could be created, positive behavioral reinforcement through satisfaction received from the use of reclaimed water could help to change behavioral norms. Some problems with the quality of the water existed because of the high requirement for purification which left a residual color and taste in the water. In addition, detergents and other impurities created foaming water at taps in the homes of the town. The color, the taste, and the foaming would certainly not provide a condition conducive to positive reinforcement of a behavior pattern including the use of reclaimed water. Therefore, positive reinforcement is contingent upon the development and use of techniques which will provide high quality water. This factor then is closely tied to the quality of water reclaimed through various techniques. Those that produce higher quality water would be expected to provide stronger positive reinforcement.

The Chanute example provides another socio-legal factor which could be used in regulating the supply of water available for particular uses. During the period of water shortage certain uses were prohibited, such as car washing, sprinkling, and some other purposes. As in the case of Chanute, lower quality water such as highly mineralized well water could become the supply source for these uses. Or in extreme cases, these uses could be completely legally prohibited.

Social change in acceptance of water reuse

Hanke and Athanasiou (1970) summarized some social psychological factors related to the adoption of reused wastewater as a potable water supply. They wrote:

The variables of age, income and occupational status worked rather well as predictors indicating that the demographic character of a community is an important consideration *vis a vis* the acceptability of water reuse. This may suggest that pilot programs for

> water reuse, or other potentially sensitive programs, be instituted in carefully selected communities. These communities would be populated with young, educated persons with relatively high income who would be expected to be early adopters. Implementation and acceptance of an innovation in such a community would affect the communicability of the innovation and might provide a model of acceptability for other communities. A trial community would, however, have to be selected with great care. It would have to be one which had high status in the views of the surrounding communities. If an innovation is adopted by a low status community made up of young, rich, educated persons, it might very well be rejected by surrounding groups. A college town, for example, might not be the best trial community whereas a white-collar or professional suburb might be better.
>
> The public's attitude regarding the safety of the product resulting from the purification process was a good predictor of acceptance. It is likely that this item tapped an underlying attitude of faith in technology since some subjects indicated that they felt anything was possible, even purifying wastewater, if we were able to do something as advanced as walking on the moon. This suggests that the public's perception of the engineering feasibility of many innovations could be an essential factor in acceptance.
>
> In addition to the variable of perceived safety the degree of knowledge about the innovation was a fairly consistent predictor of the behavioral components of acceptance. These items seem closely related to the complexity that even an innovation with such obvious rational and economic benefits as reused wastewater must be presented along with an effort toward educating the public with regard to its safety and benefits. Zajonc (1968) has noted that, if an object is initially effectively neutral, mere repeated exposure to it will produce liking for the object. The concept of reused wastewater is probably not affectively neutral but repeated exposure to the concept in a positive setting might go a long way toward preparing the public to accept such an innovation.
>
> Water supply officials attitudes toward acceptance of processed wastewater for drinking purposes correlated .46 (p .03) with their awareness of water pollution levels in the region. In general, all the officials were well informed about the wastewater treatment and their acceptance of the hypothetical innovation seemed to be based primarily on the perceived need for the innovation rather than their own personal characteristics such as age, income, etc. (Hanke and Athanasiou, 1970, pp. 9,11)

Understanding of these variables is somewhat dependent upon some familiarity with the social change paradigm used by La Piere (1965) and others. This paradigm divides the change process into three main parts: Innovation, advocation, and adoption. In the case of reclaimed water, the technological developments by engineers and other inventors provide innovations. The advocates are those who strongly advocate the adoption of these innovations.

Hanke and Athanasiou (1970) provided some of the characteristics of early adopters. These characteristics could be used in conjunction with characteristics of the population of an area to ascertain expected response to reuse proposals. The examples provided in their quotation show which variables are likely to be important. For example, if it is projected that the proportion of young, educated persons with high incomes is going to increase, one could assume, based on the findings of the above authors, that attitudes and behavior change in the direction of water reuse adoption will be facilitated. In addition, if public attitude regarding the safety of reclaimed water could be improved, it could be assumed, based on the earlier quotation that acceptance and consequent use (behavior change) would increase. Education of the public concerning the innovations could also increase acceptance. Awareness by water supply officials of pollution levels in the region was positively correlated with attitudes toward the acceptance of processed wastewater for drinking purposes.

Advertising and marketing techniques could be used to inform officials and the public about reclaimed water. Studies related to the use of natural resources have indicated that educational programs such as the Smokey Bear campaign for fire control can affect the attitudinal and behavioral norms of society. As the attitudes change and larger numbers of associational groups accept the innovations, the principles of socialization indicate that accepted ideas will be transmitted to those with whom group members interact. Thus, after acceptance by early adopters, the acceptance rate could increase to the point where a general acceptance of the use of reclaimed water could exist.

Public environmental awareness. In recent years public awareness of environmental problems and potential shortages has increased. New voluntary conservation oriented organizations have been formed to exist alongside older organizations like the Sierra Club. Problems and shortages have occurred throughout the United States, and many officials have made efforts to correct existing problems. In some areas efforts have been made to change the behavioral and attitudinal norms toward resources in short supply. For example in the Washington, D.C., metropolitan area officials responsible for water use are promoting programs to encourage those living in the area to conserve water and have had plastic bottles distributed for placement in toilet tanks to lower the amount of water used. In other areas some consumers have become aware of shortages or potential shortages and have made efforts to lower use and waste.

Both the quantity and quality of water discharged after use could be affected by social forces related to the current environmental movement. Laws which provide an institutionalized framework reflecting social attitudes and values already regulate water disposal, and if additional problems develop, more social and legal prohibitions may be placed on the disposal of water by municipalities, industries and agricultural water users. Regulations may also be placed on the efficiency of water use.

In addition environmental groups acting as advocates of particular policies may influence the sequential use of water. For example, conservation of water may be accomplished by encouraging sequential use by those needing water.

Summary

The attitudes provided by Bruvold and Ward (1972) as a base for current opposition to the use of reclaimed water coupled with rates of change implied from the data given by Hanke and Athanasiou (1970) indicate the basis and process for the future use of reclaimed water. In addition, decreasing supplies for various types of uses such as culinary, could bring about an accelerated behavioral change and more readily acceptance of reclaimed water for household use as indicated by Metzler et al. (1958).

The actual implementation of water reuse policies and policy changes would come through the social structure of the community, state, region, or nation. This includes not only the formal legal structure which exists, but also reference groups, family, peers, work and others.

CHAPTER IV

LEGAL ASPECTS OF WATER SALVAGE AND REUSE

The implementation of water salvage and reuse programs will necessarily have to comply with constraints that are operative under existing water law. Particularly in the arid west, where water is in short supply, water law is generally based on the doctrine of prior appropriation. The basic legal concept which serves to prevent the waste of water in water use is that beneficial need is the measure and limit of the water right. Beneficial need is measured by the reasonableness of the water use—whether agricultural, municipal, recreational, or industrial—as it relates both to the purpose of the use and to the efficiency of the works and facilities used to divert and transport the water to the place of use.

The doctrine of beneficial need operates in conjunction and in competition with the doctrine of prior appropriation. The latter provides that the seniority of water rights are determined in order of the dates acquired. Once reasonableness of beneficial need has been established and a water right conferred, the concept of prior appropriation protects the use and the means of use.

Arguing that a legal means already exists in the states for preventing the waste of water, the National Water Commission Report (Legal Study No. 8-C, September, 1971) contains recommendations that have important implications for water reuse.

a. *The states should enforce existing laws to prevent waste or excessive use of water.* No legal reform is needed to prevent excessive uses of water beyond that reasonably required for the purpose of use, and no legal reform is needed to require reasonable efficiency in diverting works and transporting facilities. But better administration might be needed to assure that existing laws are being complied with to prevent waste from excessive water uses and unreasonably inefficient practices.

b. *The states should quantify "reasonable efficiency" for particular areas in order to reduce water waste.* Where feasible, which presumably will be those areas where water shortage is most critical, an administrative evaluation should be made of the reasonableness of water use efficiency, and standards and criteria should be promulgated to specify the level of efficiency required for the particular area. This might be akin to establishing a duty of water for use on particular crops or classes of land, or in setting maximum allowable losses in diverting works and transporting facilities. Judicial review would be provided to test the reasonableness of the standards and criteria, and, so long as they were found to be reasonable in light of existing conditions in the area, it is unlikely that any private property interests in water rights would be unconstitutionally diminished or impaired.

c. *Where waste cannot be enjoined by law, and where salvage practices cannot be compelled by law, the states should adopt doctrines and procedures to encourage voluntary salvage programs.* This recommendation has two basic legal aspects. The first is that where salvage operations are feasible but cannot be compelled (such as seepage losses in natural streams), the law should clearly identify the persons who will be entitled to use the water salvaged and provide procedures for the acquisition of a formal water right to the salvaged waters (the same would hold true for salvage operations in artificial facilities). The second aspect is that water rights in salvaged waters should be freely marketable and transferable, without legal restraints other than the protection of other existing water rights. This is so because salvage operations in privately owned facilities will not be instituted by the owner of such facilities unless he has a need for the water to be salvaged *or* unless a sale of the water salvaged would provide an economic incentive for making the salvage. In other words, where the law cannot require the salvage, it should encourage the salvage, by clarifying ownership rights and administrative procedures and by giving the market a free reign to produce economic incentives for salvage practices.

