

# Hydrogeology of the Alluvial Aquifer Along the Curtiss Reach of the San Pedro River

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## Abstract

Remedial investigations supporting the Apache Powder Superfund project since 1990 have revealed examples of hydrogeologic features characteristic of heterogeneous alluvial aquifers. West of the San Pedro River, groundwater flow is strongly influenced by (1) narrow and varying width of the alluvial aquifer between the alluvial materials (Qal) and St. David Formation (Qsd) contact and the San Pedro River, and (2) lateral variations in lithofacies. These lithofacies changes relate to paleodrainages and isolate portions of the shallow aquifer, thereby affecting groundwater flow and solute transport. Additionally, the aquifer width and the meandering and incisement of the San Pedro River in some locations influences groundwater-surface water interactions.

**Keywords:** San Pedro River, groundwater-surface water interactions, nitrate, Superfund

## Introduction

The Curtiss reach of the San Pedro River (the river) is located along the Apache Powder Superfund Site and west of the Town of St. David in Cochise County, Arizona (Figure 1).

The alluvial basin within the St. David area comprises a typical intermontane basin formed within a Basin and Range structural valley. Adjacent to the Apache Powder Superfund Site, the river courses along the western edge of the basin.

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Basinfill alluvium comprises a thick, greater than 1,000-ft, sequence of fine- to coarse-grained late Cenozoic sediments derived from the surrounding mountain ranges. The geologic conditions were described in detail by Gray (1965).

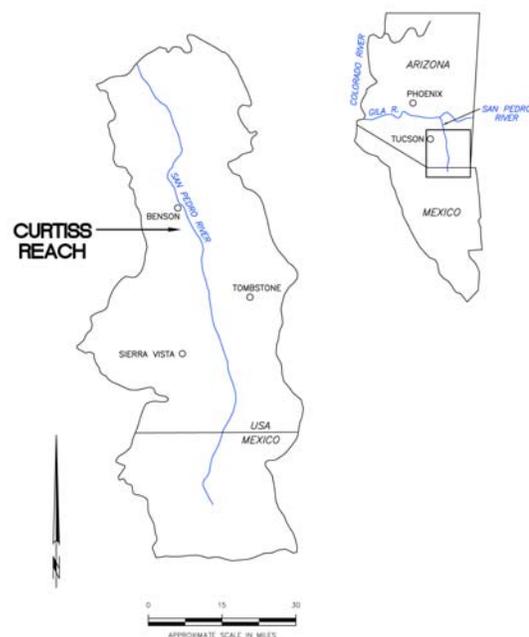


Figure 1. Location of the Curtiss Reach of the San Pedro River.

Two aquifers are present: (1) a shallow aquifer in the alluvial materials (Qal) overlying the St. David Formation (Qsd), and (2) a regional aquifer within sandy to gravelly units of the Qsd. A thick Qsd clay member serves both as the base of the alluvial aquifer and the overlying confining unit of the regional aquifer. The regional aquifer is under artesian pressure, as is the shallow aquifer in most places.

Groundwater and surface water monitoring, lithologic logging, geophysical surveys, and

geochemical characterization primarily of the shallow aquifer have been performed since 1990 as part of a Superfund Site investigation. These investigations have focused on the source and fate of nitrate-nitrogen (nitrate-N) in groundwater and resulted in a conceptual hydrogeologic model for groundwater flow and solute transport in the shallow aquifer and for groundwater-surface water interaction with the river.

## Summary of Investigations

Apache Nitrogen Products, Inc. (ANP) has been the lead Superfund investigator acting with the oversight of the U.S. Environmental Protection Agency (EPA). Formal Superfund studies began in 1990 and have involved the construction of 34 monitor wells, 12 piezometers, and 12 exploratory borings. These studies have been supported by various geophysical surveys employing seismic reflection and high-resolution resistivity. Groundwater levels and quality are monitored quarterly within this network of monitor wells and piezometers plus strategically located private wells. In addition, the river is sampled and gaged at several locations along the Curtiss Reach.

A remedial action featuring a pump-and-treat system was completed in 1997. This system is known as the Northern Area Remediation System (NARS), and comprises a high capacity extraction well, delivery piping, a treatment wetland, and an effluent return system. The NARS is designed to remove nitrate-N and ammonia-N from the groundwater via biological denitrification and aerobic nitrification, respectively.

Detailed studies of the river under baseflow conditions were recently completed (Hargis + Associates, Inc. (H+A) 2003). These studies involved cross channel surveys of the surface water including extensive sampling and analysis for nitrate-N and perchlorate; wellpoint sampling of shallow groundwater adjacent to the river; and flow gaging.

