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PROJECT COMPLETION REPORT

OWRR PROJECT No. A-011-ARIZ

Optimizing Salvageable Water Resources in a Semi-Arid Inland Basin

Agreement No. 1071

Project Dates: July 1967-June 1969

Principal Investigators

W. Clyma
W. G. Matlock
W. J. McConnell
H. K. Qashu
S. D. Resnick

The University of Arizona
Tucson, Arizona

August 1969

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ABSTRACT

The purpose of this investigation was to characterize salvageable water resources in the semi-arid Tucson basin and to evaluate appropriate treatment and control methods and management procedures for reuse of these salvageable waters.

A preliminary inventory of salvageable water resources in the Tucson basin indicated a conservatively estimated annual total of 30,000 acre-feet available, as follows: municipal system effluents, 25,000 acre-feet; industrial cooling effluents, 1,000 acre-feet; urban runoff, 2,000 acre-feet; and industrial processing waters and other minor sources, 2,000 acre-feet per year. The City water utility has ample information on hand regarding quality of municipal effluents; data collected during this study are sufficient to define representative quality of industrial effluents; and presently developed processes evidently are adequate for the control and treatment of salvageable waters. However, little was known of the quality of urban runoff in this semi-arid environment, and efforts were directed toward exploratory sampling and analysis as indicators of potential problem areas in runoff quality.

A ground-water recharge investigation at the Rillito Creek recharge site near Tucson produced a mathematical model which can be used to represent fluctuations of ground-water levels resulting from line-source recharge. Findings can be applied to alternative management schemes in the utilization or storage of salvaged waters.

Initial formulation of management alternatives by examination of local salvaged-water subsystems appeared not to require elegant mathematical solution but rather an improved system framework defining community objectives and criteria for salvaged water allocation.

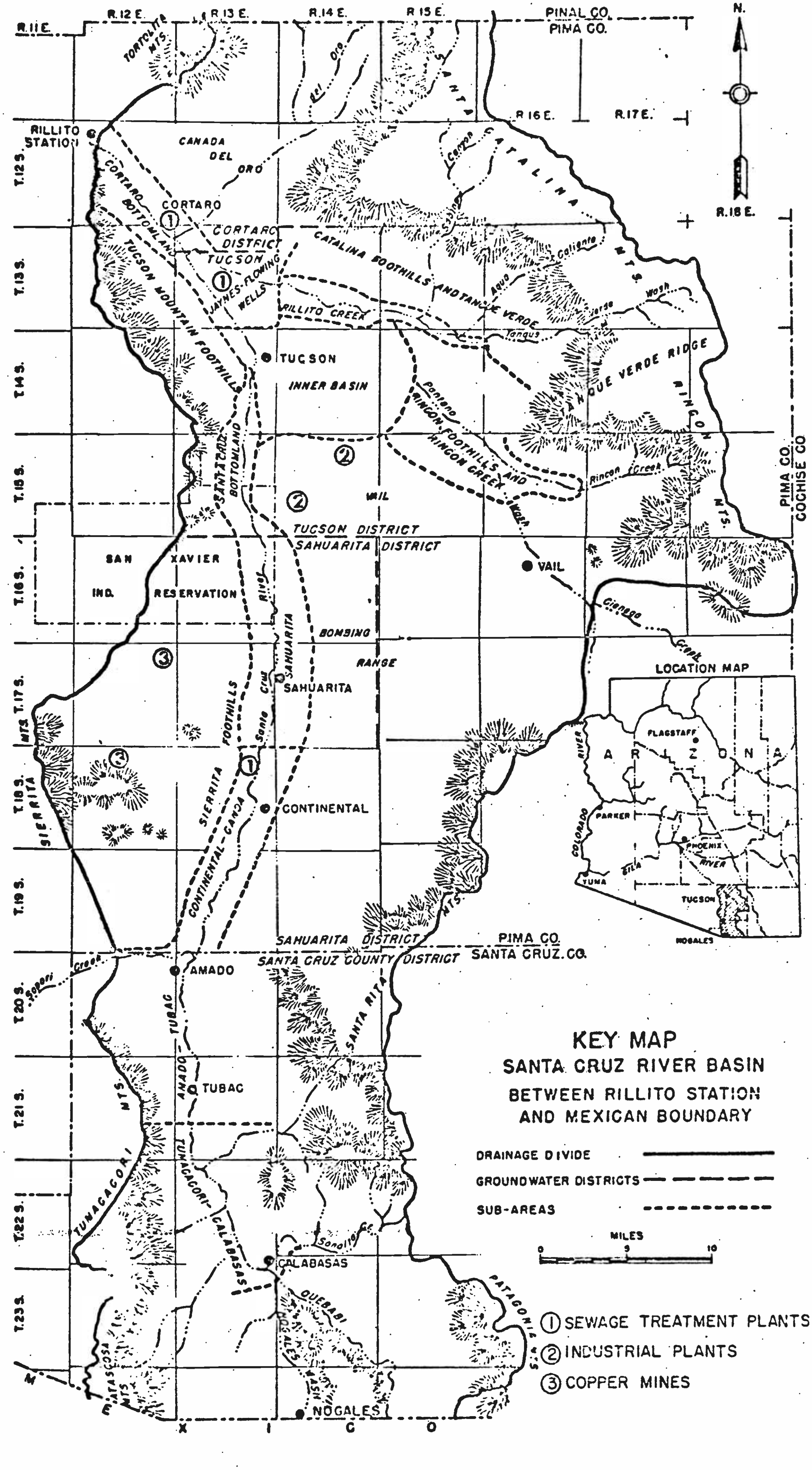
Key Words: *Water Reuse, Treatment, Natural Recharge, Water Management (Applied)

INTRODUCTION

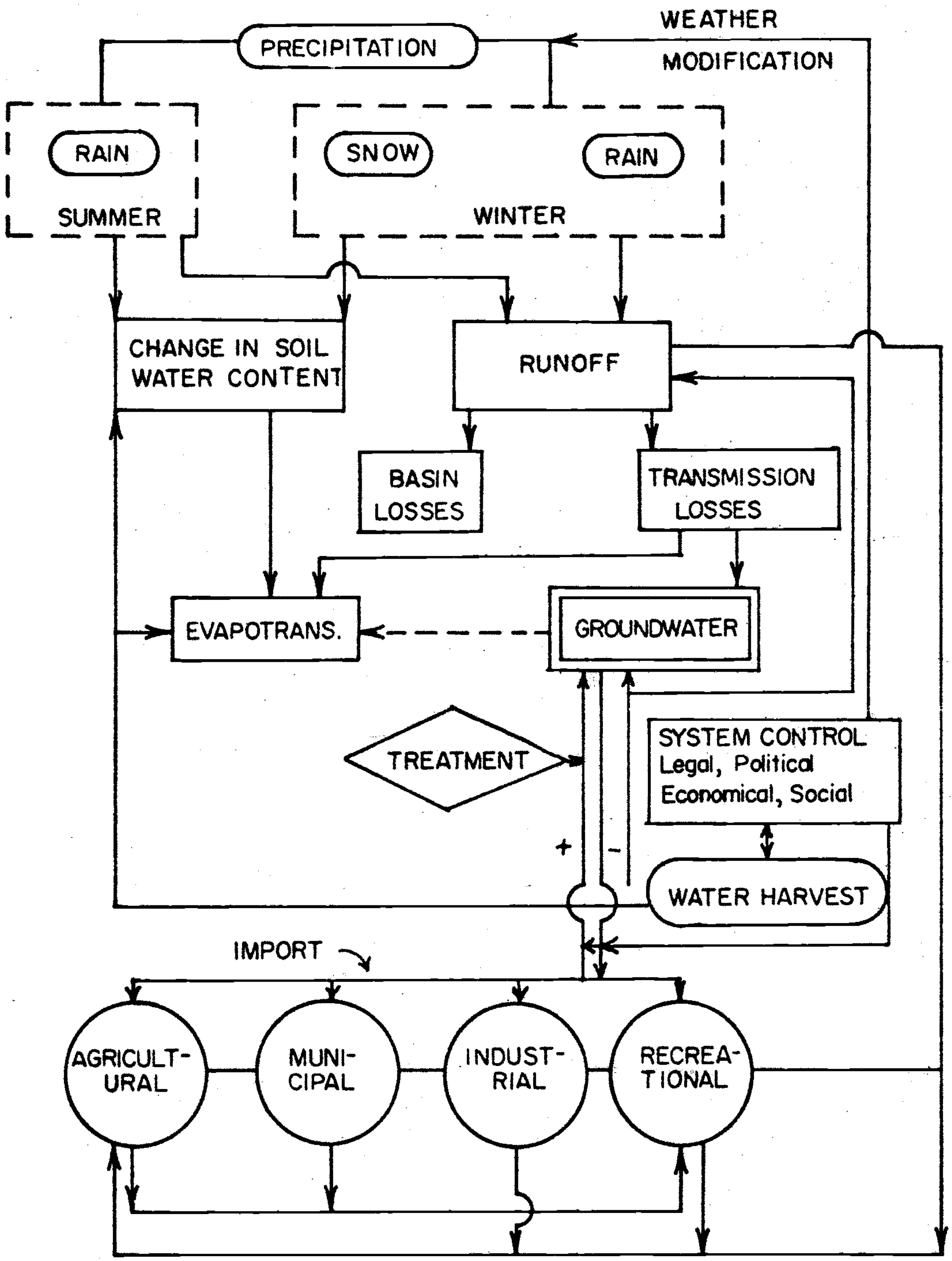
Water uses in the semi-arid Tucson basin are for domestic, industrial, agricultural, commercial, recreational and public purposes. Water for these uses is derived from ground-water aquifers and associated natural recharge processes along ephemeral stream channel beds. (See Key Map.) A graphical presentation of water sources and water uses in Tucson is given in Figure 1. There are at least three sources of water in the area which have great potential for expanded development--surface runoff, importation, and salvageable water which is the principal concern of this study. With each of the water uses and sources there is associated a quality factor directly related to the quantity and management. Also, there are several institutional constraints in the form of quality criteria, economics of models for alternative management schemes, and legal factors which must be met. In the City of Tucson and Pima County, there are several water companies and public water uses with independent management and operation policies which would make an optimal water management plan for the area difficult to achieve. However, it is apparent from Figure 1 that an optimal allocation model for water sources and uses, including use of salvageable water, is feasible within this existing framework.