These recommendations state, in effect, that the law as it now exists should be enforced; that, where needed, standards of efficiency should be established to require a genuine reasonableness in water use; and that, where the law cannot compel water salvage or more efficient uses, it should encourage and facilitate voluntary salvage and improved efficiency. In applying these recommendations, the difficult question which arises is that of determining to what extent standards of reasonableness may change from time to time and from place to place, depending on improved technologies of use and application, and on the seriousness of water shortage and other water use demands.

These recommendations were not included or implemented in the Federal Water Pollution Control Act of 1972. There are, however, several legal means by which these recommendations might be given force. One means is through judicial review. Under the Federal Administrative Procedure Act, a federal court will set aside an agency's actions if they are arbitrary, capricious, abusive of discretion, contrary to the Constitution, in excess of statutory jurisdiction, or unsupported by substantial evidence (5 U.S.C.A. 706, 1967). Similar statutes have been established for the review by state courts of state administrative agencies. Although limited review by courts has been the general rule, the process of judicial review seems to be gaining momentum as a significant judicial control in environmental management. Through the avenue of judicial review, an individual or group might appeal to a federal court to determine whether a water conservancy district or to a state court to determine whether a state water agency has applied the doctrine of beneficial use reasonably in conferring water rights and/or in quantifying reasonable efficiency for particular areas in order to reduce water waste and encourage water reuse.

Class actions suits might provide another means for requiring a state or federal water agency to implement the National Water Commission recommendations. A number of states have passed legislation enabling class action to be taken. The Michigan legislation, drafted by Joseph Sax of the University of Michigan Law School, has become a model both for other states and for the Hart-McGovern Bill in Congress. The latter declares that each person has a right to the protection of the environment and that it is in the public interest for Congress to provide adequate remedy to implement this right through class action. The bill is offered as an explicit response to the need for more public participation in decisions affecting environmental values. This bill would sweep away the defenses of lack of standing and would shift "burden of proof" from the plaintiff to the polluter. Section 4 of the bill states:

> When the plaintiff has made a prima facie showing that the activity of the defendant affecting interstate commerce has resulted in or reasonably may result in unreasonable pollution, impairment, or destruction of the air, water, land, or public trust of the United States, the defendant shall have the burden of establishing that there is no feasible and prudent alternative and that the activity at issue is consistent with and reasonable required for promotion of the public health, safety, and welfare in light of the paramount concern of the United States for the protection of its air, water, land, and public trust from unreasonable pollution, impairment, or destruction.

Although the Hart-McGovern Bill may never be enacted–it has been opposed both by the Environmental Protection Agency and the Council on Environmental Quality as well as industry–class action is gaining momentum in various states and has already gained a federal foothold through the Federal Rules of Civil Procedure Act.

The 1972 Federal Water Pollution Control Act also recognizes citizen suits. Section 505 of this Act states that any citizen or group of citizens having an interest which is or might be adversely affected [as interpreted in Sierra Club v. Morton, 40 U.S.L.W. 4397 (1972)] may, after a 60-day notice, commence a civil suit in the district court against alleged violators of effluent standards or limitations or orders issued with respect to such standards or limitations by either EPA or state control agencies.

A class action suit might be brought for the purpose of requiring water agencies to apply the doctrine of reasonable efficiency in the establishment of water rights as a means of reducing water waste. Still another legal means that might be used by private citizens as a means of reducing water waste on the part of other citizens is through the common law remedy of private nuisance. A plaintiff might claim that he is deprived of water on the grounds that it is being wasted by one or more other users. If such cases should become numerous, pressure would be placed on water agencies to follow the National Water Commission recommendations.

The National Water Commission Report (Legal Study No. 8-C, 1971) also contained a recommendation to Congress, namely that no further water supply project be submitted to Congress for project approval until

> (1) a complete evaluation and report is made with respect to the physical efficiency of use of the presently developed supplies, including the prospect for salvaging waters lost in natural water-courses; and (2) that a report be made on the prospects of satisfying existing shortages by water savings practices in lieu of further project development.

A principal means of salvaging water in a given area is through water reuse in that area. In order for water to be reused, for the same or a different purpose, it is important and now enjoined by law that the water meet certain quality standards. Water quality standards are classified according to use. The standards that must be met in order for water to qualify for drinking water are different (more stringent) than those that are established for certain recreational, agricultural, municipal, and other water uses.

In some ways, the legal obligation of a water user to insure that the water he uses complies to certain standards at the conclusion of that use serves to prevent water waste. Given the expense of having to "clean up" the water he uses, a water user may opt to reuse the same water rather than incur the added expense of paying for additional water. Also, the next user will be more confident in utilizing previously used water if he can be assured that the supply conforms to certain minimum standards.

At the same time, however, water quality standards serve to discourage sequential water reuse when the water required for the next use must conform to higher or more stringent standards than a present use. *Ceteris paribus,* the present water user has no incentive and cannot be expected to restore water to higher quality standards than those which apply to the use to which he has put the water.

Section 402 of the 1972 Water Pollution Control Act requires a permit for the discharge of any pollutant from any point source, including publicly owned waste treatment works. Until the 1972 act was passed, permits granting activities related to water pollution were administered under the Refuse Act of 1899 by the Corps of Engineers in cooperation with EPA. The EPA has now taken the activity over and has issued guidelines to the states for developing a permit-issuing program. The state control agency, in operating its permit granting program, must notify the public and the EPA of each application and provide opportunity for public hearing before making a ruling. If granting a permit would affect another state downstream from the permitting state, the downstream state is notified by EPA and has an opportunity to express its views. Each permit granted by a state control agency must have a fixed term and can be for no longer than five years. It must set forth the applicable effluent and other limitations plus the monitoring requirements needed to demonstrate compliance. The state control agency will notify EPA of every action it takes on every permit application, including its decision to grant a permit. Even after approving the state agency program, EPA retains the right to review and approve any proposed permit, unless it specifically waives that right at the time it approves the state program.

Since future water uses will be governed under state permit programs, it might, when water shortage is acute and/or water waste is excessive, be possible and desirable to couple the issuance of a permit with a subsidy to encourage the present water user to "clean up" his water to levels acceptable for the next water use, even when the next use requires higher standards than the present use. Unless a subsidy or some other incentive program is established, sequential water reuse will probably fail to increase under the present system.

An alternative to a subsidy program is strict enforcement of the zero discharge requirement articulated in the Federal Water Pollution Control Act of 1972, which amounts to the abolition of the concept of standards by water use in favor of a uniform set of standards. Considerable confusion exists over the meaning of the zero discharge requirement. Many experts argue that it applies—or plausibly could only apply—to environmentally hazardous and persistent substances.

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Since future water uses will be governed under state permit programs, if at all, when water shortage is acute and/or water waste is excessive, by penalties and sanctions to compel the recipient of a permit with a priority to [illegible] the permit water user to "develop" his water to levels [illegible] for the most water use, even where the users are [illegible] than the [illegible] are. Unless a [illegible] of some other incentive program is established, [illegible] water users will probably fail to increase under the present system.

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CHAPTER V

ECONOMIC CONSIDERATIONS IN WATER REUSE

The use of salvaged water in any sector, agriculture, municipal, or industrial, depends jointly upon the value derived from that water resource by the user and the cost of salvaged water, particularly with respect to alternative sources of water. Given that social, environmental, legal, and technological factors modify both the value of water to users and the costs which users experience, economic "demand and supply" is important in analyzing water reuse. Of course, demand and supply analysis ignores some important economic effects of water use, particularly the income redistributions (welfare) and regional economic activity which may result.