## Conceptual Model

The cumulative information derived from the various stages of the remedial investigations have resulted in a conceptual hydrogeologic flow model, which in turn serves to explain important aspects of the dynamics of nitrate-N within the shallow aquifer. The geomorphic and sedimentary history of the shallow aquifer involves a degradation stage

followed by a construction stage (Gray 1965, Deane 2000, Hargis + Associates, Inc. 2003a). The shallow aquifer is present in the alluvial materials deposited by the San Pedro River since the Pleistocene Epoch of geologic time. The shallow aquifer comprises a heterogeneous alluvial system emplaced upon the underlying Qsd clay unit, which serves as its base and acts as an effective hydraulic barrier between the shallow aquifer and the underlying regional aquifer.

Fundamentally, the most productive portions of the aquifer are situated near the present river channel and within areas where the ancestral San Pedro River and its tributaries once flowed. Lateral facies changes likely represent overbank deposits and uneroded paleotopography. In most areas, the shallow aquifer is overlain by finer-grained silts and clays. These lower permeability sediments create semi-confined conditions in the alluvial aquifer. In proximity to the river channel, this confining unit may be absent, particularly where the channel has meandered over a significant distance.

Generally, the base of the shallow aquifer is found between 80 to 120 feet (ft) below land surface (bls). Depths to groundwater range from the base of the river channel to over 60 ft bls with increasing distance from the river. The general direction of groundwater flow is to the northwest, essentially subparallel to the direction of flow of the river.

The western boundary of the shallow aquifer is found along the Qal-Qsd contact and is highly irregular along the Curtiss reach. Several indentations are found where present day ephemeral channels have cut back into the Qsd or into the Granite Wash sediments (Qgw), which are largely reworked Qsd and alluvium from the surrounding mountain ranges (Whetstones and Dragoons). At least some of these areas were probably eroded by ancestral tributary streams that flowed along these same approximate alignments (Figure 2).

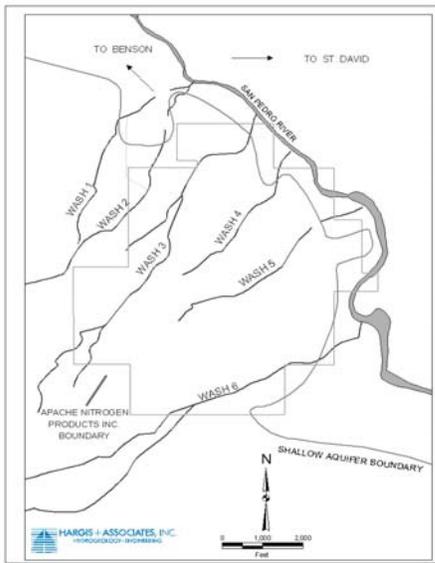


Figure 2. Shallow aquifer boundary and ephemeral washes along the Curtiss Reach.

It has been proposed that the source of the nitrate-N is related to historical surface runoff from the ANP plant site that recharged into the sediments above the shallow aquifer and also to water that recharged on the plant and migrated laterally eastward in the subsurface over the Qsd clay, eventually commingling with the shallow aquifer.

Another important feature of the conceptual model is the laterally confining unit (LCU). This feature was suspected as a result of significant differences observed along an east-west grouping of monitor wells (MW-22, -14, and -24) constructed as a transect normal to the direction of groundwater flow in that portion of the shallow aquifer (Figure 3). Along that transect, significant differences in hydraulic head, hydrochemical facies, water quality, and piezometric surface trends had been noted. This prompted speculation with regard to some lateral hydraulic barrier located between monitor wells MW-14 and -24. Subsequently, exploratory drilling and seismic reflection surveys were carried out to determine whether there was evidence for a lithostratigraphic change and/or elevation differences in the surface configuration of the underlying Qsd clay. The results of these field investigations confirmed both (Deane 2000, Hargis + Associates, Inc. 2003a). The lithology encountered during drilling of exploratory boring, EXB-3, drilled directly west of monitor well MW-14 confirmed the existence of a fine-grained unit, marking a sharp contrast in hydraulic conductivity as compared with typical shallow aquifer materials.

