SOURCES AND POTENTIAL USES OF SALVAGEABLE WATERS IN ARIZONA URBAN REGIONS

by

K. J. DeCook

Water Resources Research Center
The University of Arizona
Tucson, Arizona

Prepared for Presentation at The Third
National Conference on Complete Water Reuse,
Cincinnati, Ohio, June 27-30, 1976.

SOURCES AND POTENTIAL USES OF SALVAGEABLE WATERS IN ARIZONA URBAN REGIONS

INTRODUCTION

In the light of recent economic and demographic trends in the arid and semiarid regions of southwestern United States, various impacts on water supply and water use patterns are apparent, leading to a growing interest in reuse of water. Significant among these trends are the following:

1. Population growth and resulting increases in domestic water use in these regions have yielded a rapidly increasing rate of discharge from municipal sewage collection and treatment systems. Increasing demands for total water supply indicate the increasing desirability of feasible substitution of reused waters into that supply.

2. The discharge rate of industrial effluents has risen to a level which contributes significantly to local overloading of the sewage collection systems.

3. Effects of urbanization have increased the rates of storm runoff which not only must be controlled for public safety but may be salvaged for public use.

4. Gradual changes have become evident with regard to water use in the local and regional agricultural economy (to which portions of the municipal effluents are presently allocated), which portend shifts in water use among kinds of crops as well as from agricultural use in general to other kinds of uses.

5. The apparent demand for water-based outdoor recreation is expanding, not only from population growth and urban social changes, but also owing to recent federal and state legislation and administrative activity enhancing

the acquisition and development of sites and facilities for outdoor recreation.

7. The recent surge of governmental activity in the realm of "quality of the environment" has produced both federal and state legislation imposing water pollution control measures and water quality standards upon effluent producers.

Some economic implications of these predominantly institutional trends can be identified. First, it would seem timely to consider the relative benefits of supplying the increased requirements of mining, recreation, and other uses from wastewater sources as against supplying them entirely from primary sources, principally ground water.

Second, whereas many effluent producers, both municipal and industrial, have previously regarded effluent discharge basically as a disposal problem (thereby assigning the effluent water a negative value), the requirements of effluent quality standards now necessitate post-use water treatment or quality improvement, thereby imputing to the effluent water a positive value as an input to some form of reuse; the discharger supposedly will be forced to more efficient recycling (a desirable result from the aggregate supply viewpoint) or to contracting for sale of his effluent to a beneficial reuse, to recover in part the costs of his water treatment.

Identification of Salvageable Waters

The kinds of water discussed herein are called "salvageable" waters, and include for the most part the various "wastewaters" such as municipal and industrial effluents which are or can be recovered and reused, in addition to increments of storm runoff from urban or suburban watersheds (DeCook, 1970). The runoff, as it occurs, has not been used and so cannot be said to be reused, but it can be salvaged for use along with the effluents. All these

classes of water have in common some characteristic of substandard resources, such as impaired quality or uncertain availability.

Geographic Areas of Study

In Arizona the principal locales of salvageable waters and points of potential use are the Phoenix and Tucson regions. Minor sources are found in some of the smaller cities and mining communities around the State. Specifically discussed below are the existing and proposed uses of municipal effluents of Phoenix and Tucson, and of urban storm runoff and selected industrial effluents in and near Tucson.

Arizona Standards for Wastewater Use

Regulations were adopted in 1972 under which a permit system governs the "--- direct reuse of wastes originally containing human or animal wastes ---," under the authority of the Arizona State Department of Health Services. The form of the regulations is to specify required treatment for an array of uses, with stated limits of coliform density as monitored after each type of treatment.

SOURCES AND POTENTIAL USES OF SALVAGEABLE WATERS

Three kinds of salvageable water that have received study in the southern Arizona region are municipal effluents, industrial discharges, and urban storm runoff. Each will be considered in turn by example, in terms of quantity, quality, and potential application to various beneficial uses.

Treated Sewage Effluent

At the City of Tucson sewage treatment plant, secondary effluent is presently being produced at a rate approaching 40,000 acre-feet per year (ac-ft/yr), or an average between 12 and 13 million gallons per day (mgd). Virtually all of this is discharged to the Santa Cruz River channel and is currently unused. At Phoenix the aggregate discharge of treated waste-

water (at the 23rd Avenue and 91st Avenue plants) is almost double that at Tucson, about 75,000-80,000 ac-ft/yr, much of this effluent is discharged to the Salt and Gila River channels, and some is used for irrigation, as described below.

