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MODELLING ARTIFICIAL RECHARGE IN THE TUCSON BASIN

A proposal submitted to the
Pima County Department of Sanitation

by

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INTRODUCTION

Artificial recharge techniques may play a role in an overall water management program for Pima County by providing an effective countermeasure to the excessive extraction of groundwater. Available water sources for a recharge program include flood water, sewage and industrial effluents, and urban runoff. Additional supplies may become available for artificial recharge with the implementation of the Central Arizona Project.

With respect to the Central Arizona Project, several desirable features of artificial recharge should be mentioned. For example, artificial recharge permits storage of imported water in underground reservoirs, away from the effects of evaporation. Since the storage area in underground reservoirs of the Tucson basin is so vast, the amount of surface storage could be reduced if a "conjunctive" operation of surface and subsurface reservoirs were implemented under C.A.P. A recharge operation also allows the porous underground formations to cleanse recharge effluent of entrained microorganisms. Furthermore, mixing of recharged water and groundwater could lead to an overall improvement in quality.

Results of natural recharge studies (e.g., Wilson and DeCook 1968; Davidson, 1973) illustrate that the river systems of the Tucson Basin are highly effective natural recharge units. It would appear logical, therefore, to use the normally dry channels in an artificial recharge program. Not only would recharge in stream channels take advantage of naturally favorable intake rates, but also the recharge facilities would be located on land unsuited for many other purposes, particularly in light of the restrictions imposed by the recent flood plain ordinances in Tucson and Pima County. Two other advantages of river channel recharge should be mentioned. First of all, water levels have been dropping at a drastic rate in wells along the stream in recent years because of excessive pumping drafts coupled with below-average natural recharge. Large scale recharge operations could offset or retard the recession rate of water levels. Secondly, the poorest water from the viewpoint of chemical quality is located along the Santa Cruz River (Davidson, 1973). Artificial recharge using better quality water would, therefore, promote underground mixing with indigenous groundwater and generate an overall improvement in quality.

Although artificial recharge using the stream channels of the Tucson Basin has not been pursued on a planned, intentional basis, such recharge has in effect occurred incidental to the disposal of sewage effluent. Since 1955 the City of Tucson has released a portion of the secondary treated sewage effleunt of the City Treatment Plant to the Santa Cruz River. Thus the river has functioned essentially as an extensive artificial recharge facility. Furthermore, the response of groundwater levels and quality to sewage effluent recharge mirrors the response to be expected during recharge of a supply such as Central Arizona Project water, should the river channel be utilized for artificial recharge. The project proposed herein would, therefore, consider sewage effluent recharge in the Santa Cruz River as a case study of artificial recharge. An ongoing field study involving collection of data on water quality and water levels would be continued, and combined into a comprehensive water balance study of the area.

In order to extrapolate results from the case study region of the Santa Cruz River to other regions, and to provide a predictive tool, it will be necessary to simulate field results via a suitable model. In fact, field data would be used to "calibrate" such a model. A number of computer models are available for the simulation of groundwater flow during recharge for conditions such as those of the Tucson Basin. Of particular promise is a finite element model developed by G. F. Pinder and others at Princeton University. A comprehensive model would account not only for the flow regime during recharge but also for the mass transport effects. A particular mass transport model is not available at this time. However, it appears that such a model could be constructed using the finite element approach. The real difficulty is in obtaining realistic values for diffusivity coefficients in the mass transport model.

Data on changes in groundwater levels and quality, obtained from an ongoing recharge pit study at the Water Resources Research Center Field Laboratory, will be examined to provide a first estimate of values for the diffusivity coefficients. During the proposed study the pit operation would be continued to obtain additional data to refine coefficient values. Also, field data garnered from the river recharge study will be used to provide other estimates of these coefficients.

The proposed study would thus involve two parallel efforts: collecting and analyzing data on groundwater levels and quality during field investigations of artificial recharge, and concurrently, developing a comprehensive groundwater flow and mass transport model for recharge in the Tucson Basin.

OBJECTIVES

1. To collect and utilize results from past and ongoing groundwater monitoring programs for development of a computer model for predicting the effects of artificial recharge in the Santa Cruz River on regional groundwater flow-patterns and chemical quality in the Tucson basin.

2. To evaluate the resultant model as a management tool for predicting the consequences of recharging imported or other water supplies on native groundwater levels and quality in Pima County.

PROCEDURES

1. Field Studies

Field studies associated with the project will be conducted at two locations: in that portion of the Tucson Basin in the vicinity of the Santa Cruz river downstream of the Tucson Treatment Plant (see Figure 1); and on the WRRC Field Laboratory a short distance upstream of the Treatment Plant.