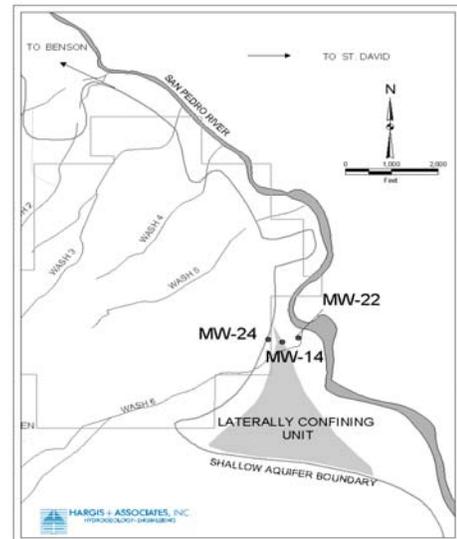


Figure 3. Features of conceptualized hydrogeology along Curtiss Reach.

Another seismic survey, complemented by exploratory borings, was completed further to the southwest and west of the shallow aquifer boundary. This survey revealed a lower elevation alignment on the surface of the Qsd clay that projected to the location of monitor well MW-24 and beyond. This feature was interpreted by Deane (2000) as the paleochannel of an ancestral San Pedro River tributary, which was termed Molinos Creek. Thus, Deane (2000) was able to demonstrate that at that location, the shallow aquifer appeared to be hydraulically compartmentalized into two areas termed the Molinos Creek sub-Aquifer (MCA), which occupied the ancestral paleochannel, and the San Pedro Aquifer (SPA), situated along the present San Pedro River.

The lower hydraulic conductivity materials separating the MCA from the SPA were interpreted as overbank materials deposited between the two perennial ancestral streams. The presence and geometry of the LCU was further delineated by additional, recently drilled exploratory borings that showed essentially a triangularly shaped unit (Figure 3). The importance of the LCU is that it has apparently served as a barrier to eastward migration of historically contaminated perched groundwater discharging from the southern, most heavily industrialized, portion of the ANP plant site from migrating eastward into the SPA and the river. This fact became even more evident with the 1998 discovery of perchlorate in perched zone and MCA groundwater. Fortunately, and apparently owing to

the hydraulic isolation provided by the LCU, perchlorate has never been detected in the SPA or the river.

### Groundwater-Surface Water Interaction

The interaction between groundwater systems and surface streams manifesting as alternating gaining and losing reaches has been studied extensively in southern Arizona (Usunoff 1984, Ellett 1994, Roudebush 1996). Along the Curtiss Reach, at least two gaining reaches have been identified as a result of extensive in-stream surveys involving quality sampling and analysis, gaging, and well points during extreme baseflow conditions. Specifically, an extensive survey involving water quality sampling and analysis over an approximate 3-mile distance incorporating the Curtiss Reach and involving installation and sampling of 27 wellpoints and collection of 75 surface water samples was completed in October 2001 (Figure 4). Additional wellpoint and surface water sampling was performed in 2002.

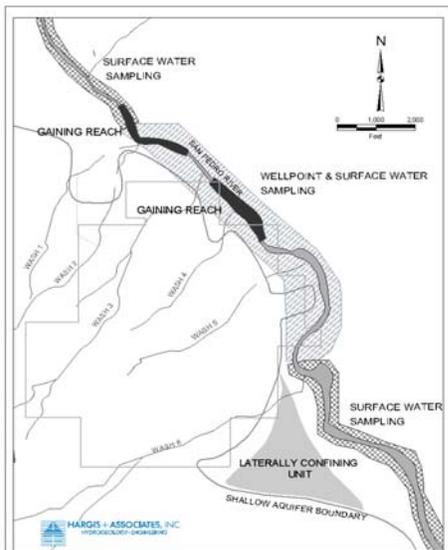


Figure 4. San Pedro River sampling network during October 2001 baseflow conditions.

On the basis of nitrate-N concentrations detected in the water samples, two gaining reaches were inferred (Figure 4). Further examination of these two reaches revealed common features in regard to topography and fluvial geomorphology. Both gaining reaches were located at or downstream from locations where the river meandered sharply westward from its generally northwestward course. Also, the river channel was deeply incised in both areas. This

morphology appears to favor interception of the shallow aquifer groundwater flowing subparallel to the river in a northwestward direction. Additionally, the incisement and meandering of the river serve to remove the confining strata above the shallow aquifer allowing upward movement of groundwater in the vicinity of the channel.

Another interesting aspect of this regime was the alignment of these gaining reaches with the aforementioned indentations in the shallow aquifer boundary corresponding to the locations of Washes 4 and 5 (Figures 2 and 4). Again, inferences can be drawn with regard to the potential for such areas to have contributed historically to the presently observed nitrate-N discharges along these two gaining reaches (H+A 2003b).