A number of other cities and towns in Arizona are producing effluent in sufficient quantity for economic utilization. A recent compilation by the Arizona State Department of Health Services (1973) shows a total flow of almost 135 million gallons per day (mgd) from 33 communities, or a volume of more than 150,000 ac-ft/yr. This is a substantial water resource in the context of water availability in Arizona.

The quality of the effluent at Tucson, as compared with local ground water, is indicated in a general way in Table 1, reproduced in part from Cluff, et al. (1972). The treated wastewater at Phoenix may be more saline at times, but does not differ appreciably from this example as to composition.

Crop Irrigation

One beneficial use of treated municipal wastewater is its application, without advanced treatment, to irrigation of field and forage crops. In both Phoenix and Tucson areas, extensive cropped acreages are found within a short distance of large wastewater treatment plants.

The Buckeye Irrigation Company west of Phoenix, where the gross irrigation diversion requirement for some 18,000 acres is approximately 100,000 ac-ft/yr, utilizes the secondary effluent from the 91st Avenue treatment plant. This discharge became available to the irrigation area in 1962 by gravity flow down the Salt and Gila River channels. The wastewater, being less saline than much of the ground water in the district, was used opportunely by the Buckeye irrigators in increasing amounts, eventually reaching more than 40,000 acre-ft/yr, in partial substitution for the ground-water supply. This impor-

Table 1

Comparison of Quality of Representative Ground-Water Samples in Avra-Marana Area with a Composite Sample of Treated Sewage Effluent at City of Tucson Plant
(All units are milligrams per liter except pH)

Chemical Constituents	Marana* Ground Water	Tucson Composite** Sewage Effluent
Total Dissolved Solids	280	656
Calcium	42	77
Magnesium	4	19
Sodium	43	90***
Chloride	30	95
Sulfate	40	167
Bicarbonate	154	313
Carbonate	0	0
Fluoride	0.6	-
NH_3-N	-	19.1
NO_2-N	-	0.5
NO_3-N	3.2	0.4
Organic N	-	8.8
Total N	-	28.8
Potassium	2.9	10***
Silica	25	35
Iron	0.03	0.5
BOD	-	26
COD	-	60
pH	7.7	7.7

*Well Location T11S,R11E Sec. 16cdd; Sampled 8/18/66[1]
**Composite weighted effluent sample using average daily discharges from 1971-72[2]
***Separation of sodium and potassium was made from samples taken by the Water Resources Research Center.

1. Dutt and McCreary (1970).
2. Data published by Dye (1972).

tation of wastewater and concurrent decrease in ground-water pumpage tended toward an improved hydrologic balance in the district as well as an improvement in quality of irrigation water.

The irrigation company in 1971 entered into a long-term contract with the City of Phoenix for 30,000 ac-ft/yr of the effluent, at a delivery price not less than $1.50/ac-ft, the exact price being determined monthly according to a stipulated formula. It may be noted that 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 for use by the field and forage crops irrigated in this area, so that wastewater cost to the user is relatively quite low.

An additional benefit is the fertilizer value in the wastewater, since 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 can be conservatively estimated as about $5/ac-ft of wastewater. 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 more beneficial, the optimal mix depending upon the specific crop-soil-water combination.

An additional portion of the Phoenix municipal wastewater is proposed to be allocated from the City of Phoenix 23rd Avenue treatment plant 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 (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 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. In this instance, where additional treatment is needed to bring the water to higher quality, the price of the treated wastewater at the delivery point is subject to contract negotiation between the water user and the seller (the City).

Reference is made next to the City of Tucson wastewater system. For many years in the past, some of the treated wastewater there has been used for irrigating approximately 2,000 acres of land in the Cortaro area; however, the present land owners have ceased irrigation and other uses have been proposed for these lands. Presently, except for a minor quantity being used on the City treatment plant farm, the effluent 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 ground water along the river in the Cortaro area.

These conditions suggest that, when it becomes legally feasible, it would be desirable to salvage this water supply and convey some or all of the treated wastewater by gravity flow to the Avra-Marana agricultural area, several miles to the northwest, for irrigation use. The same nutrients which under present conditions are contributing to pollution of the ground-water basin would be beneficial to the farmer if the effluent were properly used in irrigation.