Salvageable waters in the area vary in quality and needed treatment according to the intended use of such water. Quantities, quality and the economic model associated with water uses and water salvage are necessary for derivation of optimal operation and management plans for the area's water resources.

In the report that follows, the objectives of the study are listed and then discussed in the same order in which they appeared in the original proposal and in subsequent progress reports. It is recognized that Objective (1), dealing with recharge as a natural process, is closely related to artificial recharge, and would be considered as a management alternative under Objective (4).



KEY MAP
SANTA CRUZ RIVER BASIN
BETWEEN RILLITO STATION
AND MEXICAN BOUNDARY
DRAINAGE DIVIDE
GROUNDWATER DISTRICTS
SUB-AREAS
MILES
0
5
10
① SEWAGE TREATMENT PLANTS
② INDUSTRIAL PLANTS
③ COPPER MINES
LOCATION MAP
ARIZONA
FLAGSTAFF
PARKER
PHOENIX
YUMA
TUCSON
NOGALES
COLORADO RIVER
GILA RIVER
N.
R.11 E.
R.12 E.
R.13 E.
R.14 E.
R.15 E.
R.16 E.
R.17 E.
R.18 E.
T.12 S.
T.13 S.
T.14 S.
T.15 S.
T.16 S.
T.17 S.
T.18 S.
T.19 S.
T.20 S.
T.21 S.
T.22 S.
T.23 S.
PINAL CO.
PIMA CO.
PIMA CO.
COCHISE CO.
PIMA CO.
SANTA CRUZ CO.
RILLITO STATION
CANADA DEL ORO
CORTARO
CORTARO DISTRICT
CORTARO BOTTOMLAND
TUCSON
JAYNES-FLOWING WELLS
TUCSON MOUNTAIN FOOTHILLS
CATALINA FOOTHILLS AND TANQUE VERDE
RILLITO CREEK
TUCSON
INNER BASIN
RINCON FOOTHILLS AND RINCON CREEK
TANQUE VERDE RIDGE
RINCON MTS.
SANTA CATALINA MTS.
TORTOLITA MTS.
SANTA CRUZ BOTTOMLAND
VAIL
TUCSON DISTRICT
SAHUARITA DISTRICT
SAN XAVIER IND. RESERVATION
VAIL
BOMBING RANGE
SAHUARITA
SIERRITA FOOTHILLS
SIERRITA MTS.
CONTINENTAL
CONTINENTAL-CANOA
SAHUARITA DISTRICT
SANTA CRUZ COUNTY DISTRICT
AMADO
TUBAC
AMADO-TUBAC
TUBAC
SANTA RITA MTS.
TUMACACORI MTS.
TUMACACORI-CALABASAS
CALABASAS
QUEBABI
NOGALES
PATAGONIA MTS.
ATASCOSA MTS.
NOGALES
MEXICO
Cienega Creek
Rincon Creek
Pantano
Sopori Creek
Sonoita Cr.
Santa Cruz River



Generalized Flow Chart of Water Resources in the Tucson Basin

FIGURE 1

OBJECTIVES

1. To study the hydraulics of natural recharge from sandy ephemeral stream channels and evaluate analytical theories for defining the growth and dissipation of a ground-water mound.
2. To characterize salvageable water resources, namely flood runoff and industrial and municipal waste water, according to their sources, quantity, and quality (physical, chemical and bacteriological).
3. To evaluate treatment procedures required to make the potentially salvageable water suitable for municipal (including recreation) and industrial use.
4. To determine and evaluate, within the framework of existing investigations, the management alternatives for optimizing the conservation, use and reuse of salvageable water supplies.

DESCRIPTIVE REPORT

The procedures used, principal findings and general discussion of results are presented in this section.

Hydraulics of Natural Recharge

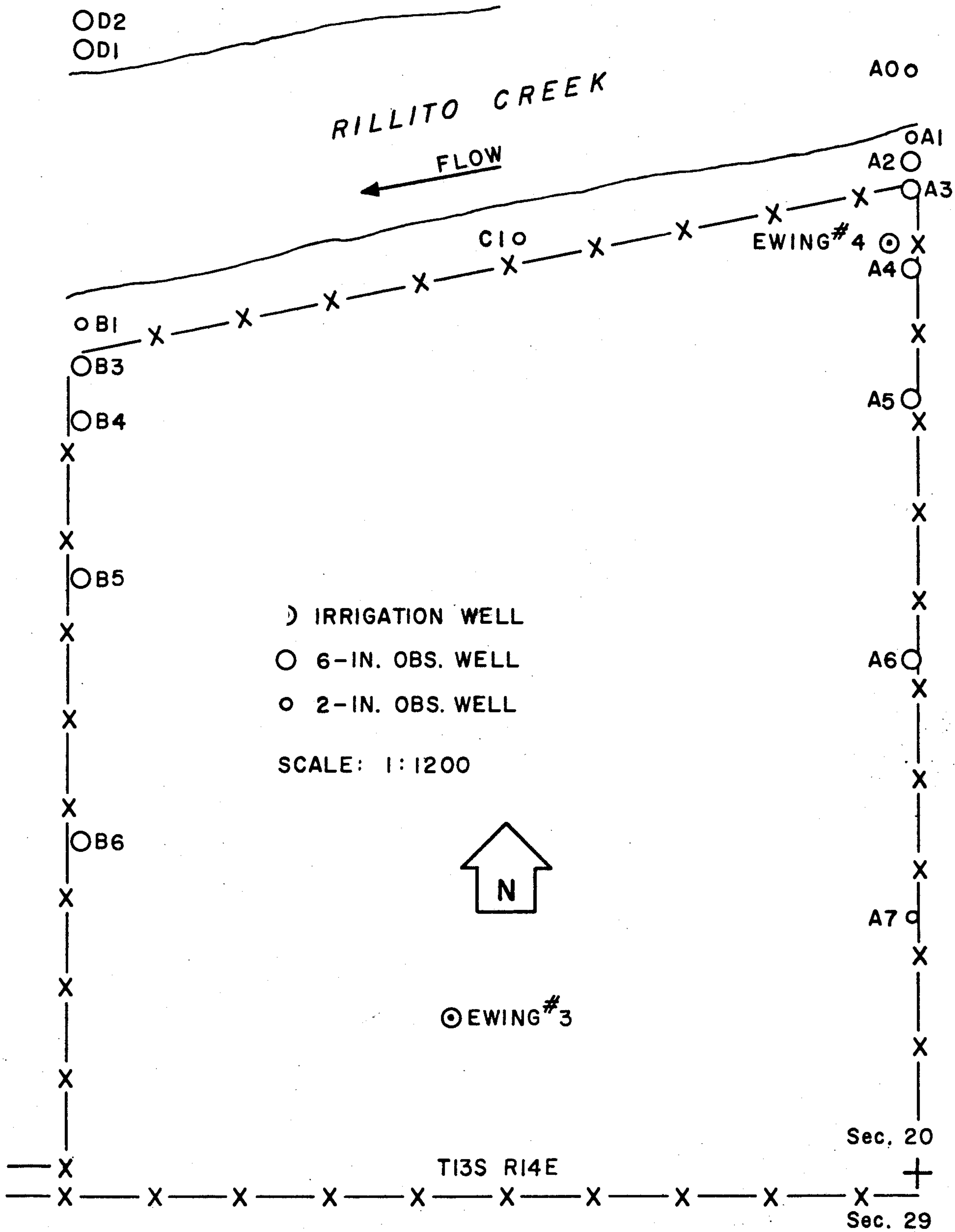
The hydraulics of natural recharge from an ephemeral channel (line source) was studied. Several analytical theories were evaluated; that of Glover (1961) was selected as best meeting the field conditions for defining the growth of the ground-water mound. No analysis was made of the dissipation of the mound because of the interference caused by ground-water pumpage in the study area.

Research Procedures

A network of 16 observation wells was installed along Rillito Creek north of Tucson (Figure 2). Water level measurements were made in these wells on an irregular schedule before, during, and after flood flows in normally dry Rillito Creek. U.S. Geological Survey streamflow data were analyzed to determine the relationship between flow at the gaging stations and flow at the recharge site.

FIGURE 2

OBSERVATION WELL NETWORK U of A CAMPBELL AVE. FARM



Existing ground-water flow formulas were used to develop a theoretical model of the recharge mound. The equation of Glover provided the "best fit" when calibrated with field data. Other recharge events were adequately described using the mathematical model with either streamflow or water level data as input (Foster, 1969).

Soil moisture studies were initiated to describe the movement of water in the unsaturated phase from the streambed to the water table. A neutron moisture meter was used in several of the observation wells for this purpose.

Conclusions

The fluctuation of ground-water levels caused by recharge from a line source can be represented by a mathematical model. The model can be used in any area of uniform geologic characteristics where the hydrologic parameters describing the aquifer are known, and an observation well is available to measure water level changes. Other aquifer parameters can be determined if recharge rate is known. For example, a knowledge of infiltration rate, flow duration, and water level changes can be used to calculate the aquifer transmissibility-storage constant. The model provides a guide for management of a recharge site in maintaining optimum recharge, and thereby supplies background information for Objective (4).

Characterizing Salvageable Water Resources

The kinds of water dealt with in this project include but are not limited to "waste" waters. The more general term "salvageable" waters is used, to signify not only industrial effluents and domestic sewage discharges but also increments of surface water runoff which are not presently salvaged or used in any way.