### Influence of Vertical Heterogeneities

Another interesting phenomenon has been observed in conjunction with the pumping of extraction well SEW-01, which withdraws groundwater with high concentrations of nitrate for treatment at the NARS. Extraction well SEW-01 is located about 50 ft from the MW-17 /18 monitor well pair. MW-17/18 are within close radial proximity, however, monitor well MW-17 is screened across only the upper 20 ft of the shallow aquifer, approximately 60 to 80 ft bls; whereas MW-18 is screened across approximately the lower 15 feet of the shallow aquifer, approximately 83 to 98 ft bls. By comparison, extraction well SEW-01 is screened across the entire shallow aquifer saturated thickness from approximately 62 to 110 ft bls.

The hydrographs and nitrate-N concentrations observed in MW-17/18 were nearly identical prior to the 1997 installation of extraction well SEW-01. Thereafter, greater hydrograph separation during periods of extraction well SEW-01 pumping is observed generally with MW-18 exhibiting greater drawdown than MW-17. During periods of non-pumping, however, both return to approximately the same static water level (Figure 5). Similarly the time-concentration plots for nitrate-N in MW-17/18 show separations with the concentration in MW-18 generally lower than in MW-17 (Figure 6).

These observations are believed to result from vertical heterogeneities in the shallow aquifer in the vicinity of monitor wells MW-17/18. Specifically,

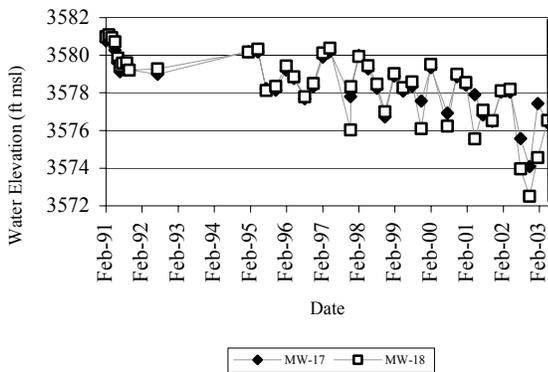


Figure 5. Hydrograph for monitor wells MW-17/18.

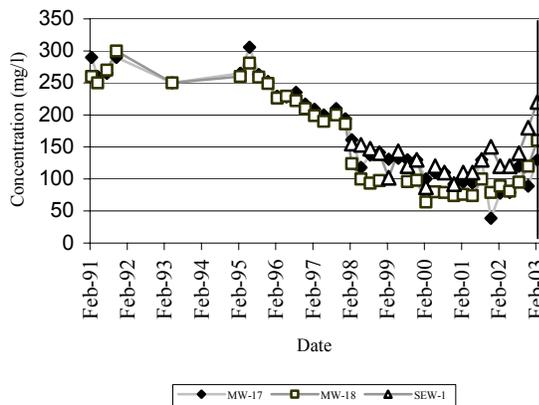


Figure 6. Time-concentration data for monitor wells MW-17/18 and extraction well SEW-01.

the lithologic log for an exploratory boring drilled and logged prior to the construction of monitor wells MW-17/18, shows a 7-ft clay unit 83 to 90 ft bls. Thus, it appears that the pumping of water from nearby SEW-01 differentially draws water from above and below the clay unit and hence from the intervals open to monitor wells MW-17 and -18, respectively. During periods of pumping stress, the water level in MW-18 is affected more than the water level in MW-17. The greater effect on the water level in MW-18 occurs either because downward vertical recharge through the clay is slow or because the pump in extraction well SEW-01 is set near the bottom of well, across from the monitor well MW-18 screened interval, or a combination of these factors (Figure 7).

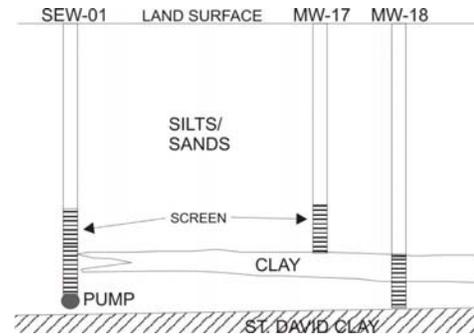


Figure 7. Schematic of monitor wells MW-17/18 and extraction well SEW-01.

## Conclusions

The hydrogeology along the Curtiss reach displays a heterogeneous alluvial system with features that control the occurrence, availability, and quality dynamics of groundwater. The opportunity to discover these features arises from remedial investigations associated with Apache Powder Superfund Site. The results of these investigations provide a detailed understanding of the water quality dynamics and the relationships among the shallow aquifer, regional aquifer, and San Pedro River.

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