Recycling water is one of several alternative sources of water, each of which has an associated marginal or incremental cost schedule. Assuming a competitive market with no externalities, these marginal cost schedules make up the supply curve for water. The amounts of water used from the alternative sources will be in part determined by the shape of the supply curve, and shifts in that curve which take place over time or which are due to social, legal, or technological changes. It is obvious that many of the sources of water have prices which are not market-determined, but rather are administratively established. The users of water are, however, generally restricted to a competitive market situation in which they are price takers, that is, the users cannot influence through the market the price which they pay for water. Therefore, recycled water will be used when it is cheaper than alternative sources of water. It is in the area of cost of treatment that most previous economic analysis of reuse has been done. Many cost-effectiveness studies have been made for both specific industries and plants (Highlands et al., 1966, and Shaw, 1966, for example), and for general application in larger areas (for example, Alamo Area Council of Governments, 1972). These studies most frequently establish some specific requirements, both for water quality and quantity, and examine the costs of achieving those requirements. Then comparisons are made to find the least-cost, most efficient technology for meeting the requirements. Essentially, this approach establishes a supply curve in which each increment in water use is done at prices associated with the least-cost source. It may be expected that this curve would be stopped if costs are relatively constant over some amount of water. Figure 5-1 illustrates such a curve, where discontinuities occur at quantities of water beyond which the given source cannot be used. These approaches, however, are not complete economic analysis, since they take demand as fixed (perfectly inelastic) at some

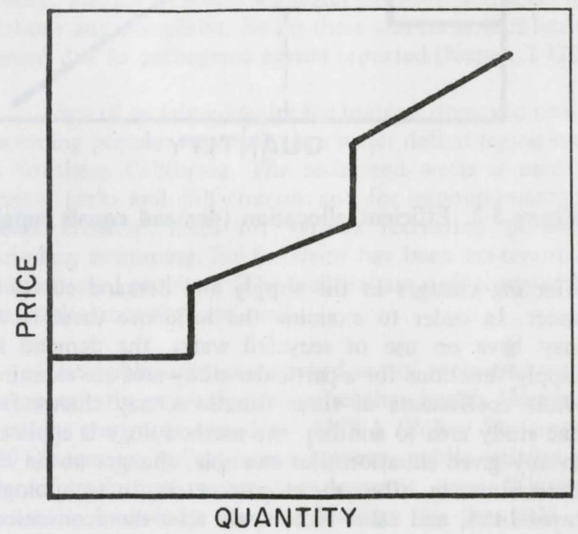

Figure 5-1. Marginal cost of supply schedule.

quantity. The inclusion of demand relationships is necessary to establish economically efficient water use.

Demand for water by a user is, as mentioned, dependent upon the marginal or incremental value which water produces for that user. Aggregate demand functions depend upon the sum of individual demands, given that other prices and incomes (or at least income distributions) do not change. For a given hydrological area or cultural unit of population, this total demand for water will determine the quantities of water used and the maximum price which will be paid. The greater the marginal value of water, the more water will be used at a given price, or the higher the price the user will be willing to pay. Some studies have examined the value of water in given uses (for example, Gavis, 1971, and Andersen et al., 1973) from which demand (value of regional product) curves can be obtained. Others have attempted to derive demand curves directly using econometric techniques (for example, Turnovsky, 1969). Once demand and supply functions are available, the efficient allocation can be determined, as shown in Figure 5-2, and the appropriateness of recycling can be examined.

Within the context of this study, the social, environmental, and technological factors can be viewed as

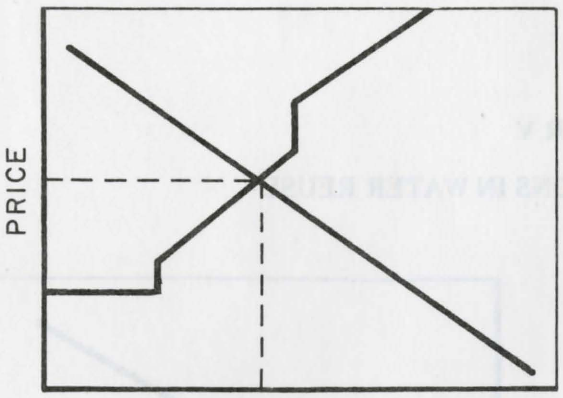

Figure 5-2. Efficient allocation (demand equals supply).

affecting changes in the supply and demand curves for water. In order to examine the influence these factors may have on use of recycled water, the demand and supply functions for a particular study area are examined. While coefficients of these functions may change from one study area to another, the methodology is applicable to any given situation. For example, changes in the legal constraints, in other social parameters, in technological capabilities, and other factors will alter the economically efficient (optimal) allocations and uses of water. If water recycling is an unacceptable water source to the public, then the demand for recycled water will be zero. If other sources are nonexistent physically, some recycled water may be used, but much of the demand may be satisfied with bottled or distilled water (as noted in the sociological discussion section)

Often these factors can be more easily analyzed by examining effects of the supply function, even though the apparent change occurs on the demand for water. For example, water pollution controls will make the use of water more costly, thus lowering its marginal value to users. Even though the buying price of the water input has not changed, the effect can be viewed as an increase (upward shift) in supply, since buying and treating water will cost more. Recycling technology might have the opposite effect. Thus the supply and demand analysis will facilitate an examination of expected use of recycled water.

Supply and demand, or efficiency, analysis excludes consideration of both equity, or income distribution, and local, regional, or national growth. These factors are also relevant to recycling or reuse policies. Unfortunately, little research in the incidence of costs and benefits of water developments, pollution control, or recycling are available (Boulding and Pfaff, 1972). Theoretical treatments of these issues suggest that the costs of water pollution control, be it from recycling or effluent charges, is born by those users with the least elastic demand for water (Hufbauer, 1973). These users are most probably culinary in nature, both for municipal and industrial sectors. Further research into the distribution aspects of water control and reuse is definitely indicated.

The problem of economic growth can be examined using supply and demand analysis, coupled with input-output (I-O), export base, or other multiplier analysis. Changes in production can be predicted from efficiency analysis, given technological data for the industries. Using these production changes, backward and forward linkages in an I-O model, or multiplier analysis, will predict the changes in final demand (local, regional, or national production). These kinds of production have proved fairly accurate in the past (see Lewis et al., 1971, for a complete discussion of growth models, measurement problems, and I-O analysis).

Given these theoretical underpinnings, an economic analysis of water reuse can be applied to any specific region. In a later section, a brief economic efficiency analysis of water reuse in the Jordan Basin, Utah, is undertaken to illustrate the techniques.

CHAPTER VI

ENVIRONMENTAL CONSIDERATIONS IN WATER REUSE

The use of reclaimed wastewater raises a number of questions related to environmental effects on existing water and related resources. In theory, reclaimed wastewater could be applied to every water use inasmuch as processes exist which can reclaim wastewater to any desired degree of quality. However, the economics of treatment, quality control monitoring, and assured safe operation may preclude the production of a suitable water from wastewater for certain purposes where quality requirements are high.

Although reuse does offer a solution to a part of the total ecological problem, it may contain an inherent hazard to the bio-communities or alter physical properties of an ecosystem that may lead to an unfavorable condition for human beings, animals, or plant life.

In this chapter, a case history of reuse in domestic irrigation is presented with its implications. The physical and biological effects of reuse of groundwater and surface water sources are presented with case demonstration, along with a general discussion of how reuse can affect the environment, physically and biologically, on both a micro- and macro-scale.

Environmental and health effects in water using sectors

Domestic (municipal). Domestic reuse is classified broadly as direct domestic reuse in which reclaimed water is directly added to domestic water supply sources, and indirect domestic reuse in which reclaimed water is used in irrigating public areas, impounded for recreation purposes, or for the aesthetic appeal. Direct municipal reuse has mostly been questioned on the basis of health, yet, behavior is more often the key in acceptance.

During a severe drought in 1952-1957 when the City of Chanute was forced to recycle its waste to supplement deficient water supply (Metzlev et al., 1958) for several months, the problems that existed were not basically health problems but public acceptance of the use of reclaimed water. Some of the public at Chanute rejected the water for human consumption, apparently, not of fear of illness, but of aesthetic reasons. At Windhoek, South West Africa, reclaimed water is successfully used as a city water supply supplement (Clayton and Pybus, 1972). The city has been using a 1.2 mgd reclaimed water since 1969. The reclaimed water furnished approximately 13 percent of the city's potable supply. The use of reclaimed water has been well accepted without any complaint. So far there was no serious health hazard due to pathogenic agents reported (Nupen, 1970).

Uses of reclaimed water for indirect domestic uses is becoming popular especially in a water deficit region such as Southern California. The reclaimed water is used to irrigate parks and golf courses; and for impoundments to create artificial lakes for various recreation purposes including swimming. So far there has been no report of health hazard problems. The facilities are well accepted by the public once they are used.

The public attitudes toward use of reclaimed water are apparently psychological rather than health. However, a policy statement issued by AWWA (Policy Statement, 1971) seems to indicate contemporary public opinion on use of reclaimed water for domestic uses. "Current scientific knowledge and technology in the field of wastewater treatment are not advanced sufficiently to permit direct use of treated wastewaters as a source of public water supply."

Agriculture. Irrigation with sewage effluents at various levels of treatment is not new. A good example of how treated sewage effluents can be used for irrigation is the system developed at Pennsylvania State University (Kardos, 1970). The objectives were to use sewage nutrients as crops fertilizer, replenish groundwater, and minimize stream pollution. A sprinkler irrigation system is used to apply effluents on forest and cultivated crops. With application rate of 2 inches of rainfall equivalent per week, yields of crops were about double those not receiving the effluent.