It has been suggested (Cluff et al., 1972) that good-quality ground water from the Avra-Marana irrigated area could be transferred to the City of Tucson for municipal use in exchange for treated effluent to be applied to irrigated croplands. In a sense, the ground water would by cycled through

the municipal system prior to use on the farm, picking up plant nutrients en route.

Industrial Use: Mining-Milling

The City of Tucson wastewater product also is being considered as a source of water for use in the copper mining district about 20 miles south of Tucson. Presumably the secondary effluent could be used without additional treatment for some purposes such as dust control, and with additional treatment for some phases of the milling operations. The cost of conveyance to the mining district, however, would be quite high in terms of pipeline construction and energy for pumping, since it happens that a lift of several hundred feet would be required, as dictated by local geography. Presently, water for the mines is supplied from ground water pumped from adjacent Santa Cruz Valley.

There is no apparent incentive for the mines to obtain the wastewater under a least-cost objective. Litigation is pending, however, as between the mines and the irrigation water users in the same valley, and the City of Tucson has intervened. It is possible at this time only to speculate as to the possible outcomes which could either alter or reinforce the incentive for continued ground-water utilization as opposed to procuring wastewater.

Technical questions remain unresolved at present, regarding suitability of the effluent in various ore-processing operations. Studies have been conducted recently on this problem by Fisher and Rabb (1975), whose preliminary test results indicated two significant problems in use of sewage effluent in a copper milling operation. These problems are excessive frothing (not useful for flotation) and low molybdenum recovery. Study was used to investigate methods to control non-productive frothing and to improve recovery of molybdenum. Approaches taken include (1) blending of sewage effluent

with fresh water and water recycled from the flotation processes, (2) modification of the flotation process by using different flotation reagents, (3) treatment of the sewage effluent to remove constituents detrimental to flotation, and (4) blending sewage effluent with copper mill tailing to determine if the tailing itself may modify the sewage effluent. The investigation was carried out using an ore supplied by the Cyprus Pima Mining Company containing 0.49% copper and 0.011% molybdenum. The sewage effluent was acquired from one of the activated-sludge treatment plants in Tucson. It was found that detrimental effects can be moderated considerably by changing the flotation reagents and by treating the effluent prior to flotation. These results are only valid for the ore tested and for the first step of flotation.

Further investigations have been initiated recently by the City of Tucson and the mining interests, to examine in detail the effects of certain advanced treatment methods on the above problems.

Industrial Use: Power Plant Cooling

Water requirements are growing rapidly in Arizona and the Southwest for cooling in electrical power generation. In addition to increasing trends in per capita electrical power usage, generating needs must keep pace with population growth and migration. Evidently, water requirements for cooling in electrical generating plants will increase apace with generating load growth. An additional factor is present, however, in that a rapidly increasing proportion of electrical generation, at least in the western states, will be derived from nuclear-fuel plants, which commonly have a lower total thermal efficiency than the fossil-fuel plants. A nuclear unit may require 20 to 30 ac-ft/yr/MWe; Fazzolare and Scofield (1973) calculated the average water use for a number of cooling methods at nuclear plants as 22.4 mgd or 25.1 ac-ft/yr/MWe, depending upon type of cooling system and details of plant design.

A significant corollary to this growth in energy and water demand is the increasing quantity of available municipal wastewater, which is also a function of population growth. In some localities the demand for cooling water can be satisfied from wastewater, rather than from already heavily appropriated streamflow or from ground water of good quality which is increasingly needed for domestic supplies. An example of this situation is the proposed Palo Verde nuclear plant site west of Phoenix, for which an option has been taken on a portion of the Phoenix wastewater. Projected quantities evidently will be sufficient to supply this requirement in addition to the irrigation uses discussed earlier.

A quantitative comparison can be made between wastewater supply and cooling water demand for power in a given locality. If a nuclear power plant is located close to a large urban area, the urban populace will generate approximately three times the quantity of wastewater needed to cool a plant large enough to serve the electrical energy requirement of that same population. For example, a metropolis of one million persons, with a sewage discharge load of 100 gallons per day per capita (City of Tucson, 1973), would yield about 112,000 ac-ft of wastewater per year; its electrical energy needs (at current per-capita demand) would require a generating capacity of approximately 1,500 MWe which, at 25 ac-ft/yr/MWe, would demand 37,500 ac-ft/yr for cooling. Therefore, if the power plant were to serve only the adjoining municipality from which the wastewater could be delivered (a condition not often realized), the total cooling water requirement could be supplied and a large fraction of the wastewater would be left over for allocation to other uses.