These waters are characterized as to quantity and quality in the pages following. The quantitative assessment led to a form of "inventory" of salvageable waters which is not exhaustive but serves to indicate the magnitude of each currently or potentially available source; the quality-of-water characterization includes intensive sampling and chemical analysis in a few instances but more generally consists of exploratory sampling in hitherto unknown areas with the principal intent of identifying quality problems which might warrant more intensive future study. It is felt that the objectives of characterization with regard to both quantity and quality have been accomplished as originally intended; knowledge has been gained in matters of procedure, and guidelines have been established for the direction of future research in certain areas. One of the more significant results of this work is the initiation of studies of water quality in relation to runoff patterns on urban watersheds. This subject will be discussed more fully below.

A characterization of salvageable waters according to source is presented in Table 1. The table is largely self-explanatory, but a few comments are in order. The salvageable storm runoff from watersheds (category A) excludes runoff from the high mountainous areas and the principal drainageways through which it flows and is in part recharged to the ground-water reservoirs (e.g., Rillito and Pantano Wash, Figure 3); this type of runoff is considered to be an undeveloped primary source. The watersheds of interest herein are those in the urban-suburban and surrounding desert areas, in which flow occurs only immediately following storm periods. It is in these areas that attempts are being made to improve knowledge of the hydrologic variables for design and management and of the water quality characteristics in relation to possible hazards and potential salvage and use.

TABLE 1

Characterization of Salvageable Waters

A. Storm Runoff

1. Urban and Suburban Watersheds

2. Desert and Foothill Watersheds

B. Municipal, Domestic-Industrial Effluents

1. City

2. County

C. Domestic Effluents

1. Separate Sources

a. Green Valley

b. Avra Valley

c. Small Peripheral Plants

2. Separable Sources: Examples

a. Randolph Park

b. Kennedy Park

c. Hughes Aircraft Company

d. Tucson International Airport

D. Industrial Effluents: Separable Sources

1. Cooling Water

2. Process Water

3. Other Sources Identified by Water Usage

NOTE: With regard to quantity, a preliminary inventory of salvageable water resources in the Tucson basin indicated a conservatively estimated annual total of 30,000 acre-feet available, as follows: municipal system effluents, 25,000 acre-feet; industrial cooling effluents, 1,000 acre-feet; urban runoff, 2,000 acre-feet; and industrial processing waters and other minor sources, 2,000 acre-feet per year.

Storm Runoff

Two urban watersheds were chosen for characterizing urban runoff and hydrology of urban watersheds in Tucson, and for undertaking a preliminary study to determine needed data and sampling methodologies. Atterbury Experimental Watershed, a rural watershed in the same area, was used as a control. These are shown on Figure 3. Atterbury Watershed has been in operation for more than 12 years and available data on spatial and temporal distribution of rainfall will be used in testing the behavior of the urban watersheds. However, the Atterbury data are not used in this report.

Recognizing that decisions relating to salvageable water management will depend on the quantity, quality and economics of routing and treatment of such water, a preliminary sampling program was initiated in this area, to derive a better data acquisition program. The objectives of the study were to find the right data, in a usable form for a transient system. As will be noted later in this report it was apparent that future uses of collected data have not been fully identified and a data acquisition model useful in development of a mathematical prediction model would be needed for future studies.

Storm runoff from the two urban areas was measured for quality and quantity characteristics. Both areas are in residential communities; High School Watershed and Arcadia Watershed are 0.92 and 3.14 square miles in area respectively. Their combined surfaces are 5.6 percent of the City of Tucson area.

The watersheds are equipped with recording raingages; the stream channel flows exiting from each watershed are gaged with a water level recorder. Manning's equation and the channel slope and cross-section measurements were used in relating stream discharge to head.

Figure 4 shows, in a general way, the influences to which precipitation is subject in its sojourn from falling rain to its concentration in channel flows.

The boxes outlined in dashed lines indicate elements of the routine which have received interest in this study. The effort here is not an exhaustive investigation of all elements of the routine, but rather an attempt to focus on problem areas related to salvage of storm runoff water.

A data acquisition model should provide information required by management for optimal use of runoff data. The hydrology and water quality models are coupled for best results.

Rainfall in the Tucson area is characterized by frontal storms during the December-February period; short duration, high-intensity summer thunderstorms; and occasional late summer storms originating as tropical hurricanes off the west coast of Mexico (Fogel, M. M., 1968).

Storm runoff resulting from two precipitation events on High School Watershed (see Figure 5) is expressed in Table 2. About 8% of the storm water appeared as runoff in both of these events even though average rainfall and intensities of the two storms differed widely. Further sampling should indicate how closely runoff quantities follow average rainfall of the area and how dependent or independent they are of intensity.

Water quality tests were accomplished on storm runoff waters. These tests included:

a) inorganic ions
b) bacteriological analysis
c) trace metals
d) chemical oxygen demand
e) phenol equivalent
f) pesticide
g) suspended sediments

Figure 6 shows the distribution of common ions for all analyses made on High School and Arcadia Washes, while Table 3 shows specific numerical values representing water frcm the two summer storms illustrated in Table 2 and a February storm on High School Watershed.

FIGURE 5

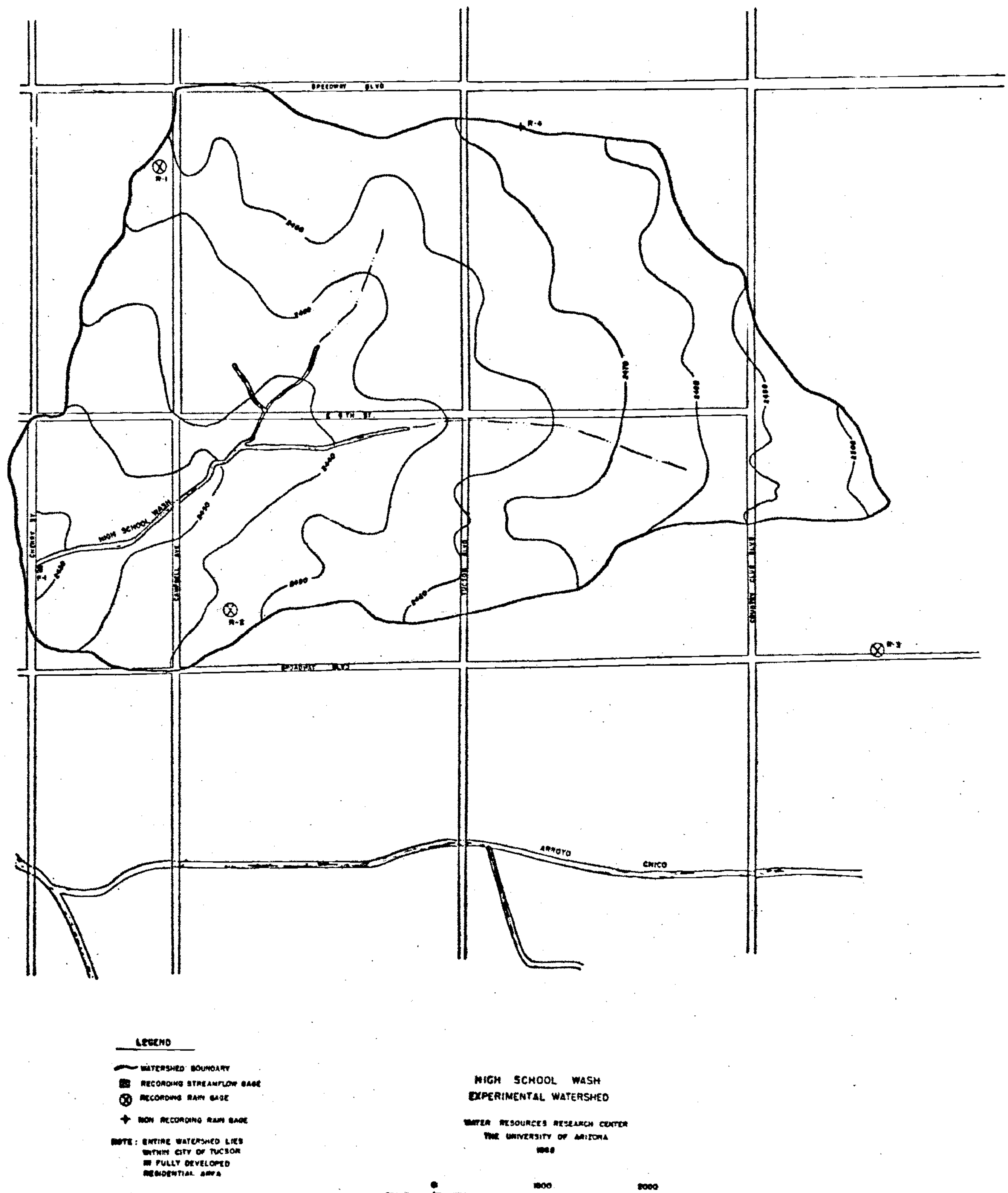

SPEEDWAY BLVD
R-1
R-2
R-3
R-4
E 6TH ST
HIGH SCHOOL WASH
CAMPBELL AVE
TUCSON BLVD
ARROYO
CHICO
LEGEND
WATERSHED BOUNDARY
RECORDING STREAMFLOW GAGE
RECORDING RAIN GAGE
NON RECORDING RAIN GAGE
NOTE: ENTIRE WATERSHED LIES
WITHIN CITY OF TUCSON
IN FULLY DEVELOPED
RESIDENTIAL AREA
HIGH SCHOOL WASH
EXPERIMENTAL WATERSHED
WATER RESOURCES RESEARCH CENTER
THE UNIVERSITY OF ARIZONA
SCALE:
1000
2000
FEET

TABLE 2

Rainfall and Runoff for Two Summer Storms on High School Watershed

	$\bar{R}$ (in)	Ro (in)	L (ft)	I (in/hr)	q (cfs)	Q (in)	B (%)	V (a-f)
July 21, 1968	0.15	0.16	2,000	0.8	25	0.010	7	0.54
August 6, 1968	0.28	0.54	4,000	2.4	25	0.024	9	1.18

