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REUSE OF WASTEWATER IN DESERT REGIONS

by

K. James DeCook
Water Resources Research Center
University of Arizona
Tucson, AZ 85721

Paper Presented to Conference on Alternative Strategies for Desert Development and Management, United Nations Institute for Training and Research and California Department of Water Resources, Sacramento, California, 31 May - 10 June, 1977.

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IN DESERT REGIONS

ABSTRACT

In a developing desert region, reuse of wastewaters can serve to enhance economic efficiency and improve environmental preservation in water-using activities, through incremental substitution of wastewater for groundwater under limited water-resource conditions. Municipal wastewaters can be used for irrigation of certain commercial crops without advanced treatment, although dilution with other sources of water is necessary to achieve the optimal application of irrigation water and plant nutrients. For most other uses, wastewaters must receive selective advanced treatment to meet water quality criteria. At Tucson and Phoenix, Arizona, municipal wastewaters have been allocated to irrigation of forage, fibre, oilseed, and vegetable crops, and to landscape irrigation and recreational lake replenishment in a regional park; additional allocations of wastewaters are pending for use by the copper mining-milling industry and for power generating plant cooling. Environmental hazards of wastewater disposal are reduced or avoided by planning and management procedures which include control, treatment, and application of wastewaters to beneficial use.

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K. James DeCook*

In the formulation of plans for development in desert or arid regions, water resources are implicitly limited and are therefore critical to any planning strategy. Furthermore, virtually any use of water will yield a by-product of wastewater in some form. If not properly included in planning, wastewaters commonly will effect diseconomies or will produce environmental degradation. On the other hand, when wastewaters are efficiently managed they can become a supplementary resource which will serve some water-using activity.

WATER REUSE IN AN ARID REGION

Therefore in a developing country, and more specifically in a developing natural resource community, the recovery, treatment, storage, conveyance and reuse of wastewaters should be considered along with water supply in the earliest stages of planning. In any event, disposal of wastewater without further use should be the last alternative. Such waters commonly cannot be discharged into streams because in a desert region streams are ephemeral and their assimilative capacity is negligible; also, subsurface disposal may be impractical without expensive treatment because of the danger of polluting the ground-water reservoir, which is likely to be the sole source of primary water supply. Accordingly, in such an environment a wastewater discharge should not be regarded as a waste product (with negative value) but rather as a resource with positive value as an input factor for some beneficial reuse.

*Associate Hydrologist, Water Resources Research Center, University of Arizona, Tucson, AZ 85721, U.S.A.

Wastewater Sources and Potential Uses

Wastewater discharges which emanate from partially consumptive uses and which can be collected at point sources may be classified as municipal (principally domestic) sewage effluents and industrial process or cooling effluents. Industrial discharges are so varied in quantity and quality that generalization is difficult, and each must be evaluated individually. Sewage effluents, however, are common to any area of development where a concentration of resource production, and therefore population, occurs.

Accordingly, for the purpose of this presentation municipal wastewater will be cited as the principal example. This kind of wastewater source commonly is concentrated (1) at a treatment plant served by an integrated (urban or metropolitan) sewerage collection system and employing a conventional primary-secondary treatment, or (2) at a relatively smaller plant serving a local residential or commercial service area, and generally utilizing an oxidation pond or a "package plant" treatment mode.

Appropriate kinds of use to which the treated wastewaters can be applied are classified herein as follows:

1. Irrigation
   - Forage, Fibre, and Oil Producing Crops
   - Orchard
2. Industry
   - Cooling or Process Water
3. Recreation
   - Fishing and Boating
   - Landscape (Park and Playground) Irrigation

Matching Source to Use

Conceptually, a specific wastewater can be directed to a particular use by subjecting it to appropriate treatment. Which treatment processes are required for each source-to-use combination can be determined by comparing the quality occurring at the source with the criteria relevant to the use. The procedure is to identify a quality vector for influent flow to the intervening treatment process and a quality vector for effluent flow following treatment. These vectors are simply an ordered listing of all the significant water quality parameters. The influent and effluent flow vectors are linked by the parameters which are critical in common to both the source and the use. These "critical parameters" determine the treatment process or combination of processes that will be required.

