

**INTRODUCTION**

The twin cities of Nogales, Arizona, in the United States and Nogales, Sonora, in Mexico have undergone rapid urban growth in recent years, and the growth is expected to continue in the coming decades. Nogales, Arizona, is in the Santa Cruz Active Management Area and is subject to the assured water-supply requirements and conservation mandates of the 1980 Groundwater Management Act (State of Arizona, 1980). The primary water supply for both cities, which are commonly referred to as *Ambos Nogales*, is ground water pumped independently by each community from shallow aquifers that underlie the upper Santa Cruz River and its tributaries, principally Nogales Wash and Potrero Creek, Nogales, Sonora, also obtains ground water from the Los Alisos basin, which is south of the Santa Cruz basin in Mexico.

Wastewater treatment for *Ambos Nogales* is provided by the Nogales International Wastewater Treatment Plant (NIWTP) near Rio Rico, Arizona. Some of the ground water that is withdrawn from the alluvium of the upper Santa Cruz River and from the Los Alisos basin is returned to the Santa Cruz River near Rio Rico as treated effluent. The NIWTP presently produces about 10,000 acre-ft/yr of effluent (Richard L. Caldwell, City of Nogales, written commun., 1995). About 60 percent of the influent is from Nogales, Sonora. The discharge of effluent creates an intermittent reach in the Santa Cruz River as far north as Tubac, Arizona. Flow is continuous in the reach during the winter months when evapotranspiration and local ground-water withdrawal are minimal. In the summer months, flow in the reach below NIWTP is interrupted locally as ground water is pumped from wells in connection with the shallow alluvial aquifer. The effluent released by the NIWTP also has caused a rise in water levels in wells that penetrate the shallow alluvial aquifer that is in hydraulic connection with the river indicating that a portion of the effluent reaches the aquifer underlying the upper Santa Cruz River.

The conservation mandates of the 1980 Groundwater Management Act (State of Arizona, 1980) in Arizona require the City of Nogales, Arizona, to prove the existence of a 100-year water supply as a condition for future growth and allows Nogales, Arizona, to receive recharge credits for the portion of effluent that recharges the aquifer underlying the Santa Cruz River. The recharge credits will be used by the City of Nogales, Arizona, as partial proof of a 100-year water supply. To qualify for a recharge credit that allows effluent to remain in the stream, a study must be submitted to the Arizona Department of Water Resources (ADWR) that quantifies (1) the consumptive use of the effluent by the downstream riparian area and (2) the percentage of effluent that recharges the aquifer underlying the Santa Cruz River.

In 1994, a multiagency study was begun to quantify the volume of effluent that recharges the aquifer underlying the upper Santa Cruz River in the reach below the NIWTP. Participants in the study include the Arizona Research Laboratory for Riparian Studies and the Department of Hydrology and Water Resources at the University of Arizona, the Center for Environmental Studies at Arizona State University, and the U.S. Geological Survey (USGS). The scope of the project includes measurement of the hydrologic characteristics needed for the development of an accurate water budget for the defined reach of the river below the NIWTP. The scope of the USGS work is to use seismic refraction at selected transects to determine the cross-sectional area of the aquifer and selected tributaries.

The cross-sectional area of the main water-bearing unit beneath the upper Santa Cruz River needed to be defined at two locations downstream from the NIWTP for water-budget calculations and for placement of monitoring wells. A previous study (Arizona Department of Water Resources, 1994) indicated that the stream-channel alluvium of Holocene to late Pleistocene age of the upper Santa Cruz River and its major tributaries (referred to as younger surficial deposits by Drewes, 1980) is the most productive water-bearing unit in the study area. Existing wells along the upper Santa Cruz River penetrate the stream-channel alluvium, and individual wells yield as much as 3,000 gal/min. A review of drillers' logs and local geology (Simons, 1974; Drewes, 1980) indicates that the stream-channel alluvium ranges from about 30 to 150 ft thick and is as much as several miles wide. The older alluvial deposits of middle Pleistocene to late Pliocene age store large quantities of water; however, the deposits do not yield water readily to wells (Arizona Department of Water Resources, 1994). Consolidated rocks of pre-Pliocene age and consolidated Tertiary sediments (including the Nogales Formation) underlie the older alluvial deposits. The study area extends 9 mi from the NIWTP effluent-discharge point north along the Santa Cruz River to Tubac, Arizona.

**CROSS-SECTIONAL AREA OF THE STREAM-CHANNEL ALLUVIUM**

Seismic refraction was used to obtain information about the subsurface units that control the location and movement of ground water in the study area. The seismic surveys were analyzed in the framework of known geology and drillers' logs to determine the cross-sectional area of the stream-channel alluvium. Seismic data were collected using an EG&G Geometrics' Model 2415 24-channel signal-enhancement seismograph. An interactive personal computer program for interpreting seismic-refraction data was used to model the field data.