$\bar{R}$ = mean storm precipitation over watershed area

Ro = maximum storm precipitation over area represented by one gage

L = distance of raingage with maximum rainfall from gaging station

I = maximum intensity for five minutes

q = hydrograph peak at gaging station

Q = runoff generated

B = watershed efficiency calculated by $B = \frac{Q}{\bar{R}} \cdot 100$

V = volume of runoff water, acre-feet

FIGURE 6

Common Ions - Urban Runoff From

High School & Arcadia Watersheds

Data Collected 1968-69

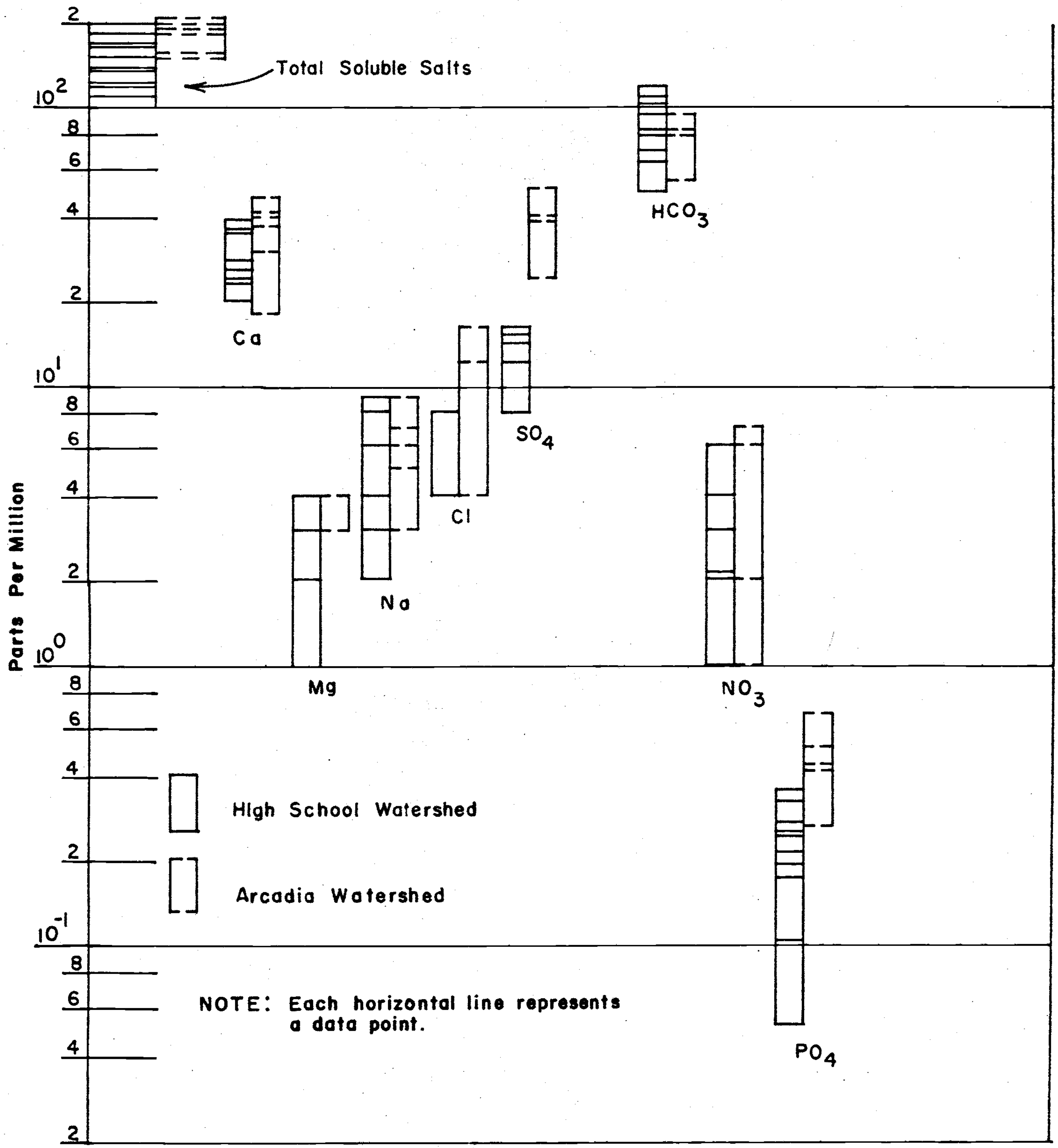


TABLE 3

Solutes Concentration in Runoff Water in February, July, and August, 1968
(Units are ppm and all times are PM except as noted)

	2/12	7/19	7/20	7/21/68			8/6/68								
	10:30	7:40	11:55AM	11:15AM	12:30	12:40	5:10	5:20	5:30	5:40	6:03	6:20	7:10	7:30	7:50
Air Temp. °F	--	--	--	--	--	--	--	--	--	76.5	--	--	75.5	--	--
Water Temp. °F	--	--	--	--	--	--	84.0	80.5	80.5	80.5	81.0	80.0	79.5	79.5	78.0
% Sodium	42.0	--	--	--	--	--	8.9	14.7	11.0	9.2	10.0	8.5	14.9	14.0	14.1
Soluble Salts	147	206	195	182	187	153	200	155	147	141	124	115	114	111	114
$ECx10^3$	0.11	0.30	0.26	0.22	0.25	0.21	0.25	0.21	0.20	0.19	0.17	0.16	0.16	0.16	0.17
Calcium	18	46	41	37	40	30	43	31	32	30	26	24	24	22	24
Magnesium	4	4	3	3	4	3	3	3	2	2	3	2	2	2	1
Sodium	3	5	9	9	6	7	5	7	5	4	4	3	5	5	5
Chloride	4	16	12	12	12	10	10	12	10	10	8	8	8	10	12
Sulfate	24	50	40	40	40	38	28	26	24	25	21	20	20	20	19
Carbonate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bicarbonate	93	83	83	78	83	54	110	73	72	67	60	55	50	48	48
Nitrate	1	1	7	2	2	6	1	3	2	3	2	3	4	4	4
Nitrogen (N) lb/ac-ft	0.62	0.6	4.3	1.2	1.2	3.7	---	---	---	---	---	---	---	---	---
Phosphate	---	0.47	0.66	0.43	0.32	0.50	0.21	0.25	0.27	0.25	0.25	0.24	0.21	0.20	0.22

If we take the centers of the distribution of Ca and Mg ion concentrations and express them in terms of total hardness as $CaCO_3$, the result is about 80 ppm total hardness. This is not generally regarded as very hard water. Alkalinity, here mostly bicarbonate at about 70 mg/l, is well within the 30 to 500 mg/l range considered for satisfactory public use (FWPCA Committee on Water Quality Criteria).

The nitrate and phosphate ions are present in sufficient concentration for substantial growths of algal blooms should the water encounter a ponding situation, although the nitrate concentrations are well below the levels considered harmful in drinking water.

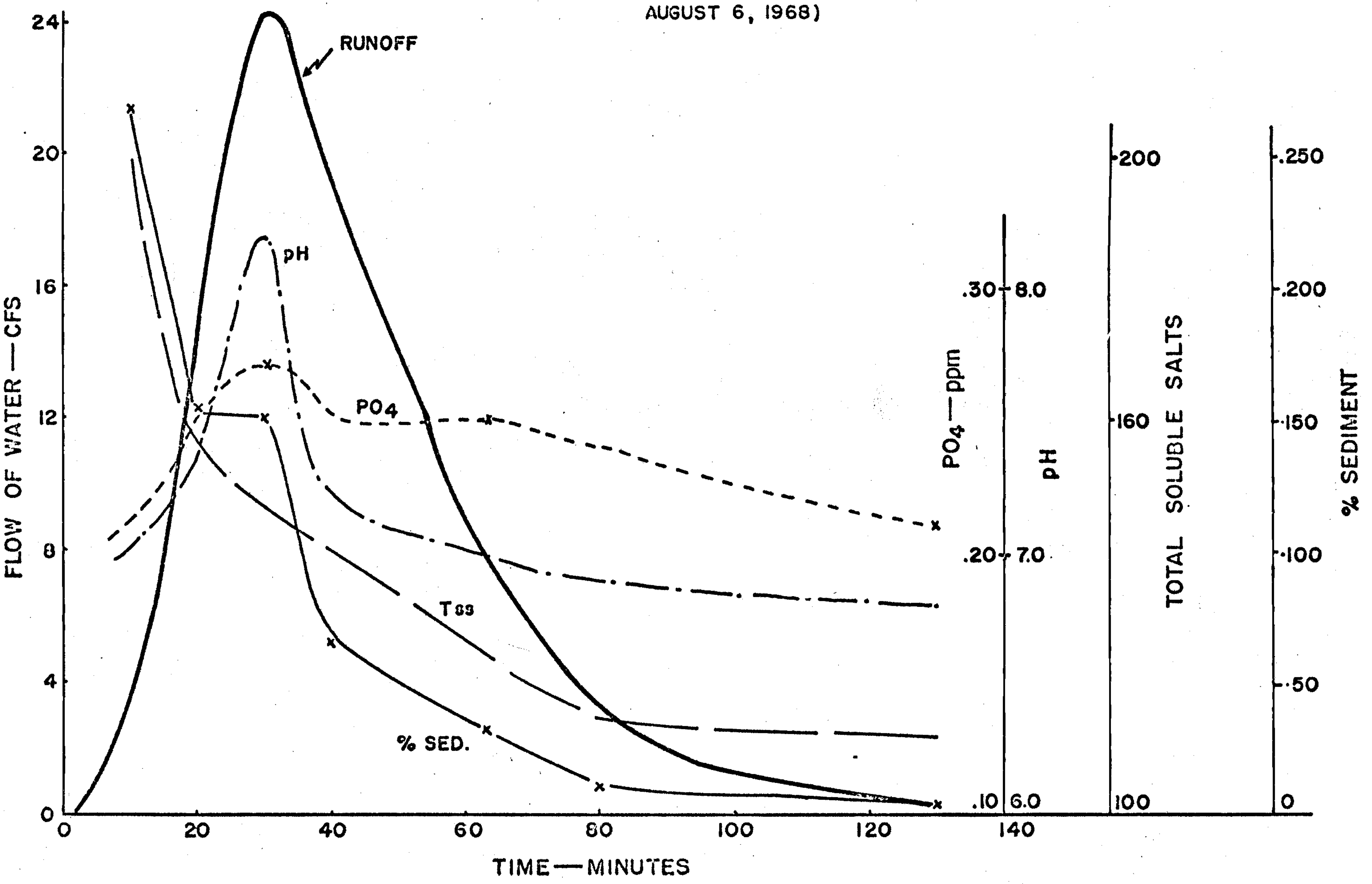
In general, the total dissolved solids content of urban storm runoff from these relatively small areas compares favorably with waters such as ground water in wells of the City of Tucson and storm runoff in the ephemeral main drainage channels of the basin, i.e., those handling discharges of 1000 second feet or more.