The conventional (primary, secondary) treatment methods applied to municipal effluents are in many respects standardized and well known, although there is room for increased efficiency. Primary treatment reduces coarse, settleable solids, removes some amount of suspended organic materials by settling, and reduces biological oxygen demand (BOD_5) by as much as 35 percent. Secondary treatment methods (trickling filter, activated sludge, or oxidation pond) consist of some form of biological oxidation and partial settling of the residual organic materials, with a resulting cumulative reduction in BOD_5 of up to 95 percent with the activated sludge process and somewhat less in the other processes (FWPCA 1968, p. 4-5).

At the advanced treatment level, the general classes of critical parameters and the corresponding treatment processes which effectively act upon them are as follows, the underlined items being those specifically cited for examples in Table 1 below: (1) Suspended solids removal--lime or alum <u>coagulation-sedimentation</u> (=chemical clarification), sand or mixed-media <u>filtration</u>, and <u>microstraining</u>; (2) inorganic removal--<u>electrodialysis</u>, distillation, freezing, ion exchange, and reverse osmosis; (3) organic removal--<u>activated carbon adsorption</u>, advanced oxidation, foam separation, and <u>filtration</u>; (4) nutrient removal--<u>precipitation of phosphate</u>, biological denitrification of nitrate-N, air stripping of ammonia-N, and <u>sand (soil) filtration</u>; (5) removal of turbidity, color, odor, and toxic substances--activated carbon adsorption; and (6) removal of pathogenic microorganisms--<u>chlorination</u>.

Application of these methods to the source-to-use matrix for wastewaters through the appropriate critical parameters produces a "treatment-method matrix," as detailed in Table 1.

Unit costs of the appropriate treatment combinations at various plant scales can be estimated for a specific design and location, but it is difficult to generalize because of the widely diverse locations of the world's desert regions. Until recently the unit total costs for primary and secondary treatment in southwestern United States (Arizona) could be estimated approximately as follows: At a scale of 2.0 million gallons per

Table 1. Matrix of Treatment Methods for Wastewaters Relative to Type of Reuse.

Source \ Use	A_1 Irrigation: Field and Forage Crops	A_2 Irrigation: Fibre and Oilseed Crops	A_3 Irrigation: Orchard	A_4 Irrigation: Produce	R_1 Recreation: Fishing and Boating	R_2 Recreation: Landscape Irrigation
Domestic-Industrial Effluent: City Plant or Separable Source	PRIM SEC	PRIM SEC	PRIM SEC	PRIM SEC CHLR	SEC CHEM FILT CHLR	PRIM SEC CHLR
Domestic-Industrial Effluent: County Plant or Discrete Source	OXP	OXP	OXP SEC	OXP SEC CHLR	OXP CHEM FILT CHLR	OXP SEC CHLR

Source \ Use	I_1 Industry: Cooling	I_2 Industry: Mining and Milling	S_1 Storage (Surface)	S_2 Storage (Subsurface)
Domestic-Industrial Effluent: City Plant or Separable Source	SEC CHEM FILT	SEC CHEM FILT	SEC CHEM FILT	SEC FILT CHLR
Domestic-Industrial Effluent: County Plant or Discrete Source	OXP CHEM FILT	OXP CHEM FILT	OXP CHEM FILT	OXP SEC FILT CHLR

Key to terms: PRIM-Primary; SEC=Secondary, Activated Sludge; OXP=Oxidation Pond; CHEM=Chemical Clarifi- [illegible] sedimentation; FILT=Sand filtration; CHLR=Chlorination.

day (mgd), $0.10 U.S. per 1000 gallons or $30 U.S. per acre-foot (ac-ft) for the oxidation pond, and about the same for primary treatment; at a 10-mgd scale, these same figures were roughly applicable to the trickling filter method, but the activated sludge process cost approximately $0.15/1000 gal or $40/ac-ft.

It is stressed that these figures are given only as an example, and that actual costs will vary widely with location, size of plant, and time, because of fluctuations in costs of labor, materials, and especially energy.

It may be pointed out, incidentally, that treatment plants can be built in the warm desert regions without the necessity of protection from freezing, thereby effecting considerable savings in capital expenditure.