A large scale study of reuse sewage effluents for irrigation is being carried out in Muskegon County, Michigan (Chaiken et al., 1973). Studies will indicate the best way for the removal, via crops, of the maximum quantity of nutrients from effluents; the production yield of each crop, and soil management to provide maximum improvement in soil. Included also in this comprehensive project are studies on changes in surface water and groundwater qualities; effectiveness of the system in purifying wastewater; contamination potential of pathogenic organisms and effectiveness of different levels of chlorine disinfection; social, economic and environmental impact. The project will take five years before completion.

In Israel where there are more than 200 oxidation ponds in operation (Kott, 1973), most of the effluents are used for irrigation purposes. However, the law forbids direct irrigation of raw-eaten crops by oxidation pond effluents. Such effluents are considered safe only for pasture and industrial crops like cotton and potatoes. In the year 1970, some sporadic vibrio cholerae were found in wastewater. As a result, the irrigation of potatoes was forbidden. It was concluded that safe use of oxidation pond effluents for unrestricted irrigation can be achieved only if strict regulations are issued for their treatment.

Continuing application of sewage effluents to land could eventually lead to dangerous levels of certain minor elements, notably copper, zinc, boron, nickel, cadmium, and lead (Carlson and Menzies, 1971). This seems to be causing yield reduction of crop production. Careful monitoring is required so that the application can be stopped before the soil is irreversibly damaged.

Environmental effects in water resource systems

Groundwater. Recharge of groundwater aquifers can be accomplished by surface spreading or direct well injection. The choice of method depends upon soil strata characteristics. Surface spreading is usually used in the form of surface irrigation. Nutrients in reclaimed water are used by crops and the upper soil strata serves as a natural filter. Quality of groundwater recharge will depend on quality of reclaimed water as well as effectiveness of soil strata as a purifier. Groundwater contamination by sewer effluent used for crop irrigation is reported by Schmidt (1973). Nitrate and chloride contents were monitored monthly in water samples from irrigation wells. High contents for these constituents were found to result from irrigation practice with sewage effluents. Also the contents of boron were approaching the upper limit of 0.5 ppm. (The limit is suggested for suitability of irrigation water.)

Recharge of groundwater by well injection of reclaimed water is used as a barrier against salt water intrusion in the coastal area. At the same time the soil strata is also used as natural filter to renovate water for reuse. Baier and Wesner (1971) reported on studies in waste reclamation and groundwater recharge conducted in Orange County, California. Trickling filter effluent is injected into a confined aquifer. After travelling for 500 feet, the renovated water was found to be free of bacteria, viruses, and toxic material. The quality of renovated water was suitable for domestic use, although it has a disagreeable taste and odor and high dissolved solids.

In a study conducted in Israel (Rebhun and Schwarz, 1968), water of drinking quality is injected through a dual purpose well. It was reported that the injection rate was reduced as suspended solids present in the injected water formed a blanket around the well. The quality of water drawn back from the well showed a high level of pathogenic contamination if the water is pumped 2-5 days after completion of recharge operation.

Deep well injection as means of waste disposal has been practiced in the United States for a long time, especially in the oil industry. However, little was known of any physical change which occurred in the strata below. One cause of concern relates to subsurface pressurization by injection, which could result in the rupture of strata at the periphery of a rock formation miles away (Sheldnck, 1969).

Experiences with a deep-well injection system at the Rocky Mountain Arsenal 10 miles northeast of Denver have focused attention on environmental risks (Cleary and Warner, 1970). At the installation, wastes were pumped into a fractured gneiss rock zone at a depth of 12,040 feet. Shortly after the operation began, the Denver area became subject to a series of earth tremors, which were previously uncommon. It was theorized that the injected fluids reduced friction in faulted rock zones, which in turn led to slippage and thus triggered the quakes.

Surface water. Change in surface water qualities can be caused by direct discharge of effluents, return flow from irrigation and groundwater. The physical changes are obvious and can be easily detected. These changes included color, odor, and taste. The physical changes can be a direct result from concentrated effluents or derived from biological changes resulting from the effluent discharge.

The biological changes are more complex in nature, since there are certain interdependencies within the aquatic communities. However, direct extermination of some aquatic species can be attributed to toxic substances present in the effluents. High increase of salts concentration can cause absence of certain aquatic species (Bryan, 1971; Brown et al., 1970). The excess nutrients (N,P) in the effluents or return flow can lead to excessive growth of aquatic plants (Svinath and Pillai, 1972; Jordan and Bender, 1973), in which other changes can occur such as change in population or species diversity in the aquatic communities.

Discharge of effluents from upstream can cause considerable effect on water qualities downstream (Vogt, 1972). This can lead to higher treatment cost for water supply or even render the stream unsuitable as a water supply source.

It is recognized that streams and lakes possess a self-purifying capacity. However, there is a limit to which this capacity can be exercised. The Great Lakes, which are one of the world's biggest inland water resources, once were thought to be unpollutable due to their size. Now, remedies are being sought both by the U.S. and Canada to revitalize the lakes.

CHAPTER VII

SYNTHESIS AND INTEGRATION: WATER REUSE WITHIN THE WATER MANAGEMENT SYSTEM

The potential for water reuse depends on the interrelation of social, economic, environmental, and technological factors in an area which affects the way that water supply and wastewater treatment systems can be linked by options for water reuse. Generally, approaches to water reuse have focused on specific technological processes for water salvage, or on the waste treatment facilities for the improvement of water quality. However, region-wide opportunities for water reuse must be analyzed as part of the total regional, social, economic, and hydrologic systems.

In order to bring these relationships into better focus, the following discussion is developed with reference to a specific area. The Wasatch Front region of Utah provides an excellent example. In the region, a limited water supply is used to satisfy municipal, industrial, agricultural, recreational, and other beneficial uses. The economic and social trends are toward continued industrial development and urbanization. In this setting, water salvage and reuse is becoming more and more important as a means of expanding water supplies to meet the growing demands for water for virtually all social, economic, and environmental uses.

Overview of water reuse relationships

An overview of the possible water reuse relationships in an area such as the Wasatch Front of Utah is given by Figures 7-1, 7-2, and 7-3. A summarization of factors

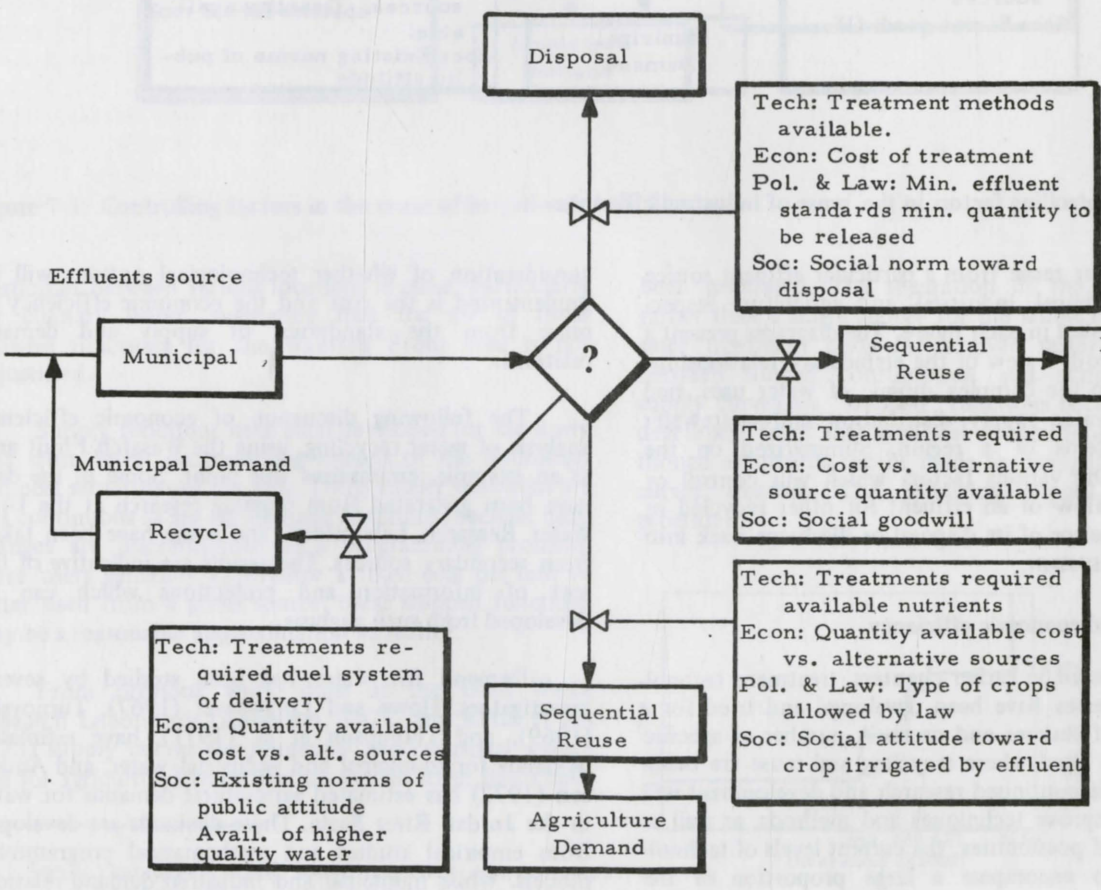

Figure 7-1. Controlling factors in the reuse of municipal effluents.