Regarding power plant location near smaller cities or outlying communities, an economic advantage is apparent if even a portion of the water supply function can be filled by substitution of wastewater for other sources, as

was the case for irrigation supply. The actual financial gain would depend largely on the cost of required treatment of the wastewater versus the cost of obtaining the alternative water supply.

Recreational Use and Landscape Irrigation

Treated municipal wastewaters also can be applied to landscape or turf irrigation in parks, playgrounds, golf courses, and other places where non-water based recreational activities take place; perhaps the most common of these in Arizona and elsewhere is golf course irrigation. Another application is direct use of the waters to form a water body such as a lake for water-based outdoor recreation.

Recently the City of Tucson has built and is operating a satellite treatment plant, with a capacity of about 2.0 mgd, in Randolph Municipal Park, where it is planned that the liquid fraction or treated wastewater will be applied to those uses just described. At this and similar park localities in the urban regions, it may be feasible to utilize treated urban storm runoff or industrial wastes, in conjunction with this treated sewage effluent, for these purposes.

Industrial Discharges

Industrial wastewaters produced in Arizona may be classified as cooling effluents and industrial processing effluents. The principal kinds of process waters are (1) numerous point sources of aggregate-processing waters discharged at sand-and-gravel operations along major stream channels, (2) effluents from mineral-processing sites in various mining districts, and (3) effluents from electroplating and similar processes involving metals and electronic components fabrication. This group of wastewaters is characterized by widely scattered location, diverse and/or complex content of pollutants, and generally minor quantity at a given point source; therefore these waters will not be considered further here, except in reference to research needs.

Cooling tower effluents (blowdown) from thermal-electric generating plants probably represent the most tangible source of salvageable or reusable industrial wastewater in the Phoenix and Tucson regions. For example, the largest separable source of industrial effluent at Tucson is the cooling tower blowdown of the Tucson Gas and Electric Company-Irvington Road steam electric generating plant, which discharges not only its sanitary effluent but its cooling tower effluent, which amounts to more than 700 acre-feet per year, into the city sewage collection system. A representative sampling of the cooling effluent, as well as the input water, is shown in Table 2. The chemical content of the effluent results in part from various treatments in the cooling towers as well as a fivefold concentration of the input water by recycling. The treatments are addition of sulfuric acid for neutralization of alkalinity in make-up water, addition of chlorine for algae control, and addition of hexametaphosphates to prevent scale formation and inhibit corrosion. The outstanding effluent chemical constituents are fluoride concentration and relatively high total dissolved solids concentration, of which sulfate is predominant. At the Company's De Moss-Petrie power plant the average discharge on a continuing basis is estimated at 500 ac-ft/yr. This includes intermittent outflow of pumped well water from a nearby transformer station, with a resultant concentration of total dissolved solids between 900 and 1200 ppm.

Water temperature of course is important is considering industrial cooling effluents for reuse. Measurements of discharge temperatures at the Irvington Road plant show that the average temperature of the effluent during a typical January day is $72^{o}F$, about $20^{o}F$ higher than the January mean air temperature, and that of a typical July day is $93^{o}F$, or $8^{o}F$ above the ambient temperature for that day. The diurnal fluctuation in effluent temperature during the July day was $87^{o}F$ minimum to $97^{o}F$ maximum. This heat load may be regarded as thermal

Table 2. Chemical Character of Water from Wells and Cooling-Tower Effluent at Irvington Road Steam Electric Generating Plant.*

	Concentration (mg/l)	
	Input Water (Composite From Four Production Wells)	Effluent (Composite From Four Cooling Towers)
Chemical Constituent		
Calcium	36	161
Magnesium	6	21
Sodium	79	440
Chloride	22	116
Sulfate	145	1,167
Bicarbonate	26	28
Temperature, °C	36[a]	33
Boron	0.18	0.63
Fluoride	1.6	7.1
pH	8.2	7.8
Nitrate as NO_3	1.0	6.0
Phosphate as PO_4	0.55	3.87
Potassium	2.5	12.1
Silica (SiO_2)	18	59
Total dissolved solids	338	2,022
Trace Metal		
Iron	0.043	0.220
Manganese	0.002	0.010
Chromium	0.004	0.001
Nickel	0	0
Copper	0.014	0.058
Zinc	0.008	0.040
Lead	0.005	0
Cadmium	0	0.001
Cobalt	0	0
Strontium	1.761	3.508

*Sampled in September 1967.