The advanced treatment processes are perhaps even more sensitive to the variable factors mentioned earlier, than are the conventional processes; no estimate of costs will be attempted here.

AN ECONOMIC EXAMPLE: TUCSON AND PHOENIX

Wherever a concentration of population may develop, a municipal wastewater supply will accrue concurrently, and its form of treatment and allocation to reuse will depend in large measure upon the proximity of other water-use activities. Commonly, irrigated croplands are located nearby, and the primary-secondary treated wastewater may be utilized in part for irrigation, with no further treatment needed for many kinds of crops. Also, electrical generating plants, industrial activities, and parks or recreational areas may be located in the urban region, and a multiple allocation of wastewater to these users becomes apparent. The current wastewater production and allocation conditions in two Arizona population centers--Tucson and Phoenix--serve as an example.

At Tucson, about 40,000 acre-feet per year of secondary effluent is produced at the wastewater treatment plant. For more than 20 years, a substantial portion of the effluent was used for irrigation of forage crops and cotton. Presently, except for a minor quantity being used on the City treatment plant farm, it is being discharged to the otherwise dry channel of the Santa Cruz River, where it flows, at times, as much as 27 miles downstream. Some of the flow is recharged through the channel sediments, and is contributing to an increase in nitrate concentration in the ground-water reservoir beneath and adjacent to the river.

It would seem desirable to salvage this alternative water supply from non-use and apply it to beneficial use in agriculture, mining, or recreation. Some or all of the treated wastewater could be conveyed by gravity flow to the Avra-Marana agricultural area, several miles to the northwest, for cropland irrigation. The wastewater nutrients which under present conditions are contributing to pollution of the ground-water basin would be beneficial to the farmer if he properly used the wastewater in irrigation (Cluff and DeCook, 1974). This type of use will be assumed in the following illustration.

The farmer can view the prospective wastewater supply as an alternative to his present pumped ground-water supply, and can make a direct cost comparison, since these are the only sources of supply in the absence of surface water in the desert region. This is illustrated in a conceptual way as follows (DeCook, 1970). To evaluate the effect of imposing a wastewater supply on the ground-water supply presently available, one may consider the supply curves for both sources (Figure 1), from which two kinds of effects can result. First, the wastewater might act to augment the existing supply and move the water use level Q higher (to the right) under the prevailing demand curve. However, since agricultural water-use acitivites commonly are constrained not only by water shortage but by other factors, the added supply should not be expected to result in a directly proportionate increase in use by expanded irrigation. Rather, a different kind of effect will operate, i.e., incremental substitution of the wastewater into the water supply function in order to minimize costs at an unchanged level of use Q on the existing acreage.

This substitution in turn can take place in one of two ways, depending upon the relative shapes of the supply functions; these are illustrated in the two parts of Figure 1. In the upper diagram, the ground-water supply curve would be followed up to quantity q_x, and the wastewater supply would be used for additional quantities up to the level of use Q. The net gain to the system would be the shaded, roughly triangular area as shown. In lower diagram the wastewater supply would be utilized up to quantity q_x, and ground water would supply additional needs to level Q, while additional wastewater would become a disposal quantity or become available for other