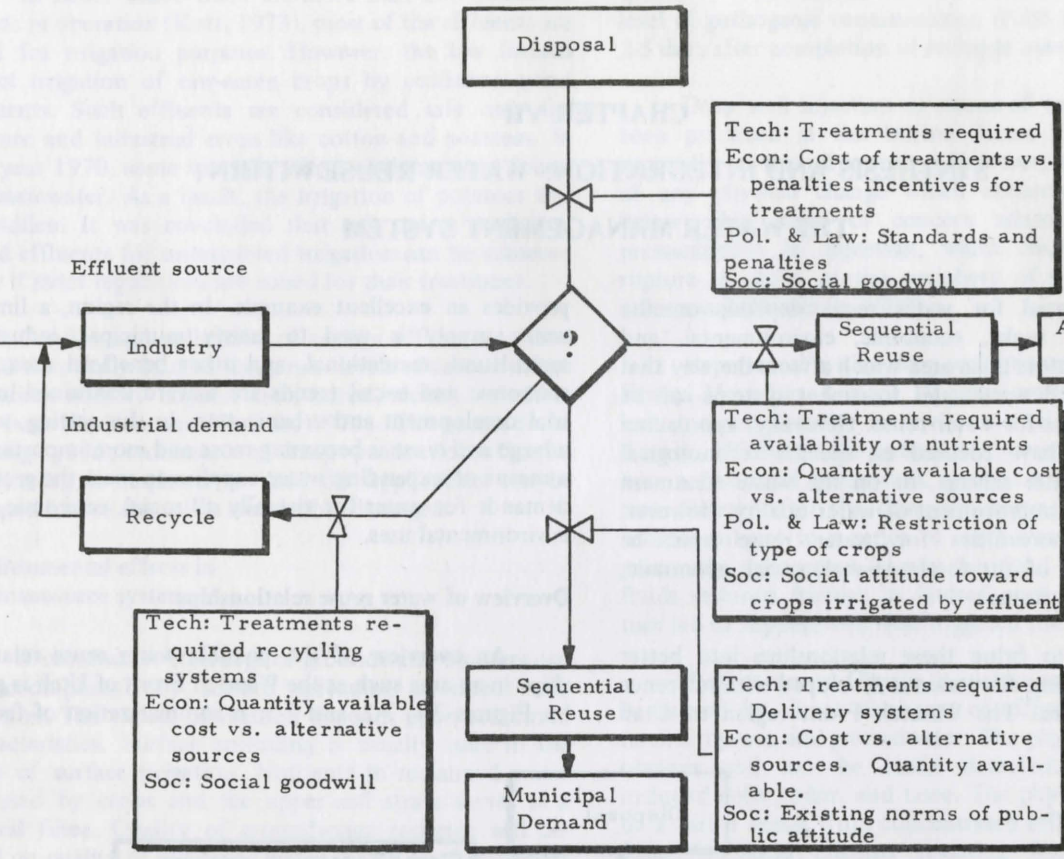

Figure 7-2. Controlling factors in the reuse of industrial effluents.

influencing water reuse from a particular effluent source of water (municipal, industrial, and agriculture respectively) is presented in each figure. The diagrams present a sort of "free body" view of the elementary relationships which make up the complex mosaic of water uses, tied together by water supply distribution and wastewater collection systems of a region. Summarized on the diagrams are the various factors which will control or influence the flow of an effluent for other recycled or sequential reuse, or of its disposal or discharge back into the hydrologic system.

Technology and economic efficiency

As discussed in earlier chapters, treatment technology and processes have been developed and tried for a wide variety of sources and users. A number of specific examples were cited where recycling and reuse are being practiced. While continued research and development will continue to improve techniques and methods, as well as open additional possibilities, the current levels of technology appear to encompass a large proportion of the possibilities for reuse. The key element, however, in the consideration of whether technological options will be implemented is the cost and the economic efficiency of reuse from the standpoint of supply and demand relations.

The following discussion of economic efficiency analysis of water recycling, using the Wasatch Front area as an example, emphasizes this point. Some of the data have been generated from ongoing research at the Utah Water Research Laboratory, and some have been taken from secondary sources. The results are indicative of the sort of information and projections which can be developed from such analysis.

Demand for water has been studied by several investigators. Howe and Linaweaver (1967), Turnovsky (1969), and Thompson et al. (1971), have estimated demands for municipal and industrial water, and Anderson (1972) has estimated agricultural demands for water in the Jordan River Basin. These demands are developed from empirical studies and mathematical programming models. While municipal and industrial demand relationships were developed for other locations, the agreement in

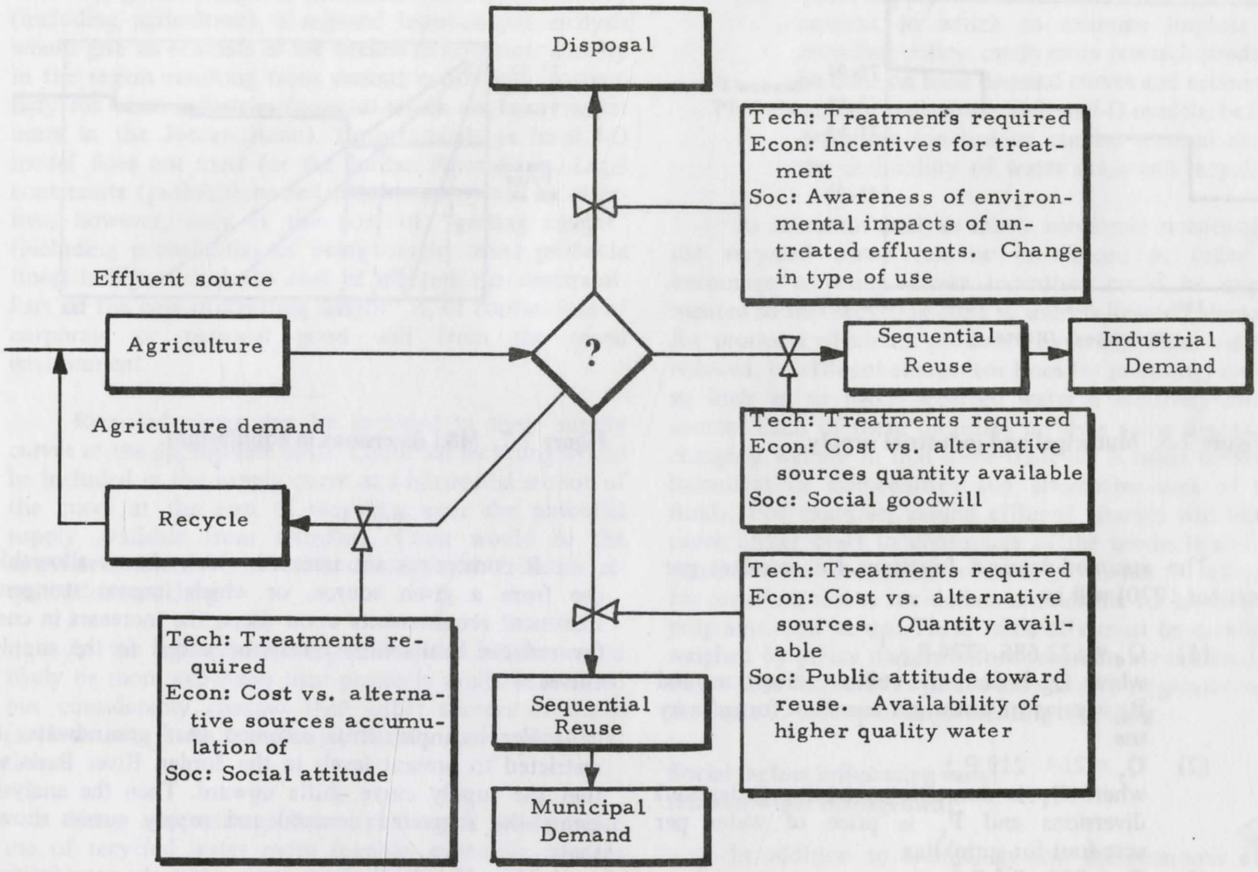

Figure 7-3. Controlling factors in the reuse of irrigation return flow.

elasticities between various locations is close, particularly for culinary water, suggesting that the use of those demand functions for the Wasatch Front area is not unjustified.

Supply functions have been developed for the study area from linear programming models of the hydrology and cost structures of the area. These supply functions are not continuous as are the demand functions, because basic changes are discontinuous in a programming problem. Since users generally experience a fixed cost per unit of water used from a given source, these stepped functions may be a reasonable approximation to reality.