To evaluate recharge in the Santa Cruz River it will be necessary to conduct a comprehensive water balance study of the region downstream of the City Treatment Plant. Existing data to be used in such a study would include a history of water levels and quality in available wells, hydrogeological information, estimates of river intake rates during sewage flows and during storm discharges, evapotranspiration losses, subsurface flow estimates, etc. To supplement and augment these data, an ongoing project in the area will be continued as a component of the porposed project.

In particular, the existing project involves a cooperative study by the Pima County Department of Sanitation and the Water Resources

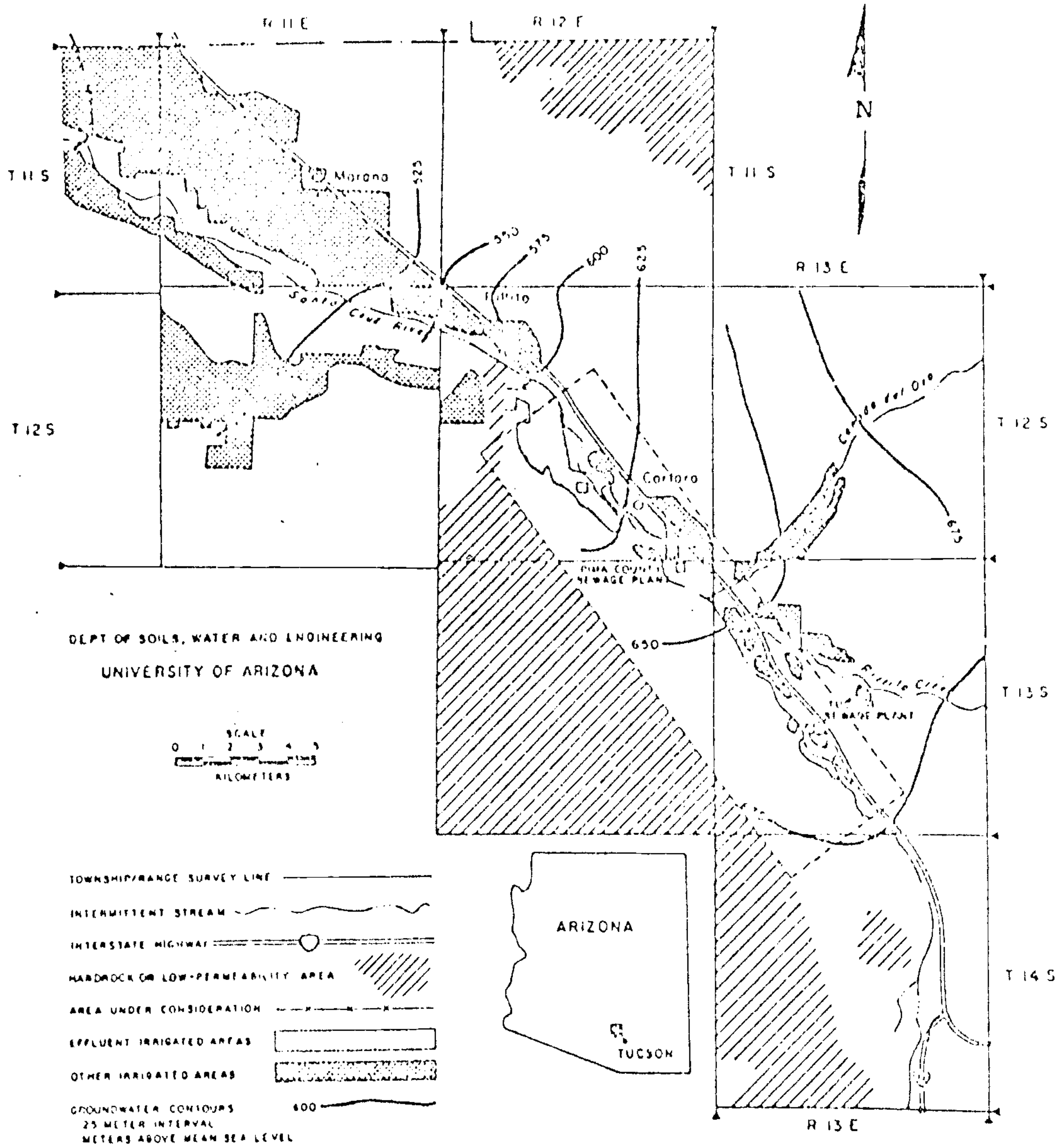

Figure 1. Location Map of Cortaro-Marana, Groundwater Contours 1972, and Irrigated Acreage.

(From Matlock, Davis and Roth, 1972)

Research Center to determine quality changes in effluent from the City Treatment Plant during downstream flow in the Santa Cruz River and during subsurface movement in the vicinity of two landfills. As part of the proposed study, the following monitoring program will be continued: routine measurement and sampling of shallow, small-diameter wells located within the landfills, in the vicinity of the landfills, and upstream of the treatment plant. In addition, several pumping wells, operating within the project area, will be sampled. Among the chemical constituents evaluated during analysis of these samples will be nitrite-nitrate nitrogen, organic-nitrogen, ammonia-nitrogen and total-nitrogen.