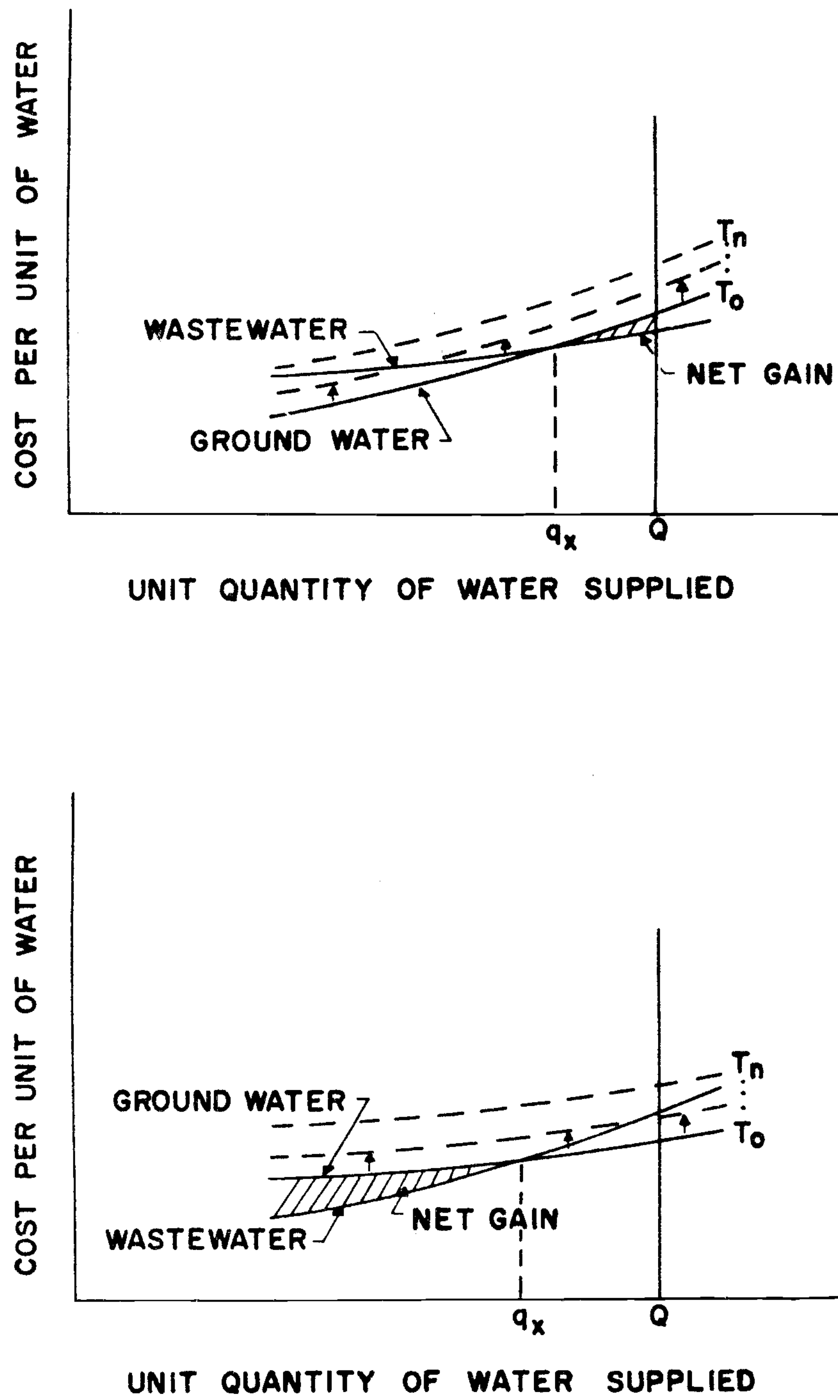

FIGURE 1. EFFECTS OF SUBSTITUTION OF WASTEWATER FOR GROUND WATER.

allocation. The net gain under this set of conditions also is indicated by the shaded area. In addition to the net gain as illustrated for a given year's use, increasing gains will be realized in subsequent years if the ground-water supply function shifts upward relative to the wastewater supply function. This is likely to be the case, because time-related increases in cost of ground water are primarily a function of increasing pumping lifts compounded by rapidly increasing energy costs. The controlling factor in supply cost for wastewater is treatment cost. This may be expected to increase with time also, by escalation of material and labor costs for construction of treatment facilities as well as energy costs; however, such increases may be tempered by the effects of improved technology leading to higher efficiency in selective treatment methods, and economies of scale due to ever-increasing effluent loads.

Two other forms of potential time-related incremental benefit from the combined supply function can be postulated-- (1) an increasing future value of the ground water not pumped as a result of the substitution, and (2) the benefits (or avoided losses) of precluding eventual local ground-water depletion which might necessitate relocation or extinction of the agricultural (irrigation) activity.