[a]Temperature ranged from 30° to 55°C, as a partial function of well depth.

pollution or thermal enrichment, depending upon intended reuse; if desired, it can be preserved, or even enhanced, by proper configuration of ponds or by heat barriers such as monomolecular film, perlite, or floating styrofoam rafts to confine heat within the water body. Examples of beneficial utilization of thermal effluents in other areas are deicing, space heating, waste conversion, warm-water irrigation, and temperature control in closed-system horticulture, aquaculture, or mariculture.

Ground-Water Recharge

The DeMoss-Petrie power plant blowdown mentioned above has been utilized since 1963 as a medium for research in ground-water recharge at the Field Laboratory of the Water Resources Research Center, University of Arizona, near Tucson. During this period, under various operational schemes, effluent quality transformations during recharge and mixing with native ground water have been defined, and the recharge and subsurface storage alternative as a water management tool has been demonstrated (Wilson, 1971).

Recreation and Landscape Irrigation

Application of cooling effluents to recreational uses and landscape irrigation, as in urban public parks and golf courses, has been proposed although not yet implemented in this region. For example, City and County parks and recreation officials in Tucson, among others, are currently investigating the feasibility of supplying a proposed new park, near the Ajo Road Flood Detention Basin, with a combination of storm runoff from Davis-Monthan Air Force Base and cooling effluent from the aforementioned Irvington Road power plant. Apparent problems are biological and chemical quality control of the combined waters; one of the apparent advantages is the dual benefit of applying the cooling effluent to beneficial use while simultaneously relieving the sewage

collection system of the present loading due to that effluent.

An operation example of combined cooling and recreational use of water is that of the Arizona Public Service Company-Cholla generating plant at Joseph City in northern Arizona, where a cooling-pond system is utilized for dissipation of heat to the atmosphere. Several years ago the pond was modified to serve as a recreational lake as well as a cooling facility. The 380-acre water surface is esthetically appealing in this desert-like region (less than eight inches annual precipitation), and is suitable for some types of boating, swimming, and fishing. The user population here is sparse and largely transient; however, if such a facility were located near a large population center, there is no doubt that recreational use would be heavy.

Urban Storm Runoff

The occurrence of urban storm runoff and its management have not been studied extensively in the arid and semiarid regions of the United States. The runoff regime on small watersheds in these regions is distinctive in terms of storm characteristics peculiar to the desert climate and because of watershed characteristics such as desert vegetation and soils. Results of urban runoff studies in the humid and subhumid regions thus cannot be extended freely to the southwest deserts.

Research has been implemented in recent years in the Tucson region by the University of Arizona Water Resources Research Center, to determine the quantitative and qualitative characteristics of runoff from small urban and suburban watersheds and to investigate management methods by which the runoff can be controlled to reduce hazards to life and property, and simultaneously can be upgraded in quality and applied to use. Several watersheds have been instrumented for hydrologic data collection in and near Tucson, and specific data are presented for two areas: (1) High School Watershed, a small (0.9-square-mile)

subwatershed tributary to Tucson Arroyo and thence to the Santa Cruz River, and consisting of an intensively developed residential area adjacent to the University of Arizona; and (2) Arcadia Watershed (3.5 square miles in area), tributary to Rillito Creek and including moderately developed suburban residential areas, some undeveloped land, and several light commercial and shopping-center complexes.

As to quantitative runoff data, reference is made first to a "control" area, Atterbury Experimental Watershed, a largely undeveloped desert area of 18 square miles southeast of Tucson, where an 18-year record of rainfall and runoff is available. The record for Atterbury and several subwatersheds shows an average annual runoff of about 2½ percent of the rainfall. On the basis of average annual precipitation of 11.0 inches or 586 ac-ft/mi^2, this percentage indicates an annual water yield of slightly less than 15 ac-ft/mi^2 for small watersheds (less than 20 mi^2) in the undeveloped condition.

For the urban watersheds the record is as yet too short to be generalized, but the data at hand for a 6-year period on High School and Arcadia Watersheds are shown in Table 3. In contrast to Atterbury, High School Watershed shows annual volume of runoff ranging from about 57 to 160 and averaging 102 ac-ft/mi^2/yr, and the Arcadia record indicates a range of 13 to 130 and an average volume runoff of 59 ac-ft/mi^2/yr. Stated another way, for this short and inconclusive period it appears that annual runoff from Arcadia and High School Watersheds is approximately four times and seven times, respectively, the amount recorded on the non-urbanized areas. For an individual year (High School, 1971) this factor exceeded ten, and for individual storm events it can be much more.