From previous work done at the Utah Water Research Laboratory (Anderson, 1972, and Keith et al., 1973) supply curves for municipal and industrial water[1] and for agricultural water for the Jordan River Basin have been generated. The separation of the supply curves, rather than a single supply for the whole basin, was used, since treatment costs for a given water source differ between human consumption and agriculture. These supply curves are "stepped" functions because they were developed from mathematical programming models, although arguments can be made for stepped water supply curves existing. The following supply curves were generated:

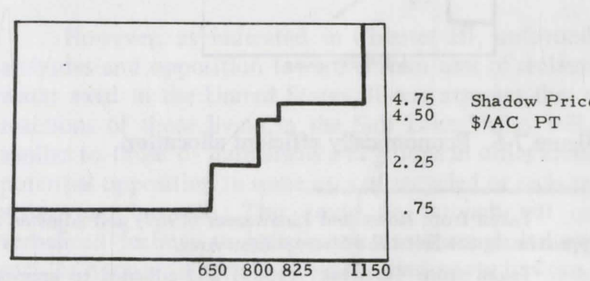

Figure 7-4. Agricultural supply.

[1] While industrial cooling water may cost less to use, treatment required for effluent water is such that water costs are considered identical for both uses in these studies.

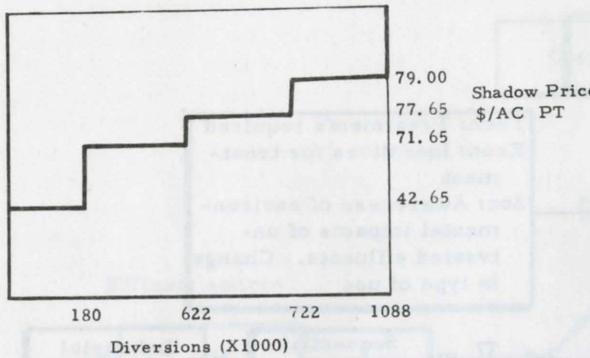

Figure 7-5. Municipal and industrial supply.

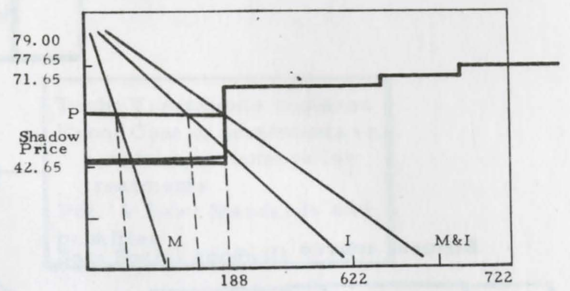

Figure 7-7. M&I diversions in equilibrium.

The assumed demand functions (in acre-feet per year for 1970) will be

(1) $Q_c = 122{,}685 - 774\, P_w$ [1]
where Q_c is domestic culinary diversions and P_w is price of water per acre-foot for culinary use

(2) $Q_s = 213 - 219\, P_s$ [1]
where Q_s is domestic sprinkling (irrigation) diversions and P_s is price of water per acre-foot for sprinkling

(3) $Q_i = 389 - 7.5\, P_i$ [2]
where Q_i is industrial diversions and P_i is price of water per acre-foot for industrial uses

(4) $Q_{ag} = 967{,}400 - 77{,}500\, P_{ag}$ [3]
where Q_{ag} is agricultural diversions and P_{ag} is price of water per acre-foot for agricultural uses

The supply and demand functions can be put together for each "use sector" to determine the economically efficient allocation or use level, as below:

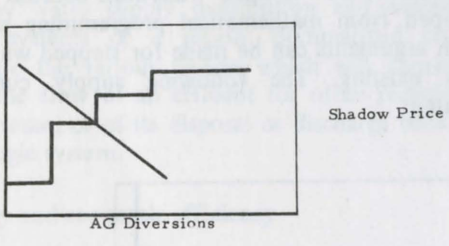

Figure 7-6. Economically efficient allocation.

If constraints are assumed which change allowable use from a given source, or which impose stringent treatment requirements upon users, the increases in cost (or reduced availabilities) may be added to the supply curves.

For example, it is assumed that groundwater is restricted to present levels in the Jordan River Basin so that the supply curve shifts upward. Then the analysis giving the suggested demand and supply curves shows that:

(1) Municipal water use is relatively constant and
(2) Industrial water use declines with additional costs and constraints

Further, it can be shown from Anderson (1972) that agricultural water use declines sharply with increased costs (required treatments).

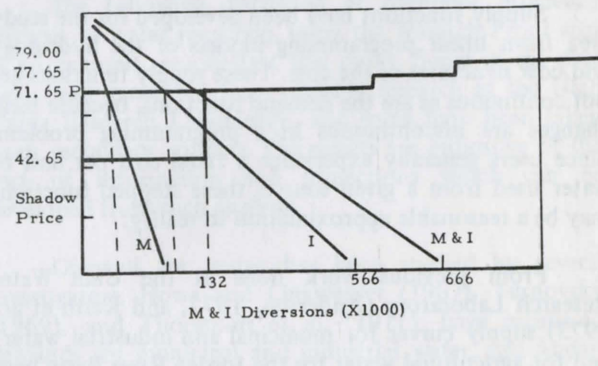

Figure 7-8. M&I diversions in equilibrium with no new pumping.

[1]Taken from Howe and Linaweaver (1967) and adjusted to approximate the Salt Lake Metropolitan Area.

[2]Taken from Turnovsky (1969) and adjusted to approximate the Salt Lake Metropolitan Area.

[3]Taken from Anderson (1972).

For given changes in production in a given industry (including agriculture), a regional input-output analysis would give an estimate of the decline in economic activity in the region resulting from various constraints, particularly for basic industries (none of which are heavy water users in the Jordan Basin). Unfortunately, a local I-O model does not exist for the Jordan River Basin. Legal constraints (prohibitions and requirements) will be effective, however, only if the cost of "getting caught" (including probabilities of being caught times probable fines) is higher than the cost of meeting the constraint. Part of the cost of "getting caught" is, of course, loss of corporate or personal good will from the social environment.

Recycled water can be included in these supply curves at the appropriate costs. Continual recycling would be included in the supply curve as a horizontal section of the curve at the cost of recycling, over the potential supply available from recycling. Costs would be the amortized construction costs of any new facilities required for recycling.

In the agricultural sector, recycled water would likely be more expensive than presently available sources, but considerably cheaper than other sources of water (such as inter-basin transfers) presently under consideration.

Many alternative policies exist which would make use of recycled water more feasible, especially in uses which users exhibit relatively inelastic demand. Mixing recycled water with water from other sources is one example; the cost of water to users is dependent upon the mixing ratios. Further, it was noted in the sociological section that treated water was pumped into a municipal water system in Kansas at apparently little increased costs. This type of recycling may be as, or more, economically feasible as developing new non-recycled sources.

Other activities can be undertaken by public agencies to encourage recycling, including allowing trades between users requiring different levels of purity (for example, using some of the municipal effluents for irrigation so that part of a recycling cost could be defrayed). Other incentive schemes could also be considered, such as subsidization of recycling facilities. However, public subsidization carries a tax cost to users, and the welfare of users may or may not be enhanced, depending upon the tax incidence.

In any event, the preliminary investigation indicates that:

(1) Recycling of water is expensive enough to preclude exclusive use of that source when other cheaper sources are available;

(2) Public policies concerning reuse must be carefully examined to determine impacts of prohibitions, limitations, and other imposed constraints; and

(3) While supply and demand analysis is a useful context in which to examine impacts of recycling policy, much more research needs to be done on local demand curves and economic activity indicators such as I-O models, before definitive conclusions can be reached about the desirability of water reuse and recycling.

As economic analysis shows, economic incentives to use recycled water can be introduced in order to encourage recycling. These incentives could be implemented so that recycling costs to users is lowered, demand for products which are produced by heavy water users is reduced, or effluent charges (or fines for polluting) are set so high as to make recycled water a relatively cheap source. Each of these measures involves some degree of changing welfare in that some trade-off is made between incentives or disincentives and alternative uses of the funds. For example, raising effluent charges will likely cause higher costs to consumers of the products so that consumer real income is reduced; payments to industry for recycling makes tax dollars unavailable for alternative programs, and so on. These trade-offs must be carefully weighed by policy makers before programs are initiated to insure that the benefits gained are equal to or greater than the costs to society of implementing recycling.

Social factors influencing water reuse in water management

In addition to technology and the economic efficiency of water reuse as reflected by the market, social factors will also have important influence on whether water reuse actually occurs. Today an attitude of environmental concern is held by many individuals and groups, and voluntary organizations have been formed to influence various aspects of environmental use and abuse. In the Intermountain West, water has always been a resource of limited quantity, and life has been dependent upon the existence of a source of water. Increasing pressures on the existing water supplies, in the metropolitan Salt Lake City, for example, have caused some to wonder what limits need to be set on development in the valley. Increased environmental concern for water as well as the localized concern about potential water shortages have created a climate in which future water reclamation and reuse may be favorably considered.