The relationship illustrated in principle in Figure 1 was plotted with real data by DeCook (1970) for actual supply conditions near Tucson. Figure 2 shows the relative costs of supplying ground water and wastewater to irrigate field and forage crops and cotton. This example assumes that the ground-water supply is provided from a diminishing stock resource, a condition described by Jacobs (1968) in his formulation of a ground-water supply function for Tucson domestic use by diversion from agricultural use. The "ground water" curve represents the cost of supplying ground water in 10-mgd increments (numbered "diversion units") from increasingly distant well fields to a central distribution point, in this case for agricultural use. The "salvaged water" curve represents treated wastewater, also available for use at the same point. The conveyance and storage costs are "netted out" in order to compare directly the variable costs for pumping ground water and for treating wastewater.

Implicit in this graph is the recognition of treatment of domestic wastes by the water agencies as a service function, since disposal is

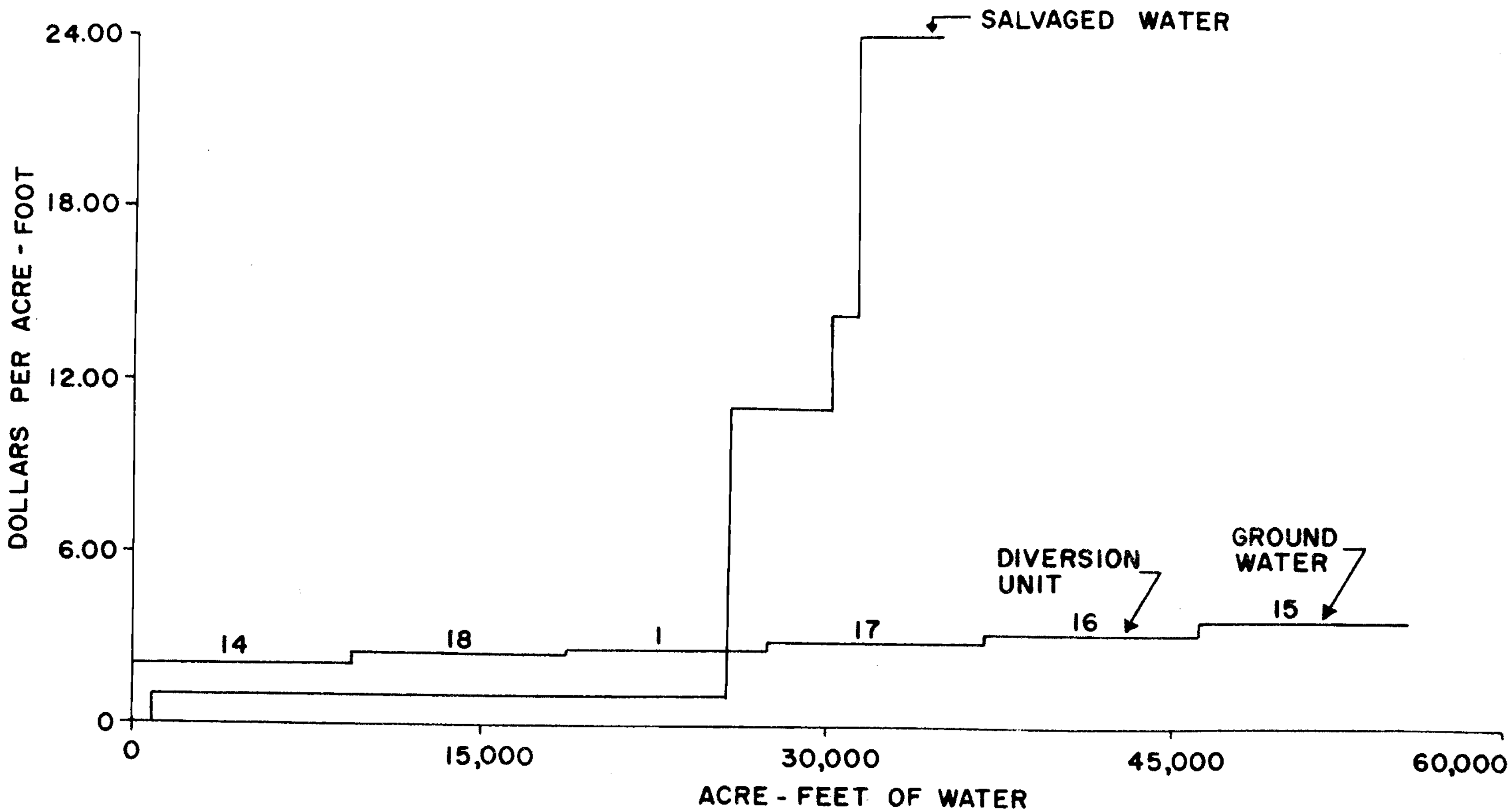

FIGURE 2. SUPPLY FUNCTIONS FOR GROUND WATER AND SALVAGED WATER TO SELECTED AGRICULTURAL USES, TUCSON REGION, 1970.

Source: Ground-water data based on Jacobs (1968).

necessitated in any event. The water users in the example paid only $1.00/ac-ft by contract. Under these conditions the wastewater supply curve is the cost-minimizing function for approximately the first 25,000 acre-feet of supply, at which point the cost veers sharply upward and ground water becomes the least-cost supply.

In the same context as Figure 2, the supply function for wastewater can be extended to all the possible uses considered. In that case the unit costs determining each increment of the supply function would not represent a blanket cost for treatment, but rather the costs of required treatment relative to each use. If higher uses require higher quality, the cost of advanced treatment would be added. Similarly, if alternative sources of water or wastewater become available to the same user, he will find a similar supply function with respect to each source and can determine which source best fits his requirements.

Other potential uses for wastewater in the Tucson region include copper mining-milling processes and irrigation of pecan orchards. The location of these water-using activities is a region 20-30 miles (32-48 kilometers) south of Tucson and about 300 to 900 feet (90-270 meters) higher than Tucson. In that region all uses are presently served by a diminishing ground-water supply, and the wastewater is a possible alternative; however, its conveyance from the Tucson wastewater treatment plant would require capital investment for a pressure pipeline and considerable energy for upgradient pumping. Also, in the case of the mines, it is necessary to determine the type and cost of appropriate advanced treatment processes before the wastewater can be utilized in the copper ore milling process.