The record of peak flows illustrates two noteworthy points -- the extreme variability of peaks from year to year (as with volumes), and the predominance

Table 3. Streamflow Data[1] for Urban Watersheds in Tucson, Arizona.

High School Wash at Cherry Avenue[3]

Calendar Year	Volume Runoff (ac-ft) Summer[2]	Winter[2]	Annual	Maximum Summer Peak (cfs)	Maximum Winter Peak (cfs)
1968				486	74
1969	38	20	58	341	50
1970	93	15	109	409	43
1971	102	41	144	664	40
1972	59	71	130	*800	110
1973	20	31	51	204	52
1974	42	16	58	126	45

Arcadia Wash at Pima Street[3]

**1968				213	*310
1969	32	13	45	265	93
1970	205	32	237	594	124
1971	363	94	456	1207	313
1972	159	184	343	940	254
1973	15	57	72	121	74
1974	38	50	87	264	104

*Peak Computed - Overflowed Flume.
**No records prior to 3-19-68.

[1]Measurements by critical-depth flume.

[2]Summer rainy season is June through September; winter season is October-December and January-May.

[3]Preliminary data, as calculated; subject to revision.

of high peak flows in the summer season due to high intensity and storm rainfall amounts resulting from convective thunderstorms of the summer monsoon, augmented at times by moisture from tropical storms moving into the region in late summer.

The quality characteristics of urban runoff in Tucson have been analyzed and monitored during this same period. Three kinds of pollutants consistently occur which would necessitate some type of treatment prior to almost any kind of use -- (1) suspended sediment, (2) bacterial loading, and (3) a complex and undifferentiated array of dissolved organic compounds. Table 4 shows representative analytical results for runoff from High School and Arcadia Watersheds. Also represented is a third area, Railroad Watershed, which contains a large area of railroad switchyards and an industrial zone. The concentrations of most constituents in samples from this watershed are significantly higher than in High School or Arcadia, except for the microbiological indicators, which are considerably lower in count.

Recreational Use and Landscape Irrigation

As an outgrowth of the quantitative and qualitative studies of urban runoff in Tucson, a concept has been developed which would provide for concurrent reduction of flood hazards and beneficial use of portions of the storm runoff. The principal elements are (1) the diversion of peak flows from urban watercourses into adjacent or nearby park areas; (2) temporary off-channel detention and treatment of increments of the runoff; and (3) utilization of the treated waters for park irrigation and/or water-based recreation.

Volumes of runoff in the individual storm events are relatively small; accordingly, in-channel diversion devices would be small, temporary, and perhaps collapsible to pass the larger flows. Field treatment would consist of directed overflow across contoured grass strips to remove sediment along

Table 4. Quality of Water From Urban and Suburban Runoff in Tucson.*

Quality Parameter	High School Watershed		Arcadia Watershed		Railroad Watershed	
	Range of Values[a]	Average	Range of Values[b]	Average	Range of Values[c]	Average
Turbidity	156-1400	556	280-4200	1320	860-3100	1980
Total suspended solids	56-3500	941	244-7152	2100	1256-6360	3081
Volatile suspended solids	20-492	205	68-712	292	232-720	438
Total dissolved solids	122-347	204	160-311	204	135-518	262
Calcium	27-100	42	32-66	41	30-82	52
Magnesium	0.1-12	4	1-13	3	1-11	4
Sodium	2.5-9	5	1.3-8	3	3-52	11
Chloride	2-14	7	0.8-21	6	2-24	8
Sulfate	7-85	27	8-36	18	15-100	39
Bicarbonate	59-312	124	88-210	121	0-264	139
pH	6.7-7.8	7.3	6.6-7.9	7.4	7.0-11.2	7.8
Fluoride	<0.2-1.2	<0.62	<0.2-0.6	<0.31	0.23-0.29	0.25
COD	102-422	231	91-314	200	141-1693	617
Nitrate	0.3-8.0	2.9	0.4-7.7	2.3	0.6-2.6	1.4
Phosphate	0.10-2.5	0.56	0.06-0.60	0.28	0.03-9.0	0.76
Total coliforms (x 10^5/100 ml)	11-230	92	1-280	56	<0.2-120	<32
Fecal coliforms (x 10^4/100 ml)	4-259	65	1-188	49	<1-167	<30
Fecal streptococci (x 10^4/100 ml)	2-61	25	1-200	22	<0.7-30	<7
Phenols	0.2-3.1	0.9	0-2.9	0.8	0-1.5	0.7
Pesticides (ppb)	0.1036-0.2913	0.1920	0.1262-0.2200	0.1838	--	0.0288

*All units are milligrams per liter unless otherwise noted.