However, as indicated in Chapter III, unfavorable attitudes and opposition toward certain uses of reclaimed water exist in the United States. If one assumes that the reactions of those living in the Salt Lake Valley will be similar to those of individuals and groups in other areas, a potential opposition to some uses of recycled or reclaimed water can be seen. This could be through not only verbalized feelings or beliefs but also through behavior, such as nonuse of reclaimed water. Earlier studies can be used to predict that verbalized opposition and nonuse will probably be more prevalent for uses requiring closer bodily contact. For example, opposition to the use of reclaimed water for drinking purposes would be high and opposition to the use of this water for road construction would be low.

However, changes in attitudes and norms could occur through social interaction by those favoring the more intimate uses of reclaimed water. These changes may be placed within a social change paradigm. Innovation begins with those who develop techniques for the processing and reclamation of used water. Advocation takes place face to face through social interaction, the use of advertising and marketing techniques, the use of educational institutions throughout the country, and in other ways. Adoption is influenced by the reference groups of particular individuals and by opinion leaders in particular areas.

In addition, the satisfaction of man's basic need for water could influence the adoption of the use of reclaimed water. Water is needed for survival, and if higher quality nonused water is not available, reclaimed or recycled water may more readily be used. Some of the social changes which may occur as a result of the shortages of higher quality water may be in the form of legal or social prohibitions or regulations related to certain uses of higher quality water. Experiences during water shortages indicate such uses as watering lawns and washing cars may be restricted to lower quality water, thus waters of different qualities would be used in different ways.

Actual experience in the use of reclaimed water could provide either positive or negative reinforcement through exposure to the physical characteristics of the water. If the reclaimed water had acceptable taste and clarity it might positively reinforce a favorable attitude toward its use. On the other hand, undesirable qualities could provide a reinforcement of negative attitudes.

More detailed examination can be made of social factors that may determine whether water is to be recycled, reused, or discharged for municipal, industrial, and agricultural sources of effluent. Figures 7-1, 7-2, and 7-3 show potential reuse or recycling possibilities for these three sources of effluent. Various social factors could be involved in each potential reuse or recycling situation.

Municipal. Figure 7-1 represents a situation in which municipal use is the source of effluent. There are four possible courses shown: (1) Disposal or discharge, (2) recycling back through the municipal system after treatment, (3) use of the treated effluent by industry, and (4) use of treated effluent in agriculture. Each of these possibilities is effected by social factors.

Disposal of water used in municipalities is effected by existing social norms. In the past the norm in some areas has little or no treatment before disposal. However, in recent years the norm in many areas has received some treatment for municipal effluent. Currently, the condition of effluent as it is discharged can be greatly affected by the social and legal prescriptions and prohibitions which exist in each particular area. Attitudes toward the environment in general and natural resources may have some direct or indirect effects. If social norms change toward favoring actions which will protect the environment, the quality requirements for effluent discharged could become higher. This assumes that through social change attitudes and behavior will move towards more environmental concern. However, if the change is not in this direction, the prescriptions and prohibitions may not be as strict or force the discharge of higher quality water.

Existing attitudinal and behavioral norms can also effect the reuse or recycling of municipal effluent, and most current norms discourage this type of recycling for many types of municipal uses. As mentioned earlier, other authors have found that the more intimate the type of use, the greater the opposition to the use of recycled water. The shortage of nonrecycled water of high quality may be able to influence the norms in a particular area. This may be especially true in the Rocky Mountain area where water availability is especially crucial. If high quality water is in short supply the components of attitude, especially the behavioral component, may change. Thus, if nonrecycled water is not available in sufficient quantity, recycled or reused, treated water may be used in the municipal system. In addition, some restrictions may be placed on use of higher quality water for purposes such as watering lawns and washing cars. If some higher quality water is available, municipal systems for water distribution may come to be accepted along with restrictions placed on the uses of higher quality water.

Changes in existing attitudes may occur after the advocation of the use of recycled water by high status persons who act as reference groups for some of those living in the Salt Lake Valley. This advocation may take place through advertising or other types of social interactions. In addition, positive reinforcement of the use of recycled water may occur if the experiences that those using this water have are positive. In other words, if the water does not have an unpleasant taste, adverse health reactions, or other negative components, positive reinforcement may occur. On the other hand, water characteristics may result in negative reinforcement and affect public acceptance of recycled water and attitudes towards it.

The sequential reuse of municipal effluent in industry is another possible alternative. Attitudes of opposition are again related to type of use. As higher quality water becomes less available, social pressure may "force" industrial use of municipal effluent. In the future, the use of higher quality water by certain industries may be prohibited either by social sanctions or through legal prohibitions. At that time higher quality water use may be restricted to municipal water systems, especially for more intimate uses

The reuse of municipal effluent in agriculture is another alternative for water conservation. Although no strong social prohibitions exist for the overall use of municipal effluent in irrigation, some prescriptions and prohibitions do exist on the crops that may be grown with recycled water. Restrictions are sometimes placed on recycled water limiting its irrigation use to cereals and similar crops. Some restrictions currently exist in the use of the recycled water for growing root crops or any other crops that may be able to transmit ill effects to man. These may be actual or imagined health hazards. It is therefore assumed that these types of prohibitions could develop in the Salt Lake Valley if recycled water were used for irrigation purposes.

Industrial. Figure 7-2 illustrates reuses to which industrial effluent may be put. This includes (1) disposal or discharge, (2) recycling industrial effluent for reuse within industry, (3) sequential reuse of the industrial effluent for agricultural purposes, and (4) sequential reuse of industrial effluent for municipal purposes.

Attitudes and behavior related to environmental protection can have a prime influence on the disposal of effluent by industry. If the current environmental protection trend and associated conservation efforts continue, the social and legal prescriptions and prohibitions regulating the quality of the water discharged after industrial use may become increasingly stringent. Strict penalties may be imposed for not meeting required standards, and occasionally may arise where an industry may be "shut down" if it does not meet required standards. Industrial recycling of water may generally become more economical than trying to treat water to meet future disposal standards. Also, as water needed for human survival becomes more scarce in, quality and quantity, restrictions may become even more prohibitive. This scarcity may be actual or perceived. Incentives could be provided for industries who make efficient use of their water through such processes as recycling.

No general social prohibitions appear to exist for the use of industrial effluent in agriculture. Some restrictions may be used if detrimental effects on man are perceived to exist. Biological and environmental factors related to agriculture may restrict the quality of water used for this purpose. For example, chemicals picked up during the industrial use may prove detrimental to plants or animals for which the water is later used. In addition, perceptions of farmers and ranchers of the impact of the industrial effluent may restrict its use for agricultural purposes. If a farmer or rancher perceives that his plants or animals will be harmed or that his market in the future may be restricted because of previous water use, he may choose not to use this particular source of water Some adjustments in this type of attitude may occur as water becomes more and more scarce and the quality of the water available for agricultural purposes is lowered. This could come about through competition between municipal use of water and agricultural use of water.

The use of industrial effluent as a source of municipal water could be influenced by controls and restrictions related to the norms of the people. The presence of certain residues (chemical and otherwise) in the water could make a health department prohibit the use of that water. Bad taste, smell, or appearance of the water could provide negative reinforcement of water use. This could mean that people would tend to avoid the use of that particular water and could develop an attitude in opposition to having it as their domestic water supply. On the other hand, positive reinforcement could be provided through the use of water that did not have a bad taste, smell, or appearance that could provide a mental image of contamination. The industrial impact upon the water could be real or perceived by the potential sequential users.

Agriculture. In Figure 7-3 agricultural use is the effluent source, which may follow four potential paths: (1) Disposal after use, (2) recycling for agricultural purposes, (3) sequential reuse by industry, and (4) sequential reuse of the agricultural effluent for municipal consumption.

In the disposal of agricultural effluent social norms related to the environment affect what may be done, including not only water used for irrigation, but also water used for animals. The presence of animals can add bacteria to the water, and the use of water for irrigation can increase the salinity or the amount of salts suspended in solution in the agricultural effluent. In both cases, social prohibitions and legal actions may be taken to restrict the quality of water that is returned to major streams and tributaries. Penalties may be applied for not meeting particular standards, and incentives may be given for treatment after use.

Changes may be made in the type of agricultural uses to which the water is put or the way in which a particular use is made. For example, one change may be toward sprinkler irrigation rather than irrigation by flooding. In the latter case, wastewater returns to streams and tributaries with a higher amount of salts present. With "sprinkler irrigation" the use may be more efficient. Changes in the future will occur through the social change paradigm described earlier, i.e., innovation, advocation, adoption.