An additional actual use of wastewater in the Tucson region is occurring in the recreational field. Randolph Park, a municipal park which includes about 400 acres of landscaped picnic and playground areas, a baseball park, a golf course, and a small lake for scenic enjoyment and fishing, is supplied by the liquid effluent fraction from a satellite "package" treatment plant. This type of plant generally incorporates processes of primary and secondary clarification, an extended aeration treatment, and chlorination. This particular plant is designed for a capacity of about 2.0 mgd, tapping a sewer main and thereby providing a measure of relief to the heavily loaded sewage collection system.

Treated effluent from the plant is used in both lake filling and park irrigation, as a partial substitute for high quality ground water.

Turning to the region of Phoenix, Arizona, we see a quite different situation relative to use of wastewater; a multiple allocation of the municipal wastewater there, in a quantity of 75-80,000 ac-ft/yr, has already been implemented. The Buckeye Irrigation Company west of Phoenix utilizes approximately 30,000 ac-ft/yr of the secondary effluent from the large Phoenix treatment plant, through a long-term contract. The wastewater, being less saline than much of the ground water in the district, has been used by the Buckeye irrigators since 1962, in partial substitution for the ground-water supply. This importation of wastewater and concurrent decrease in ground-water pumpage has produced an improved hydrologic balance in the district as well as an improvement in quality of irrigation water. The irrigation company obtains the wastewater at a delivery price not less than $1.50/ac-ft, the exact price being determined monthly according to a stipulated formula. In this instance, as seen earlier, the cost of treatment at the plant is a public cost incurred as a service function and is not borne by the water user. Neither is advanced treatment required by the crops irrigated in this area; therefore wastewater cost to the user is relatively quite low.

An additional benefit is the fertilizer value in the wastewater; it contributes not only to the water requirement but to the nutrient requirement of the crops to which it is applied. The equivalent value of commercial fertilizer was estimated by Cluff et al. (1972) as about $5/ac-ft of wastewater, but in 1977 it is undoubtedly worth much more. In terms of available nitrogen, the secondary effluent actually contains more than that needed by most crops, so that a blend or dilution of wastewater and ground water is most beneficial, the optimal mix depending upon the specific crop-soil-water combination.