[a]Complete or partial results of analyses of 61 samples in 1969, principally during summer monsoon rainy season.

[b]53 analyses.

[c]21 analyses.

with some of the bacterial and organic loads, followed by shallow natural-soil filtration and chlorination of increments of the salvaged water, depending upon intended use. And, as storm runoff is not a dependable source in this region, small-scale storage would provide only intermittent carry-over as a supplemental water supply for park use, and in times of excess, portions of the stored water would be returned to the channel at a controlled rate, enhancing recharge downstream.

Field studies have been conducted by Popkin (1973) on inexpensive treatment methods for upgrading the detained runoff. Actual conditions were simulated by diverting flow from Arcadia Wash onto an experimental plot containing a grass-covered soil filter of native calcareous loam, 200 feet long, 4 feet wide, and 5 feet deep. Water was directed along the length of the grass filter and as it progressed, a fraction of it infiltrated into the soil and was recovered by a buried collector pipe emitting at the lower end. Preliminary results of the grass and grass-soil filtration are shown in Table 5.

Economic studies in progress indicate that costs of diversion, treatment, and storage of runoff as outlined above may be justified by the combined benefits attributable to use of the water and reduction of peak flows downstream.

PRESENT PROBLEMS AND CONTINUING RESEARCH

It appears that rivers, or the normally dry channels of major streams, have become a common depository for wastes and wastewaters in the arid-semiarid urban regions. Water resources management in the desert environment should be directed toward transforming the tributary urban watercourses from unsightly litter collectors to functional and esthetically pleasing waterways-parkways, from the standpoint of not only flood control but also urban beautification and water conservation. Specifically, this will require continued study on

Table 5. Estimated Quality of Filtered Urban Storm Runoff[1]

Water-Quality Variable	Urban Storm Runoff		
	Untreated	Grass Filtered[2]	Grass-Soil Filtered[2]
Cool-season flow			
Chemical oxygen demand, mg/l	100	38	1
Suspended solids, mg/l	1000	650	4
Volatile suspended solids, mg/l	100	74	3
Turbidity, mg/l	800	24	2
Total coliforms[3], MPN/100ml	50,000	8000	100
Fecal coliforms[3], MPN/100ml	4000	100	8
Total dissolved solids, mg/l	180	180	180
Warm-season flow			
Chemical oxygen demand, mg/l	200	76	2
Suspended solids, mg/l	15,000	9750	60
Volatile suspended solids, mg/l	200	148	6
Turbidity, mg/l	1100	33	2
Total coliforms[3], MPN/100ml	2,000,000	300,000	4000
Fecal coliforms[3], MPN/100ml	600,000	20,000	1000
Total dissolved solids, mg/l	220	220	220

[1]From Popkin (1973), based on eleven trials.

[2]Grass establishment and grass-soil stabilization is assumed.

[3]Chlorination of a dose of 3 mg/l of chlorine, after filtration, reduces coliform density to zero.

quantitative characteristics of urban storm runoff, as well as distributive quality sampling keyed to specific land use areas to pinpoint pollutional sources in the arid urban area.

Major stream channels are the recipients of most of the treated municipal wastewaters, in both Phoenix and Tucson. Whereas in the more humid regions a river can assimilate some wastewater by dilution and mixed flow, in the desert region wastewater in the dry stream channels is highly visible, environmentally degrading, and subject to inordinately heavy losses by evaporation and transpiration by riparian vegetation.

In removing these wastewaters from the stream channels and applying them to beneficial uses, much work is needed to assure that through proper treatment and management the efficiency of those uses, both technical and economic, will not be impaired by the substandard quality characteristics inherent in the wastewaters. Examples are the continuing investigations in the use of treated sewage effluent in mining-milling processes near Tucson and in crop irrigation near Buckeye, west of Phoenix (Day et al., 1974).