Two seismic surveys were referred to as the NIWTP survey and the Santa Gertrudis Lane survey were made across the Santa Cruz River and were completed at the upper and lower ends of the defined study reach, respectively. The seismic survey lines combined geophone spreads with surficial exposure of the contact between the stream-channel alluvium, and these data are extrapolated across gaps in the geophone spreads. In addition, seismic surveys were conducted orthogonal to the flow direction in three of the tributary washes that join the Santa Cruz River within the study reach. The three seismic surveys in the tributary washes were the Josephine Canyon survey, the Peck Canyon survey, and the Sonoita Creek survey. The NIWTP survey consisted of seismic lines 5 and 6 and was 3,300 ft long with 1,840 ft of geophone spread. The Santa Gertrudis Lane survey consisted of seismic lines 7, 8, 9, and 10 and was 4,300 ft long with 3,440 ft of geophone spread. The seismic surveys in the tributary washes were made up of one seismic line each and varied in length—150 ft for the Josephine Canyon survey, 800 ft for the Peck Canyon survey with 375 ft of geophone spread, and 260 ft for the Sonoita Creek survey. Seismic lines 1-4 were done to test energy sources and to determine optimum spacing for geophones.

Generally, a velocity contrast of 3,500 to 5,500 ft/s was detected at the interface between unsaturated and saturated young alluvium and 1,500 to 4,000 ft/s between saturated young alluvium and saturated older alluvium (table 1). The seismic velocities for the geologic units in this study are consistent with seismic P-wave velocities of alluvium.

**Table 1.** Seismic-refraction data and interpretation, upper Santa Cruz River

Seismic survey	Seismic line number	Average velocity, in feet per second			Interpreted cross-sectional area of saturated young alluvium, in square feet
		Layer 1 Unsaturated young alluvium	Layer 2 Saturated young alluvium	Layer 3 Saturated older alluvium	
NIWTP	5	974	6,638	8,663	140,000
	6	694	5,557	8,225	
	7	1,248	6,480	8,297	
Santa Gertrudis Lane	8	1,031	6,334	8,132	200,000
	9	1,876	6,446	7,883	
Josephine Canyon	10	2,426	6,673	8,981	(?)
Peck Canyon	11	2,440	5,421	(?)	(?)
Sonoita Creek	12	1,323	6,010	10,092	<50,000
	13	1,183	4,627	(?)	(?)

<sup>1</sup>Depth to older alluvium is greater than the range of the survey.

<sup>2</sup>Insufficient seismic and geologic data to calculate cross-sectional area.

Cross-sectional area of the saturated stream-channel alluvium, which corresponds to layer two of the seismic sections, was calculated for the sections with sufficient seismic and geologic data (table 1). The saturated stream-channel alluvium or young alluvium is the major water-bearing unit in the study area. If the saturated stream-channel alluvium was believed to extend beyond the ends of the seismic survey, the interface between layer two and layer three was projected to the water-table surface and included in the area calculation. Drillers' logs and local topography indicate that the young alluvium is above the water table beyond the projected ends of the sections. A cross-sectional area of saturated young alluvium of about 140,000 ft<sup>2</sup> was calculated for the upstream end of the study reach on the basis of the interpreted seismic NIWTP. At the downstream end of the study reach near Tubac, Arizona, a cross-sectional area of saturated young alluvium of about 200,000 ft<sup>2</sup> was calculated on the basis of the Santa Gertrudis Lane survey and drillers' logs.

Lack of data precluded a cross-sectional area calculation for all the tributary washes that join the Santa Cruz River in the study reach. The cross-sectional area of saturated young alluvium in Peck Canyon probably is less than 50,000 ft<sup>2</sup>. The amount of saturated young alluvium in the other tributaries probably is also less than 50,000 ft<sup>2</sup>. The amount of saturated young alluvium in the tributaries probably varies significantly with changes in the amount of recent rainfall in the upstream watersheds.

**SELECTED REFERENCES**

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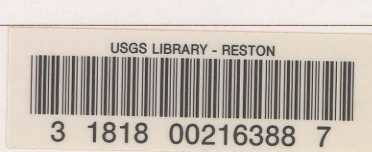
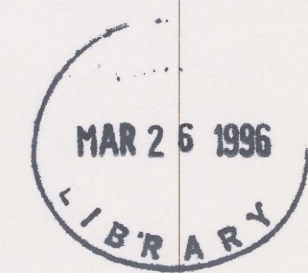
<sup>1</sup>Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

**CROSS-SECTIONAL AREA OF THE SHALLOW ALLUVIAL AQUIFER  
AT SELECTED SITES ALONG THE UPPER  
SANTA CRUZ RIVER, ARIZONA**

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