Of 115 domestic wells in the City of Tucson, average TDS (total dissolved solids) for samples was 360 ppm with a range of 150 to 1000 mg/l (Smith et al, 1963). An analysis on the Santa Cruz River water showed a TDS of 400 mg/l. Other large streams about the state show higher total dissolved solids. (11th Quarterly Report of WRRC to Office of Saline Water, Conservation and Inland Disposal of a Blended Industrial Waste Effluent Using Artificial Recharge Techniques)

Figure 7 shows the variation of TDS and suspended sediments with water stage for the runoff event of August 6, 1968. Note the relative persistence of PO_4 level throughout the runoff event as TDS and suspended sediments decline on the receding side of the hydrograph. Although only a single storm is illustrated here, some further observations can be made regarding the results in Figure 7.

FIGURE 7

CHANGES IN WATER QUALITY WITH TIME AND RATE OF FLOW, HIGH SCHOOL WATERSHED, TUCSON (DATA COLLECTED FOR UNIVERSITY OF ARIZONA ALLOTMENT PROJECT No. A-011, AUGUST 6, 1968)



The phosphate ion, and nitrate ion as well, are not naturally occurring ions in large quantities in the soils of these watersheds. These ions are used in the fertilization of lawns and gardens, however, and this is their principal source. These ions may persist throughout the runoff event owing to rainfall leaching these ions through shallow soil horizons and moving laterally to become part of the surface runoff.

On the other hand, the common ions are being leached in the sheet erosion process as well as from the suspended sediments which are carried in greater or lesser amounts in concentrated runoff water depending on the velocity of flow. Thus, there is greater opportunity for these ions being brought into solution.

Bacteriological analyses using multiple tube fermentation technique show presence of coliforms including fecal coliform and fecal streptococcal organisms in runoff. The coliforms come mainly from the soil and arise probably from surface washing and shallow leaching of the soil and from contact with the suspended sediments carried by the water. The latter groups of organisms, fecal coli and fecal streps, originate in the alimentary canals of warm-blooded animals. Their presence suggests the possibility of presence of water-born pathogens such as Salmonella, Shigella, Vibrio, Mycobacterium, Pasteurella, and Leptospira.

Table 4 shows the distribution of total coliform and fecal coliform organisms per 100 ml for a series of samples during one runoff event.

In contrast to these values, the bacterial content of some water samples from Sabino Creek, a stream flowing through an outdoor recreational area, ran from 16 to 17×10^2 organisms per 100 ml (Total Coliforms).

Although fecal strep organisms were found, the data were insufficient for stating a fecal coliform to fecal strep ratio; the ratio would be useful in distinguishing pet animal-wild life from human fecal contamination (Geldreich et al, 1964).

The use of these waters in meeting various human needs must be governed according to tolerable bacteriological standards. Use of water in categories beyond the standards must be preceded by appropriate water treatment methods.

TABLE 4

Bacteriological Quality of Urban Storm Runoff Water

High School Watershed

Runoff Event of August 6, 1968

(Organisms/100 ml)

Sample No.	Time	Total Coliform	Fecal Coliform
1	5:20 PM	17×10^5	-
2	5:30 PM	49×10^5	-
3	5:40 PM	542×10^5	33×10^5
4	5:50 PM	11×10^5	-
5	6:13 PM	33×10^5	8×10^5
6	6:30 PM	49×10^5	2×10^5
7	7:20 PM	21×10^5	8×10^5
8	7:40 PM	542×10^5	5×10^5
9	8:00 PM	49×10^5	5×10^5

Complete recommendations for bacteriological treatment must be based on more comprehensive sampling work.

The presence of heavy metals was investigated with the atomic absorption spectrophotometer technique. A single sample from each of High School and Arcadia Watersheds exhibited the following results.

Trace Metal Ions in ppm for Storm of August 6, 1968

Location	Fe	Mn	Cr	Ni	Cu	Zn	Pb	Cd	Co
High School	0.003	0	0	0	0.011	0.008	0	0	0
Arcadia	0	0	0	0	0.033	0.008	0	0	0

This sampling does not permit any statements of the variability of these substances. The levels shown are, however, below permissible surface water criteria for public water supplies. A more significant aspect may be the accumulative effect of trace metals in recharge areas over a long period of time, following partial evaporation of the incipient water. This should be studied in the future with relation to the immediate vicinity of recharge areas.

Decaying vegetable matter and other soluble organic substances were detected using phenol tests and chemical oxygen demand digestion.

Phenolic Activity for Three Different Samples

Watershed	Date	Gallo-tannic Equivalent, ppm
High School	8-6-68	1.3
	10-3-68	7.5
Arcadia	7-28-68	0.6

These numerical values signify only that both watersheds contain a source of phenolic molecular groups. The most probable natural source is the ubiquitous creosote bush; however, the higher concentrations on High School Watershed, where natural vegetation is virtually absent due to urbanization, suggest roof tars or paving materials as a predominant source. Closer identification of source materials could be made by field-testing of runoff at selected locations, if high-quality water uses are comtemplated.

Chemical oxygen demand of two samples, one from High School Wash and another from Tucson Arroyo, were 210 and 133 mg/l respectively. Chemical oxygen demand of activated sludge and raw sewage are 75 and 700 mg/l respectively.

Analysis for organic residues and pesticides showed concentrations of less than 2 ppb of organic derivative from fuel (STP).

In consideration of the above results of exploratory sampling, it is recommended that future studies should include detailed sampling and analysis from more diversified watersheds, with emphasis on those parameters which indicate possible quality problems, such as heavy metals in industrial areas, bacteriological concentrations in residential suburbs, and organic and inorganic pollutants in general.

Municipal Domestic and Industrial Effluents

The City and County sewage systems in combination collect and treat a large part of the domestic and industrial sewage flows from the Tucson metropolitan area. Although the physical collection system is intertied and actually comprises one large system, a jurisdictional boundary exists between those areas served by the City and those served by the County. The service areas fluctuate from time to time; in general, the combined sewage and industrial wastes from the central, southern, and western parts of the City accrue to the City treatment plant in the northwest area which presently handles about 26,900 acre-feet per year or 24.0 mgd as metered at the plant, while flows from the northern and eastern suburban areas accrue to the County main treatment plant which handles approximately 0.4 mgd. To be discussed later are the other County treatment plants characterized as "separate" sources of sewage effluent, and examples of locations on the main collection system characterized as "separable" sources, or places where the effluent could be segregated from the main system, treated in situ, and reused nearby.

The City treatment plant utilizes a bar screen-grit chamber pre-treatment, a primary treatment through settling tanks, and a mixed secondary treatment system containing one trickling filter unit and two activated sludge units. A representation of some of the quality characteristics of the plant effluent is given by the following (City of Tucson, 1968):

Mineral Analyses:	Unit	1967-68
Final Effluent Composite		
Total Solids by Evaporation	mg/l	659
Fixed Solids	mg/l	493
Volatile Solids	mg/l	166
Calcium	mg/l	70
Magnesium	mg/l	15
Sodium and Potassium	mg/l	96
Chloride	mg/l	88
Sulfate	mg/l	153
Carbonate	mg/l	0.0
Sodium to Calcium	Ratio	1.4
Hardness	Gr/Gal	14
Phosphate (PO_4)	mg/l	43
Nitrate (N)	mg/l	0.3
Ammonia (N)	mg/l	22.1
Nitrate (N)	mg/l	0.24
Organic Nitrogen (N)	mg/l	9.00
Total Nitrogen (N)	mg/l	31.6

Other aspects of quality with particular reference to treatment methods will be discussed below, as will the tertiary methods of treatment which are currently under research and development at the City plant.

Regarding quantity of effluent at this plant, the total of almost 27,000 acre-feet per year is received in fairly consistent quantities throughout the year. Although water production by the City utility shows a summer-winter ratio between 2:1 and 3:1, the consumptive use is much higher in the summer season, with the net result that the effluents show only minor seasonal variations.

Domestic Effluents: Separate and Separable Sources

Adjacent to the City treatment plant is the Pima County Sanitation Department "main" treatment plant (northernmost location on Key Map). Flows are not presently metered to any of the County plants; the service areas are principally residential and light commercial, and influent flows have been estimated on the basis of the number of residences served and average water-usage estimates. The County main plant on this basis treats slightly more than 0.4 mgd. In addition, twelve sites for peripheral treatment plants have been optioned or purchased by the County, and several are currently in operation, utilizing oxidation ponds. The Green Valley community plant (southernmost site on Key Map) processes about 0.15 mgd. A plant in Avra Valley 15 miles west of Tucson operates at about 0.1 mgd. Along with these, several additional oxidation ponds and small "package" plants in the region process aggregate flows of nearly 1.0 mgd.

The significance of these "separate sources" of treated effluent is their relative proximity to points of reuse, as discussed later. There are in addition several locations at which discrete sources of sewage which are now loaded into the main system could feasibly be shunted to local reuse through small-scale treatment plants and thereby reduce possible overloads on the main system;

an example is the air terminal at Tucson International Airport which discharges 20,000 gpd. At other points the collection system may be intercepted and tapped, not only to relieve system loading but also to serve local points of use for scenic, recreational boating, fishing, and park irrigation purposes.