It should be pointed out that, in essence, the above field study will constitute a water quality monitoring program. Data from the project could then be used as input to a comprehensive program, recently initiated by the State, to obtain groundwater quality data in conformance with E.P.A. regulations.

The second field project, to be conducted at the WRRC Field Laboratory, comprises an ongoing pit recharge study. This pit has been in intermittant operation since April 1973, recharging blowdown effluent from the nearby Tucson Gas and Electric Co., De-Moss Petrie Plant. Research facilities used in the study, shown on Figure 2, include a number of small diameter sampling wells, observation wells and three pumping wells. Water levels are measured routinely in the well system and water samples are obtained for chemical analysis from pumping wells. Intake rates are measured in the pit.

In the context of the proposed project the pit recharge study would comprise a controlled experiment, providing data for calibration of simulation models. Consequently, the pit will continue to be operated.

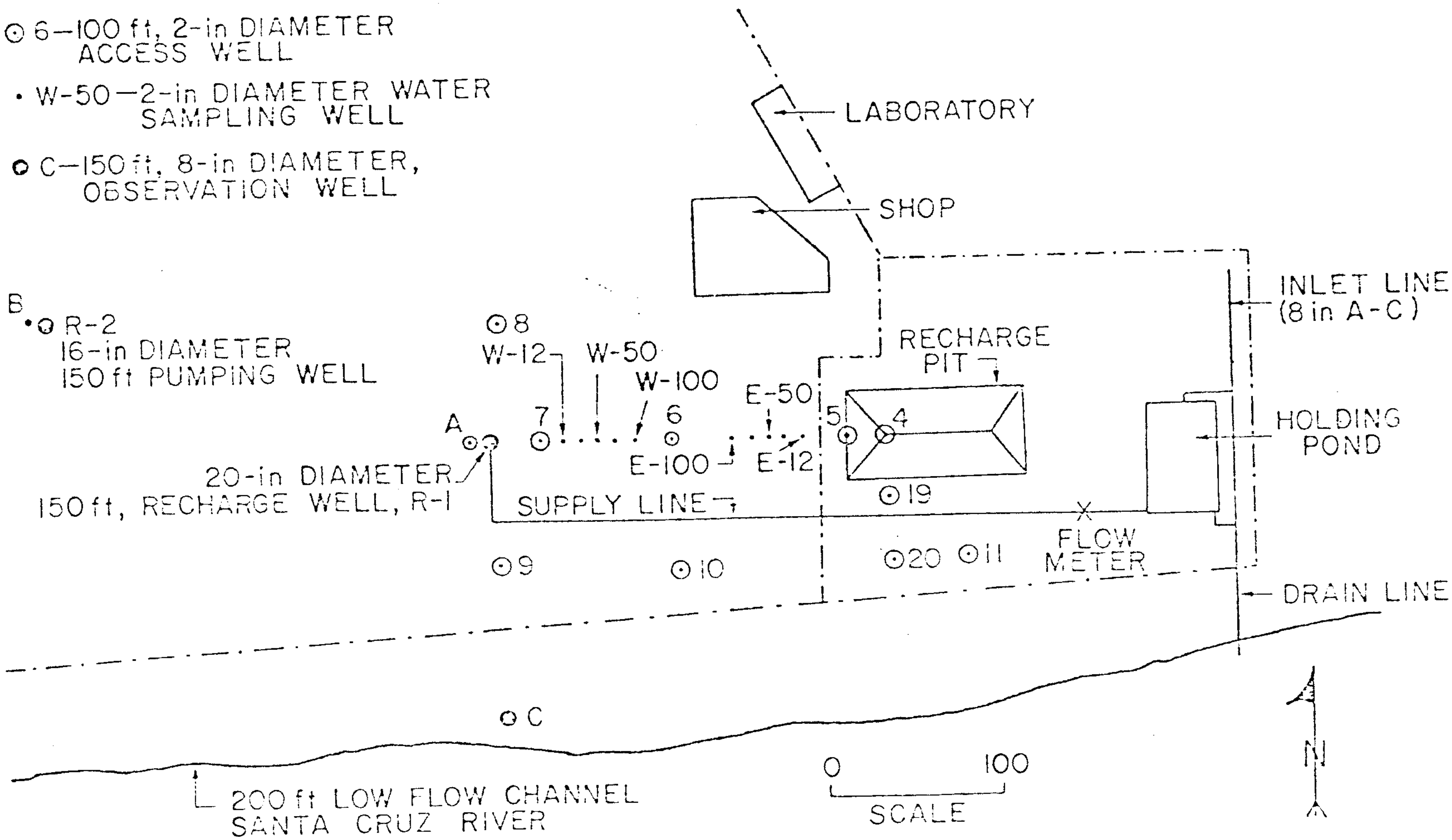

FIGURE 2. THE UNIVERSITY OF ARIZONA WATER RESOURCES RESEARCH CENTER ARTIFICIAL RECHARGE FACILITIES

A water balance will be conducted for the site. Local values of water table elevations will be compared to regional levels. Similarly, water quality data will be examined to evaluate trends in the spread of a "plume" of recharged effluent.