Wastewater also is to be used for crop irrigation, under different conditions, in a proposed allocation of effluent from the City of Phoenix to the Roosevelt Irrigation District. The effluent will receive a tertiary treatment by filtration through natural soil using spreading basins and a pump-back well system. Improvement of wastewater quality attained by this method as described by Bouwer (1973) is expected to be adequate to serve unrestricted crop irrigation, recreational facilities, or some industrial uses. As for crop irrigation, the Roosevelt Irrigation District includes acreages of not only small grains, hay and pasture, and cotton, but also a substantial acreage of vegetables such as lettuce and onions, and melons. Presumably any and all of the crops in the District can be irrigated with the product water of the filtration process.

Where municipal wastewater is used for irrigation of field vegetables which are to be consumed by humans without cooking or processing, such as lettuce, appropriate treatment must be applied to avoid the incipient hazards of possible ingestion of viruses, heavy metals, or organic toxins. Where wastewater is used without advanced treatment, as near Phoenix and Tucson, the cropping pattern commonly includes alfalfa, barley, oats, sorghum, and cotton. Additionally, secondary effluent can be used to irrigate certain oil-producing crops for which there is a growing market, as in southwestern United States and northwestern Mexico. These include safflower, linseed, and jojoba, which is a substitute for sperm whale oil and for certain petroleum derivatives, both of which are becoming increasingly scarce on the world market.

A further allocation of wastewater in the Phoenix area has been arranged through a contract option whereby the proposed Palo Verde nuclear power plant west of Phoenix would purchase, treat, and utilize approximately 35,000 ac-ft/yr of wastewater for each of three generating modules, to be completed over a period of ten years.

A fossil fuel-fired generating plant generally has better thermal efficiency, and thus requires less water for cooling, than a nuclear plant (about 14 ac-ft/yr/MWe for fossil-fueled vs. 22 ac-ft/yr/MWe for nuclear). In southwestern United States, an urban population generates approximately three times as much wastewater from its sewage collection system as is required to cool a nuclear generating plant large enough to serve the electrical energy requirement of that population. If the plant is coal-fired, the same urban wastewater production becomes about five times the cooling requirement. In either instance it is evident that in an urban area, local geographical conditions permitting, the total cooling water requirement for power can be supplied and a large fraction of the wastewater will remain for allocation to other uses.

The numerical values in this relationship would be different in other desert regions of the world; the per-capita wastewater production may be lower, but the per-capita energy requirement likely would be lower also. The principle of supplying cooling requirement for electrical energy by use of wastewater would still hold.

ENVIRONMENTAL CONSIDERATIONS

Correlative with the technical feasibility and economic advantages of wastewater reuse, its environmental implications are an important aspect of resource planning, especially in an arid region. It is clear, as stated earlier, that simple disposal in a watercourse without adequate assimilative capacity is environmentally damaging, and in fact will no longer be permitted in the United States under the Federal Water Pollution Control Act of 1972, Public Law 92-500. Neither is underground disposal acceptable without adequate treatment; off-season subsurface storage by spreading or well injection is a useful management alternative, but the injection water commonly requires extensive treatment, especially for injection, to be made compatible with native ground waters.

In the various forms of wastewater reuse, environmental protection or enhancement requires careful wastewater management practices. For example, where treated municipal effluent is applied to field crops for irrigation, analysis of the wastewater, the soil, and the plant material must be made to determine actual nitrogen requirement and utilization by the plant, and the appropriate dilution or proportion of wastewater with ground water must be maintained, so that excessive nitrogen will not be leached through the soil column and into the ground-water reservoir.

Provided such steps are taken and adequate surveillance is made by the wastewater user or wastewater management agency, the wastewater products resulting from resource development become in turn a resource of economic value and environmental acceptability, contributing to the conservation of primary water resources.

ACKNOWLEDGMENTS

Portions of the work cited herein were supported by the State of Arizona and by the Office of Water Research and Technology, U. S. Department of the Interior, pursuant to the Water Resources Research Act of 1964, as amended.

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