Industrial Effluents: Separable Sources

For the Tucson region, industrial effluents have been characterized as originating from three general sources - cooling effluents, industrial metal processing effluents, and sand-and-gravel aggregate processing effluents. Industrial effluents representing these three sources were investigated and their quality and quantity characteristics are indicated in this report.

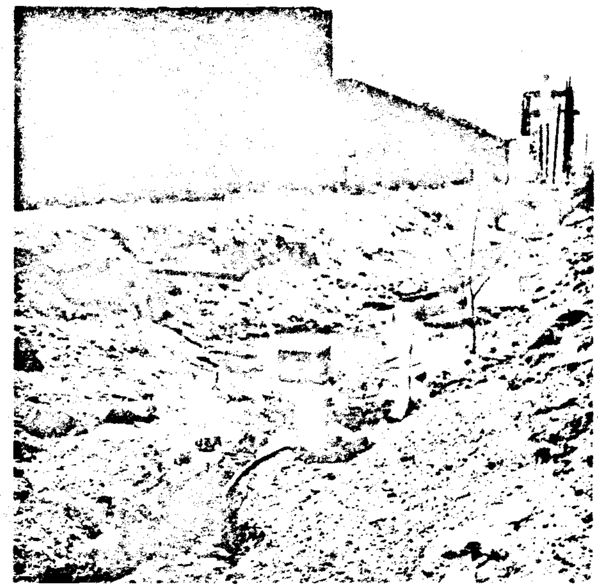
Cooling Effluents

The salt build-up in cooling water required in the process of generating electrical energy is reduced by dumping a portion of the concentrated cooling water and adding water of lower total dissolved solids. The rate of dumping depends on the evaporation rate of the cooling water. In summer when both air temperatures and electrical loads are high, the rate of dumping or "blowing down" of the cooling water tends to be high.

The accompanying photographs show a waste ditch which receives spent cooling water from the DeMoss-Petrie power plant in northwest Tucson. The flume and stream gage were used to measure the blowdown rate. For this particular plant the average discharge was 330 gpm in 1966 or approximately 530 ac-ft/yr. The monthly average blowdown rates ranged from 500 gpm in July to a low of 116 gpm during the month of November.

The quality of blowdown water changes from input to effluent states both from the evaporation of water and the addition of chemicals, principally hexametaphosphates and sulfuric acid. Table 5 illustrates the degree of change.

Cooling Tower Blowdown from Steam Electric Generating Plant Northwest of Tucson.



Blended Effluent from Cooling Towers and Power Transformer Station.

TABLE 5

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

Chemical Constituent	Concentration (ppm): Input Water (Composite of Five Production Wells)	Concentration (ppm): Effluent from Cooling Towers (1 and 2)
Calcium	50	328
Magnesium	8	49
Sodium	--	254
Chloride	18	88
Sulfate	140	1,350
Bicarbonate	148	34
Fluoride	--	4.0
Boron	--	0.35
Phosphate	0	7.8
pH	8.0	7.1
Dissolved Solids	363	2,115

Metal Processing Effluents

An electronics manufacturing plant was selected for study because its effluent is of contrasting characteristics to the other two discussed in this report. Electroplating plant waste water which is treated and cooling tower blowdown water are diverted to a holding pond where the water is dissipated via evapotranspiration and seepage.

The accompanying photographs show the ditch and holding pond. The density of vegetation along the two-thirds mile of unlined ditch and around the pond indicate that some types of plants are able to sustain dense growth under presence of heavy metals in the water used in transpiration and tissue building processes. It is more probable that the plants exclude the heavy metals at the cell membrane than that they possess life systems whose enzyme reactions are not hampered by the heavy metal cations.

Dominant plant genera along the ditch are:

a. Nympha sp. - cattail

b. Salix sp. - willow

c. Populus sp. - cottonwood

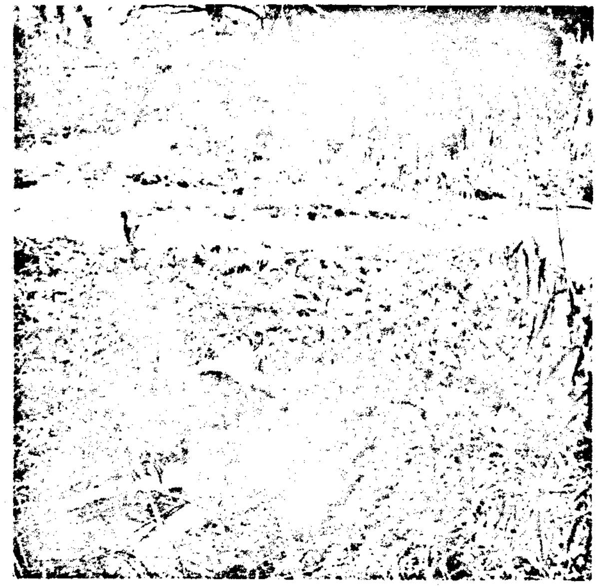
d. Cynodon dactylon - bermuda grass

Figures 8 and 9 show ranges of concentration of common ions and trace metals. The plating plant effluent is presently being treated by a flocculation process. Because the wasted plating liquors are dumped in batches, the treatment is adjusted with difficulty to wide variations in ion concentrations. Blending of plating plant effluent and cooling tower blowdown water occurs downstream from the plating plant.

Aggregate Processing Effluents

The accompanying photographs show a gravel washer at an aggregate plant. Water is pumped from a nearby well and is fed at a rate of 300 gpm through the

Blended Plating Process and Cooling Tower Effluents Entering Waste Ditch.



Same Effluents at Evaporation Pond.

FIGURE 8

Common Ions - Mixture of Treated Metal Processing and Cooling Effluents

Data Collected 1967-69

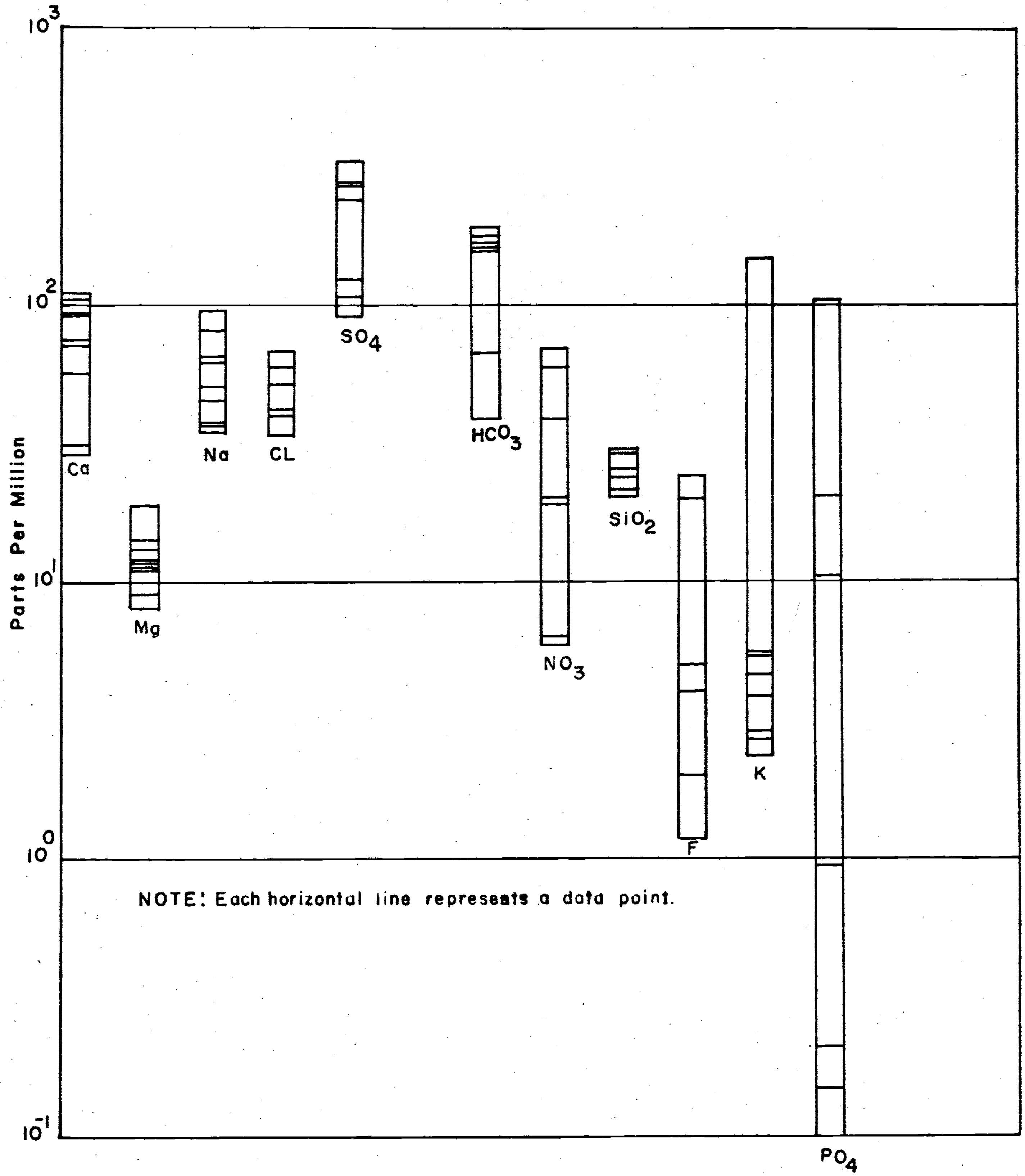
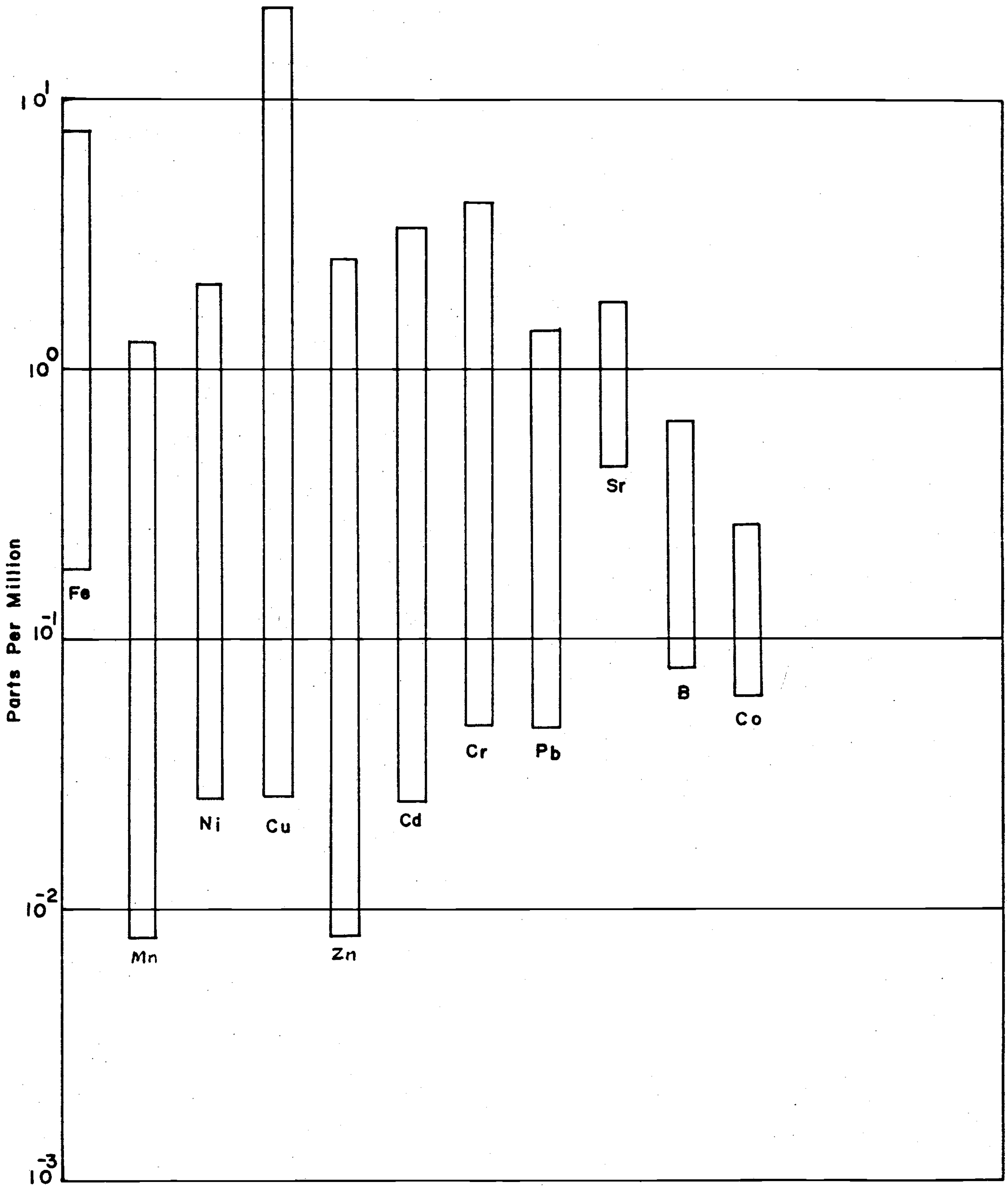