2. Modelling Flow and Mass Transport

In this phase of the study, care will be exercised to adhere to the recommended stages of simulation modelling laid down by Wigan (1972) and Huntoon (1974). For digital modelling, these stages include postulating the problem; selecting the governing mathematical expression, boundary conditions, initial conditions, etc.; selecting an appropriate numerical technique and computer program to model the mathematics; testing; calibration; and validation.

As indicated above, the purpose of the simulation program will be to model artificial recharge in the Santa Cruz River, using recharge in the reach downstream of the City Treatment Plant as a case study. Several numerical schemes are available to solve the governing partial differential equations of flow, together with the corresponding computer coding. For example, Prickett and Lonnquist (1971) developed the "Illinois State Water Survey Basic Aquifer Simulation Program" which also accommodates such conditions as variable pumping rates, leaky artesian conditions, induced recharge, etc. This model uses the alternating direction implicit scheme to solve a system of algebraic equations, generated from the flow equations. Recently, flow models have been constructed using the finite element method. Finite element schemes involve discrete subdivision of the flow region (i.e., subdividing the region into a number of regular shapes such as triangles, quadrilaterals, etc.). An appropriate model (e.g., polynomial) is then selected for the dependent variable. For underground flow systems the dependent variable might be hydraulic head or concentration. A system of equations is then established, using variational methods or the method of weighted residuals. Appropriate boundary conditions are incorporated in the system of equations. Solution of the system provides values of the dependent variable inside each element in terms of values at the nodal points.

A finite element model of Pinder and Frind (1972), using isoparametric quadrilateral elements, is currently being adapted to conditions at the WRRC Field Laboratory. During the proposed study, this flow model will be adjusted to comply with the hydrogeological conditions near the downstream reach of the Santa Cruz River.

Solution of mass transport equations using numerical methods presents no real difficulty. The main problem with using numerical schemes is in determining values for the "dispersivity" coefficients, which are the analogues of transmissivity in the flow system. During the proposed study, the mass flow of solutes in groundwater systems will be simulated by solving the equations of mass transport using the Galerkin-finite element approach and developing the corresponding computer coding. Pinder (1973) outlined, generally, the steps which should be taken. Fortunately, the solution procedure closely follows that for the flow system.

The computer program for the mass transport case will be fitted to the existing program for the flow case. The combined system will be tested against known analytical solutions of the mass transport, groundwater flow problems. With these tests, error estimates are made with respect to changing conditions in aquifer coefficients and related temporal-spatial parameters. Such estimates are important in application of pollutant dispersion.

The model will be calibrated using field data from the pit recharge studies. For example, an approach used by Pinder (1973) to simulate the spread of a contaminant in an aquifer system on Long Island, New York, will be attempted. In particular, by using appropriate assumptions and boundary conditions and knowing the change in salinity concentration of samples from the well system at the WRRC Field Laboratory (Figure 1), values for the dispersivity coefficients will be adjusted until the model and field data match. These values will be adjusted or refined by additional calibration using data from the water balance study along the Santa Cruz River.

3. Use of Model as a Predictive Tool

The final stage of the project will involve checking of the model against new data from the field sites and using the model to predict the effects of recharging in the Santa Cruz River on regional water levels and quality. Several cases might be examined. For example, we might consider recharge cases with and without the implementation of the Central Arizona Project. Thus, the effect of natural recharge alone for the condition of no-CAP could be studied and compared with the effects of recharging water available under the CAP. Other cases could include the effect on nitrate levels in groundwater within the Cortaro area by recharging CAP water; the effect of recharging in the region of greatest groundwater draft in the Tucson area; and the interrelationships of groundwater draft and recharge during the various stages of urban growth envisioned under the Comprehensive Planning Process.

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BUDGET

A.	Salaries and Wages		
	Research Assistant III		$25,000
	Research Assistant II		23,000
		Total	$48,000
B.	Capital		
	Flame Emission Equipment		5,000
C.	Expendable		6,000*
D.	Travel		1,000
E.	Indirect Costs		
	46% $25,000		11,500
	30% $23,000		6,900
			$18,400
F.	Employee Benefits		
	11% $48,000		5,280
		Grand Total	$83,680

*Includes $4,000 for Computer Services