Agricultural water may also be recycled for use. Here some incentives may be provided for this type of action. Also, social and legal prohibitions may be applied to certain types of agricultural effluents used for certain other agricultural purposes. This could occur if certain health promoting restrictions were needed for certain types of water reuse.

No apparent legal or social prohibitions or restrictions by the public as a whole appear to exist in the sequential use of agricultural effluent by industry. Some of the social decisions involved in the sequential reuse of agricultural wastewater by industry will be made by individuals and groups in industries that can reuse the water. Either real or perceived problems may exist with agricultural use residues found in the effluent. For example, salinity produced through irrigation use may create some problems. If individuals or groups in industry have influence with persons who have political power, social or legal constraints or prohibitions may be placed on agricultural users to maintain the water at a certain quality. Greater problems may exist with the sequential reuse of agricultural wastewater for municipal purposes. At the present time, legal and social prohibitions exist restricting certain types of use. For example, animals are prohibited from being on the Salt Lake municipal watershed. As the amount of higher quality water decreases, further restrictions may be placed on agricultural uses of water. Constraints similar to those placed on the reuse of municipal water could be applied, since sequential reuse of agricultural effluent could have deleterious effects on health if proper purification techniques were not used. In addition, the salinity and other property changes in the water could prove detrimental in the purification process for culinary consumption of water. As long as water exists in adequate supplies to furnish the quality necessary for purification for culinary consumption no conflicts or problems may develop. However, as the quantity of higher quality water decreases, some restrictions may have to be placed on the agricultural uses.

Summary

When considering the reuse of wastewater effluent or its discharge into nearby water sources, a wide range of controlling factors must be taken into account. Discharges must meet a required minimum standard of effluent as set by law. For a municipality, a minimum quantity of water may have to be discharged in order to satisfy water right requirements. In sequential reuse, intake minimum qualities in each sector are the first consideration in conjunction with associated cost to treat the effluent to such a standard. Upstream municipalities may be encouraged to treat their effluent to a higher standard through agreements or subsidy of treatment cost by downstream municipalities. Where household use may still be objectionable, but other municipal uses (e.g., lawn and park watering) are not, a dual system of delivery may be economically justified. In a municipal sector, reuse may also depend upon the contemporary mood of the public toward reuse and the availability of alternate sources of water.

In an industry sector, if effluent can satisfy the standard requirement and cost is competitive with alternative sources, reuse will be considered.

Industry may also have to trade between penalties cost and treatment cost in order to minimize its expenditure. Higher effluent qualities can be achieved through combination of incentives and penalties such that industry is not driven away from the community. It may also consider the goodwill impact it may have on the community in justification of its recycling system.

Nutrient availability in wastewater effluents may be important in ultimately influencing the decision of reuse in the agriculture sector. Equivalent amounts of nutrients, as a direct substitute for fertilizer, can be a real dollar savings to farmers. Presence of certain harmful agents in the effluent, however, may restrict its use even though other criteria are met. Limited water supplies may stimulate reuse in additional crop yield and justify installation of required drainage and redistribution systems, and there are no detrimental effects from saline accumulation. In agriculture, monitoring of effluent qualities is rather difficult and generally there is little treatment consideration in irrigation practice. Schemes to treat surface return flow before discharge into nearby streams are a region-wide problem requiring collective action to be effective.

Finally, a large number of social factors can be involved in the sequential reuse of various types of water and the recycling of water in various uses. Existing norms and values can be important. In addition, social changes may take place in these norms and values. These changes may be related to social interaction with others who may serve as advocates of particular ideas. In addition, physical factors related to the survival of man in the meeting of his basic needs can become increasingly important as the quanity of available high quality water is decreased. At that time, additional legal or social prohibitions controlling water use and reuse may come into existence.

CHAPTER VIII

SUMMARY

Due to limited available water resources, as the population and associate water requirement increases, the time interval in the water use cycle decreases. Thus, water reuse is becoming an important water resource in the future. It is believed that the potential for water reuse, from the standpoint of both water resources and water quality planning, far exceeds current practice. Reuse should be considered not only with respect to quantity but also in light of water quality, environmental, ecological, economic and public health aspects (Lehr, 1972). However, the total problem cannot be handled simply as each call for water reuse will be different depending on geographic location, climate, public attitudes, the availability of wastewater sources, competition of other water users and legal aspects.

Health factors with relation to direct domestic reuse are the main concern (Long and Bell, 1972). In fact, there are still many health related questions remaining to be answered before unlimited personal use of renovated water can become an every day occurrence. However, the experience at Windhoek (Clayton and Pybus, 1972) demonstrated that potable water can be reclaimed from wastewater for every day use without, yet, any detrimental effect on users. Furthermore, many cities in the U.S. derive their drinking water supply from surface sources which have been the recipient of a variety of wastes, even in some cases the water supply intake of the next town is within sight of the upstream town effluents discharge point.

Sequential or indirect domestic reuse has more success than its direct reuse counterpart. In the water deficient regions in the U.S., especially Southern California, reclaimed wastewater has been used to create artificial lakes for recreation purposes; watering parks and golf courses. Those facilities have been well accepted by the public. No health problems have yet arisen from use of these facilities.

In industry, reuse is mainly confined to closed systems, for example cooling systems or boiler systems. These systems usually have no direct outside contact which may cause environmental effects. However, industrial effluents have proven to be more difficult to handle due to the diversity of pollutant constituents. In many cases, some special treatment is required to insure that the effluents will conform to standards and cause no detrimental effects on the environment when discharged.

The reuse of water for irrigation is coming to be more commonly used, especially in water deficient regions. Here, reuse can serve three purposes at the same time: First, the quality of return flow improves dramatically due to natural filter properties of soil-plant systems; second, nutrients in the effluents can be utilized as a source of fertilizer, thus, reducing fertilizer need for crops; and third, effluents provide much needed water to growing crops. Depending on the soil-plant system excess effluents can be applied such that excess return flow can be used to replenish groundwater. However, irrigation with effluents have been generally restricted to raw-eating crops and pasture due mainly to health hazard questions. Better disinfecting techniques and pathogenic detection methods may soon lift this restriction.

Excess salts contained in effluents can cause some problem. Nitrate salt can accumulate in green leaves such that when used as animal feed it can cause nitrate poisoning. Chloride salt can contaminate groundwater and cause considerable damage to soil itself. Presence of other trace minerals and metal can cause long-term damage to soil and reduce production yield.

Reclaimed water had been used to feed cattle without any apparent health effects or objection (Synder, 1951).

Use of soil strata to remove metal ions and other trace elements has been studied (Wentink and Etzel, 1972; Leman and Wilson, 1971). The process involved in the treatment by soil profile was found to be ion exchange, hence soil after treatment is generally not going to be suitable for any agricultural purposes. Therefore, considerable care must be taken to insure that land could be reclaimed back for other purposes besides agriculture.

Overdraft of groundwater aquifers can lead to intrusion of saline water in coastal areas, or may cause land subsidence in weak rock formation. Use of effluents to replenish a groundwater aquifer can be done by surface spreading, usually in connection with irrigation practice, or by direct well injection. Rock strata also provide natural filter properties to improve the quality of renovated water. However, the suspended solids in effluents may in the long-term reduce the conductivity of the aquifer due to sealing action. It was also found that pathogenic agents can persist and multiply within a certain period. However, on the long-term these agents were found to be at a non-significant level.

Deep well injection of waste has long been practiced. However, there are little data on physical and biological conditions within the rock strata miles below. There is some speculation that the effect of high pressure injection caused slippage between faults in rock formations that led to earth tremors in the Denver area.

Surface waters have long been used for discharge of wastewater and the death of many rivers and streams has resulted from this practice.

However, standards imposed on effluent quality may have to be a relative rather than absolute. Since most water is derived from surface water sources, considerable amount of naturally available nutrients are taken out at the same time. Therefore, these nutrients need to be replenished to the water in order for aquatic communities to exist in a natural state (Henderson, 1972). Hence, presence of certain nutrients in the effluent may be of benefit to aquatic communities, rather than detrimental.

Reuse of water may solve many problems related to water resources. However, it can also cause some other problems in solid waste management, for example. The higher quality effluents require more sophisticated treatment techniques which expend more energy and generate higher volume of solid waste. In some cases, it may be advantageous to have a little lower quality effluent and let nature upgrade the residual.

Effects of reuse can tip the balance of an ecosystem. Extinction of a species in the food chain within aquatic communities can lead to extinction or absence of other species in that ecosystem. Some species may be able to adapt to the new environment, however, they may be useless in the next chain of the food web. Hence, stress will be transferred to other species.

Availability of effluents for irrigation can turn a semi-arid area into productive land. This reduces plants diversity to a few species. The existence of green land can alter the microclimate of the area. The change may be absorbed through the climatic system, but, the results in general terms are still unknown.

Reuse is a promising avenue for solving water resources problems, both in providing additional quantities of water and in maintaining water quality. Reuse is, therefore, a water management option that should be given careful consideration in future planning and utilized to its full potential.

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