FIGURE 9

Trace Elements- Range of Concentration in Mixture of Treated Metal Processing and Cooling Effluents
Data Collected 1967-69



washer. Water demand at this plant is used for gravel production of about 2000 tons/8-hr day. The water is routed via a channel to a 2.4-acre holding pond located in the dry stream bed where seepage losses return the effluent to the sands and gravels.

No appreciable changes in common ions were found between the source water and gravel washer effluent. This statement should be taken with reservation because only one set of samples was analyzed in order to gain an indication of quality change.

Suspended sediment analyses were not made. Gravel washer effluent carries a considerable load of suspended material on leaving the plant, but these settle out as the water flows to the holding pond.

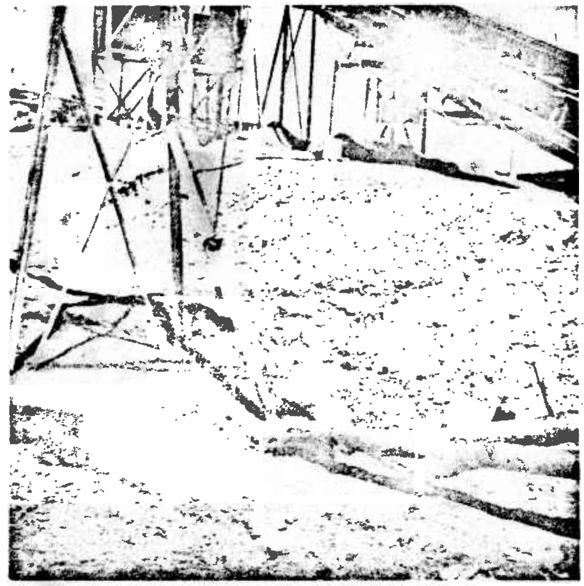
Another gravel and aggregate processing plant in the Tucson basin whose capacity is also 2000 tons/day uses 300 gpm in a six-hour day operation. Another 4500 gallons/day are used in cement block making and in housekeeping (vehicle and equipment washing).

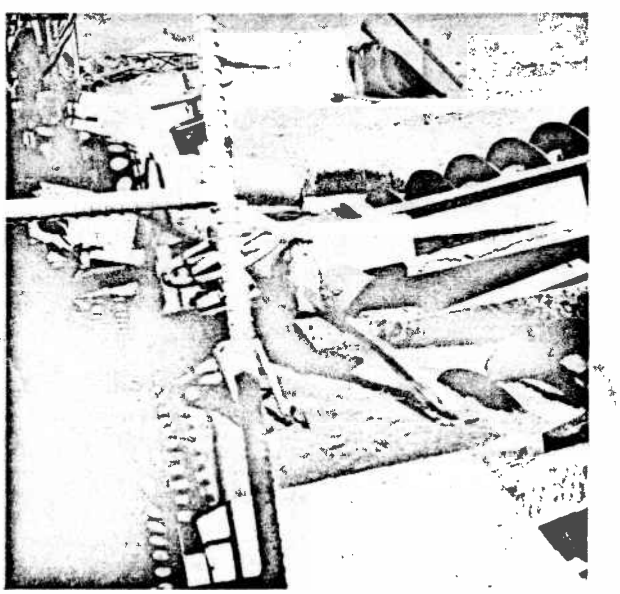
There are three such plants in the Tucson basin each of whose capacity exceeds 2000 tons of washed aggregate per day. The water coming from these amounts to about 400 ac-ft/yr. This quantity includes some water used in housekeeping and cement mixing.

Potential Sources

Other sources of potentially salvageable water were identified by the indirect means of identifying groups of the largest water users. Local inquiries and field checking and information provided by the U. S. Geological Survey in a water utilization study indicated that most large users in suburban and outlying areas can be categorized as mining operations, golf courses and country clubs, and adjoining private farms and guest ranch operations. Most of these

Waste Flow from Gravel Washer.





Recycling Water in the Gravel Washing Machine.

are self-supplied or served by local rural water companies, and their consumptive uses are generally quite high. Proportionately water salvage would be small and would necessarily be oriented to local sites of reuse, being widely scattered.

A more direct method of identification was attempted by systematic search of the printout of monthly billing records of the City Water and Sewers Department. The Department furnished these records, documenting about 65,000 water accounts, for each month for the complete calendar year 1968. The accounts were sorted according to monthly water use and then placed in decreasing order starting with the largest aggregate annual user. By this simple procedure each individual water consumer whose input was equal to or more than 10 acre-feet per year was identified by owner's name, type of use, and geographic location as coded into the account number. It was found that 183 accounts used 10 acre-feet or more and that their aggregate use was 4,864 acre-feet in 1968. Of these, 60 used 20 acre-feet or more, aggregating 3,050 acre-feet. Three general use categories then were imposed upon the 183 users, with results as follows:

Type of Use	Number of Users	Acre-Feet/Year
Schools and Hospitals	35	840
Recreation	21	1,273
Industrial or Commercial	127	2,751
	183	4,864

Much of the recreational use represents landscape irrigation, which is locally a highly consumptive use. Considering all uses, it is likely that water return from the nearly 5,000 acre-feet is less than one-half, possibly 2000 acre-feet. Thus these users do not represent a large source of salvageable water in proportion to total basin use, although a number of them could be segregated in terms of an appreciable source.

The points outlined above and data relating thereto are currently being applied in basin model development for a Ph.D. study (DeCook). The billing records are being utilized also in a study proposed for an M.S. thesis (Ray).

Evaluation of Treatment Procedures

The City of Tucson main treatment plant utilizes both primary settling and a combination of activated sludge and trickling filter methods for secondary treatment. The comparative costs according to a recent analysis (City of Tucson, 1966) were $38.62 for activated sludge and $27.11 for trickling filter per million gallons treated; however, the activated sludge method was 1.7 times more effective in the removal of suspended solids and 2.7 times more effective in the removal of BOD. The preference in method then depends not only on least cost but on objectives of treatment.

The County Department of Sanitation has in operation several small-scale treatment plants, some of local manufacture. The City is currently studying the feasibility of installing similar plants at upgrade locations on the collection system as mentioned earlier. The method in general combines primary and secondary clarification with an activated sludge process. The type of intended reuse of the treated water then governs the need for tertiary treatment; for park irrigation perhaps none is required, while for recreational uses such as fishing or swimming, tertiary methods may include lime coagulation, filtration, and chlorination (Personal communication, Infilco, Inc., Tucson, Arizona). Costs for such small-scale plants and their operation as expected pose a problem in direct comparison with those of large scale, but the small scale plants are proven feasible under appropriate conditions.