To extend crop irrigation by effluent to other areas, several kinds of applied research would be in order:

1. A determination of the optimal mixture of source waters for each crop on a growing-season basis is needed to develop irrigation schedules with effluent, well water, or dilutions applied alternately at times most beneficial to emergence, plant growth, crop yield, and other production output variables.

2. An evaluation should be made of existing and potential off-channel recharge basins and their operational criteria; because of time differences between schedules of irrigation requirement and effluent supply, facilities for controlled recharge, temporary storage, and opportune pumpback are needed under almost any plan for utilization of effluent for irrigation.

3. Appropriate planning studies could include a cost-minimization analysis under various delivery systems criteria and a determination of optimal values for the combined variables of irrigated service area, cropping pattern, sizing of conveyance canals or pipelines, design of delivery system, quantity of effluent delivered, and degree of dilution of effluent with pumped ground water. Such an analysis could be enlarged to a net benefit maximization under varying allocations of effluent to irrigation use.

SUMMARY STATEMENT

Several kinds of "symbiotic" relations are implicit in the occurrence and potential use of salvageable waters in the desert environment:

1. Treated sewage effluent disposed in dry channels infiltrates in part to the ground-water reservoir and contributes to excessive nitrate concentration; transfer of the effluent to crop irrigation removes this negative effect and creates the positive effect of nitrogenous plant nutrients on the cropped lands, where commercial fertilizer otherwise would be needed.

2. Satellite wastewater treatment plants located at urban regional parks, such as that at Randolph Park in Tucson, can simultaneously relieve local overloading of the sewage collection system and provide a source of usable water to supplement park water requirements. The same effect is achieved by removal of power-plant blowdown from the system and application to use in mixed water supplies for a park area, as proposed for the Tucson Gas and Electric Company effluent.

3. Concentrated population growth produces simultaneously an electric power demand and a water resource for power generation cooling, in the form of treated sewage effluent.

4. Diversion of short-duration peak flood flows from small urban watersheds can reduce flood danger as well as construction cost of hydraulic structures downstream, while providing supplementary water supply for turf irrigation or recreation in parks adjoining the watercourse.

ACKNOWLEDGMENTS

The work upon which this paper is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964.

REFERENCES CITED

Arizona State Department of Health Services. The Status of Arizona's Environment (April 1973).

Bouwer, H.. Renovating Secondary Effluent by Groundwater Recharge with Infiltration Basins. In Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. W. E. Sopper and L. T. Kardos, eds. The Pennsylvania State University (1973).

City of Tucson, Department of Water and Sewers Annual Report, P. 1 (1973).

Cluff, C. B., DeCook, K. J., and Matlock, W. G.. Technical, Economic and Legal Aspects Involved in the Exchange of Sewage Effluent for Irrigation Water for Municipal Use. University of Arizona Water Resources Research Center, Tucson (December 1972).

Day, A. D., Tucker, T. C., and Cluff, C. B.. Extended Use of Treated Municipal Wastewater by the Buckeye Irrigation Company: A Documentation of Effects. Research Progress Report, University of Arizona, Water Resources Research Center, OWRT Project No. A-050-ARIZ, January 1975.

DeCook, K. J.. Economic Feasibility of Selective Adjustments in Use of Salvageable Water in the Tucson Region, Arizona. University of Arizona Ph.D. Dissertation (1970).

Dutt, G. R., and T. W. McCreary. The Quality of Arizona's Domestic, Agricultural, and Industrial Waters. University of Arizona Agric. Exp. Station Report 256, 1970.

Dye, E. O.. Department of Water and Sewers, Wastewater Division Annual Report 1971-1972. City of Tucson, 1972.

Fazzolare, R. A., and Scofield, F. C.. Nuclear Power Plant Heat Rejection in an Arid Climate. Nuclear Technology, 20:140 (December 1973).

Fisher, W.W. and Rabb, D. D.. Utilization of Clear-Water Sewage Effluent in Mineral Processing. OWRT (Project A-046-ARIZ). University of Arizona Water Resources Research Center Annual Report No. 11, 1975.

Popkin, B. P.. Evaluation of a Mixed-Grass Cover and Native-Soil Filter for Treatment of Tucson Urban Runoff. In Technical Completion Report, OWRT Project B-012-ARIZ. (In Progress)

Wilson, L. G.. Investigations on the Subsurface Disposal of Waste Effluents at Inland Sites. Office of Saline Water, Research and Development Progress Report No. 650, 1971.