The City also has under study the necessary methods and costs for tertiary treatment to meet criteria for recreational and other use. This is in the research and development stage in this area, using pilot spreading basins and natural sand filtration.

From experimental work conducted under OWRR Project B-004 using soil and grass filtration for secondary sewage effluent, results were evaluated in part as follows: Soil filtration can under proper conditions--i.e., when a combination of aerobic and anaerobic environments are maintained--yield a water that will meet the trace element and nitrate requirements of drinking water; and bermuda grass filtration will remove some quantities of trace metals, but will leave relatively high nitrate and COD content generally limiting reuse of the water to agricultural irrigation (Lehman, 1968).

With regard to industrial cooling effluents, temperature is of primary interest. Measurements of discharge temperatures at Tucson Gas and Electric Company's Irvington Road Plant show that the average temperature of the effluent during a typical January day is 72°F, about 20°F higher than the mean January air temperature, and that of a typical July day is 93°F, about 8°F above the ambient temperature for that day. The diurnal fluctuation in effluent temperature during the July day was 87°F minimum to 97°F maximum. If increased heat load is an undesirable quality for an intended reuse, it may be regarded as thermal pollution; from this standpoint, some preliminary calculations have been made and an ample theoretical basis exists for determining desired areas, depths, and shapes of cooling ponds for dissipating heat. However, for some uses added heat is advantageous and the thermal load may be preserved, or even enhanced, by proper configuration of ponds or by heat barriers such as monomolecular film, perlite, or floating styrofoam rafts to trap heat within the water body.

The other quality characteristic of concern in cooling effluents is concentration of dissolved solids. The total dissolved solids content of effluent from both of the Tucson Gas and Electric Company plants in Tucson is about 2,000 ppm, although that from the DeMoss-Petrie plant is blended with cooling effluent from a nearby transformer station and the average resultant concentration is between 900 and 1,200 ppm. These waters are satisfactory for some recreational and some agricultural uses without improvement, but would require treatment for high-quality uses in lieu of a satisfactory means of disposal. Wilson et al (1968) in experiments funded by the Office of Saline Water have used the DeMoss-Petrie plant effluent for recharge to a shallow aquifer through a recharge pit. It was found that some degree of dilution of the effluent occurred in the phreatic region, and that significant dilution occurred in the vadose region following recharge from periods of flow in the adjoining ephemeral stream. By proper management techniques, such conditioning of a fair to poor quality cooling effluent by dilution with good quality ground water could be followed by pumping back the mixed waters which would be satisfactory for most uses.

Filtration of cooling and plating process effluent waters through fibrous asbestos-sand mixtures on a laboratory scale shows reduction of concentration of toxic trace metals, particularly iron and copper, as well as phosphate content. Further laboratory tests and field-scale tests are needed, for substantiating results.

Management Alternatives

Current planning and research by local water authorities in the use of salvaged water resources appear to be oriented toward point of use and kind of use. Traditionally the type of use receiving the largest allocation has been irrigation of agricultural crops; more recently the emphasis is on potential recreational uses. Concurrently the acquisition and development of sites for recreational facilities, especially in the urban and suburban areas, has been stimulated by the Land and Water Conservation Fund Act of 1965, as implemented through the Bureau of Outdoor Recreation.

As another example of this trend, the City Water and Sewers Department and the University of Arizona have cooperated in a recent study supported by the Federal Water Pollution Control Administration on methods for tertiary treatment of municipal effluent and potential recreational uses, among others. Reconnaissance surveys also have been undertaken to investigate feasibility of locating subsidiary treatment plants near points of concentrated recreational use. Additional county parksites have been acquired recently for recreational development, again oriented to use and without preference to source of water; in several instances watershed runoff is being considered as the principal source of detained water.

In the current study and to some degree by local agencies, a somewhat different approach to planning has been examined, albeit in a quite preliminary way--i.e., a multiple resource-oriented approach. Therein several sources of salvaged water can be joined in a local system in varying proportions, controlled, treated, and allocated to those uses which are appropriate at the site. An example is the 84-acre Environmental Modification Facility of the University of Arizona currently under development at Tucson International Airport, where the sources of salvageable water are both industrial cooling and metals processing effluents and runoff from a desert watershed, and the proposed uses include several kinds of research and recreational uses. Another example is a project under construction by the City Parks and Recreation Department at Kennedy Park, where filling of a recreational reservoir is to be sustained in part by runoff from a desert-foothill watershed. In recognition of the variability of inflow, the source may be supplemented by pumpage from a municipal well in which water quality is too high in salinity for drinking. A third and future source may be effluent from a local sewage treatment unit.

An economic model for the evaluation of such subsystems which allocate from multiple sources to various uses, and in the larger context of the Tucson region, is being developed and will be demonstrated as part of a Ph.D. dissertation currently in progress (DeCook).

At the present state of knowledge of systems of salvageable water in this area, the following can be stated: (1) Sources of treated sewage effluent and industrial cooling water are available, their quantities are deterministic in some respects, and the technical feasibility of their application to various uses has been demonstrated or can be documented; (2) the economic feasibility of such uses in combined systems requires more study; (3) both the technical and economic aspects of treating plating process water for local uses need further study; and (4) although urban watershed efficiencies as expected are higher than those in rural areas, improved water yield models and a well developed water quality sampling model are needed.

With regard to the last point, prior to this project available water quality data for both urban and small desert watersheds in the region were fragmentary at best; preliminary field measurements and data analysis achieved during this project were very useful in providing diagnostic indicators; and future data acquisition on water quality parameters should be based on predicted future use of data and applications in the decision-making process.

Models for management planning can presently be formulated on a theoretical basis or from empirical evidence, given a specific management objective. But future needs point to a system model for operational planning, assembling all the diverse factors--control facilities, geography, quality parameters, economic use limitations--for feasible if not optimal operation under varying community goals.

FINDINGS AND CONCLUSIONS

1. A mathematical model was formulated and calibrated with the field data collected at the Rillito Creek ground water recharge site. (See K. E. Foster M.S. Thesis in references.) The model can be used with a known rate of recharge to predict aquifer characteristics, and can aid in management of artificial-recharge installations.

2. A preliminary inventory was made of salvageable water resources in the Tucson region including municipal and industrial effluents. There is a minimum salvageable water resource in the Tucson area of 1,000 acre-feet per year from industrial cooling, with quality problems consisting principally of variable heat load and total dissolved solids content of about 2000 ppm, much of which is precipitable sulfate. The minimal recoverable sewage effluent from municipal sources is 25,000 acre-feet per year. An additional 2,000 acre-feet of urban runoff, and 2,000 acre-feet per year from industrial process waters and minor sources, are available for salvage.

3. Two urban-suburban watersheds were instrumented with recording rain-gages for measuring precipitation and flood-hydrograph recorders for measuring runoff, in order to undertake preliminary determinations of local and regional urban runoff characteristics, types of data needed, and sampling methods. Samples of runoff were collected from the two urban watersheds and from two desert watersheds, and analyses were made for the common ions, trace metals, pH, dissolved oxygen, COD, certain organic compounds, and coliforms. Concentrations of dissolved solids, nitrates, and trace metals were relatively low, approximating drinking water standards, but bacterial pollution and suspended sediments would require treatment for most uses. The quality of urban-suburban runoff

changes with time during flow; the highest suspended sediment and total dissolved solids concentrations occur on the rising limb of the hydrograph, decreasing to constant concentrations on the receding side. The surface-temperature influence on runoff temperature shows a similar trend during the flow period.

4. As expected, on the basis of several runoff hydrographs the urban-suburban watershed runoff efficiencies appear to be substantially greater than those of the desert watersheds. Changes in runoff quality with meteorological factors such as storm frequency and intensity and air temperatures, and hydrological factors such as composition and configuration of runoff surfaces, remain to be determined.

5. Analyses were made of representative samples of three kinds of industrial effluents--cooling waters, metal processing waters, and aggregate processing waters. Results indicate that metal processing effluents would require treatment for virtually all uses, while some cooling and aggregate washing effluents could be used for ground-water recharge or certain recreational purposes with little or no treatment.

6. Filtration of plating process effluent through fibrous asbestos-sand mixtures evidently can reduce content of toxic trace metals, particularly iron and copper, as well as phosphate concentration. Further laboratory tests should be conducted, plus field-scale tests. Filtration through soil columns is effective in removing trace metals in municipal treatment plant effluents; grass filtration improves these waters but leaves relatively high content of total nitrogen. (See G. S. Lehman dissertation in references.)

7. A source-use combination model for salvageable waters was examined in the form of a proposed research-recreation facility near Tucson International Airport. Three salvageable water sources--cooling effluent, plating process effluent, and desert runoff--were allocated to four or more uses at the facility.

Trial solutions indicate that, for the evaluation of optimal allocation of salvaged waters, as exemplified by the "Airport" subsystem model, enumeration and simple search, or a modified search method in the form of discrete dynamic programming, are useful approaches. This phase of the study, including more complex optimizing models for the greater Tucson region, needs and is receiving continuing attention through related project work (OWRR Project No. A-020) through graduate study (DeCook).

8. As indicated above, further studies are required to quantify more completely the physical and chemical characteristics of salvageable waters and the processes for salvaging these waters, and to develop guidelines for operational policy. However, the findings of this study appear to substantiate the great potential for expanded development of salvageable waters in the region.

RECOMMENDATIONS FOR FUTURE RESEARCH

The piecemeal past development of water supply and drainage systems in Tucson as in other cities, because of rapid and continued urban expansion, necessitates distinctions between the existing status of the system and future development in the area.

It is recommended that future data acquisition on urban hydrology and water quality conform with a policy which will allow simulation of the processes indicated in Figures 1 and 4. It is further recommended that a mathematical simulation model be developed for hydrology of all the selected watersheds and be tested to allow for full identification of inventory data required for comparison of behavior of urban and rural watersheds.

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