Santa Fe River Studies

November 2014

Stream Aquifer Interaction

By Amy Lewis, Amy C. Lewis Consulting and
Claudia Borchert, City of Santa Fe

This is one of a series of scientifically-based studies designed to provide the technical background information for decision makers and the community in evaluating management options for the Santa Fe River. The series covers the following topics: stream flow, storm flow, reservoir storage, ecosystem watershed yield analysis, stream flow losses, stream-aquifer interaction, and fate of reservoir releases. For more information on the series, please contact Andrew Erdmann at 505-955-4204 or paerdmann@ci.santa-fe.nm.us.

Santa Fe River Stream Studies: Stream/Aquifer Interaction

The potential fate of flows in the Santa Fe River, whether derived from reservoir spills and releases or from urban storm water, has implications for the sustainability of the City well field and the potential for aquifer storage and recovery. This paper summarizes current and past hydrogeologic investigations on the interaction between surface flows and the shallow and deep groundwater beneath the Santa Fe River primarily between Nichols Reservoir and the Waste Water Treatment Plant (WWTP), and includes recommendations for future studies to help fill the knowledge gap. The City of Santa Fe is interested in understanding the recharge mechanisms and how flow in the Santa Fe River may impact groundwater flow and water levels in the City well field. This can help the City identify the benefit of river flows to the city's wells, help the City decide whether to lay claim to the water under an Aquifer Storage and Recovery (ASR) permit or where to drill supplemental City wells to capture infiltrated water. An understanding of the recharge mechanisms is essential to developing groundwater models that are used for predicting impacts of pumping and help to manage the water resources. Information on the flows, storage and seepage losses of the Santa Fe River are detailed in other papers in this series (Lewis and Borchert, 2009 a, b, c).

Local Geology

The regional aquifer in the Santa Fe area is comprised of the west-dipping Santa Fe Group, including the Tesuque Formation (Tt) and the more permeable Ancha Formation (QT_a) (Figure 1). Because the beds are dipping to the west (Figure 2), the oldest beds outcrop in the east and thus, the formations that underlie the Santa Fe River on the upstream side of town are the oldest and become progressively younger downstream toward the west. The oldest layer that underlies the Santa Fe River downstream of Nichols Reservoir is Precambrian granite (X_{yu}).which is overlain by Pennsylvanian limestone (P_{zu}), and the Miocene Tesuque Formation. Koning and Read (2010) have identified multiple lithosomes within the Miocene Tesuque Formation. The aquifer material underneath the Santa Fe River and within which the City's well field is completed is Tesuque Formation lithosomes 'A' and 'S' (Figure 3). Lithosome 'A' (T_{taml}) consists of alluvial slope deposits which underlie more recent lithosome 'S' (T_{tsml}), which is formed by deposits of the ancestral Santa Fe River in a fan-shaped lobe where it exited the Sangre de Cristo Mountains. Lithosome S is described as "granitic detritus" which is coarsest near the axis of the fan (coinciding with the modern Santa Fe River and finer-grained near the margins of the fan (Koning and Read, 2010).

The Santa Fe River directly overlays Lithosome 'A' downstream of Palace St. Bridge to Delgado St. and is comprised primarily of sand, silty-clayey very fine- to medium-grained sand. For a short reach from Delgado St. to Old Santa Fe Trail Bridge, the Santa Fe River flows across the lowest layer of lithosome 'S' which is characterized by clay silt and very fine-to medium-grained sand intercalated with minor medium-to coarse-grained sandstone channel fills. The middle layer of Lithosome 'S' , which underlies the Santa Fe River from Old Santa Fe Trail to St Francis Drive, is characterized by clay, silt and very fine to fine-grained sand intercalated with subequal medium- to very coarse-grained arkosic sand and gravelly sand channel fills." The most permeable unit of the Tesuque Formation is the upper layer of Lithosome 'S' (Figure 4) which underlies the Santa Fe River west of St. Francis Drive, is described as "medium to very coarse-grained sand and gravelly sand channel fills with subordinate fine-grained floodplain deposits".

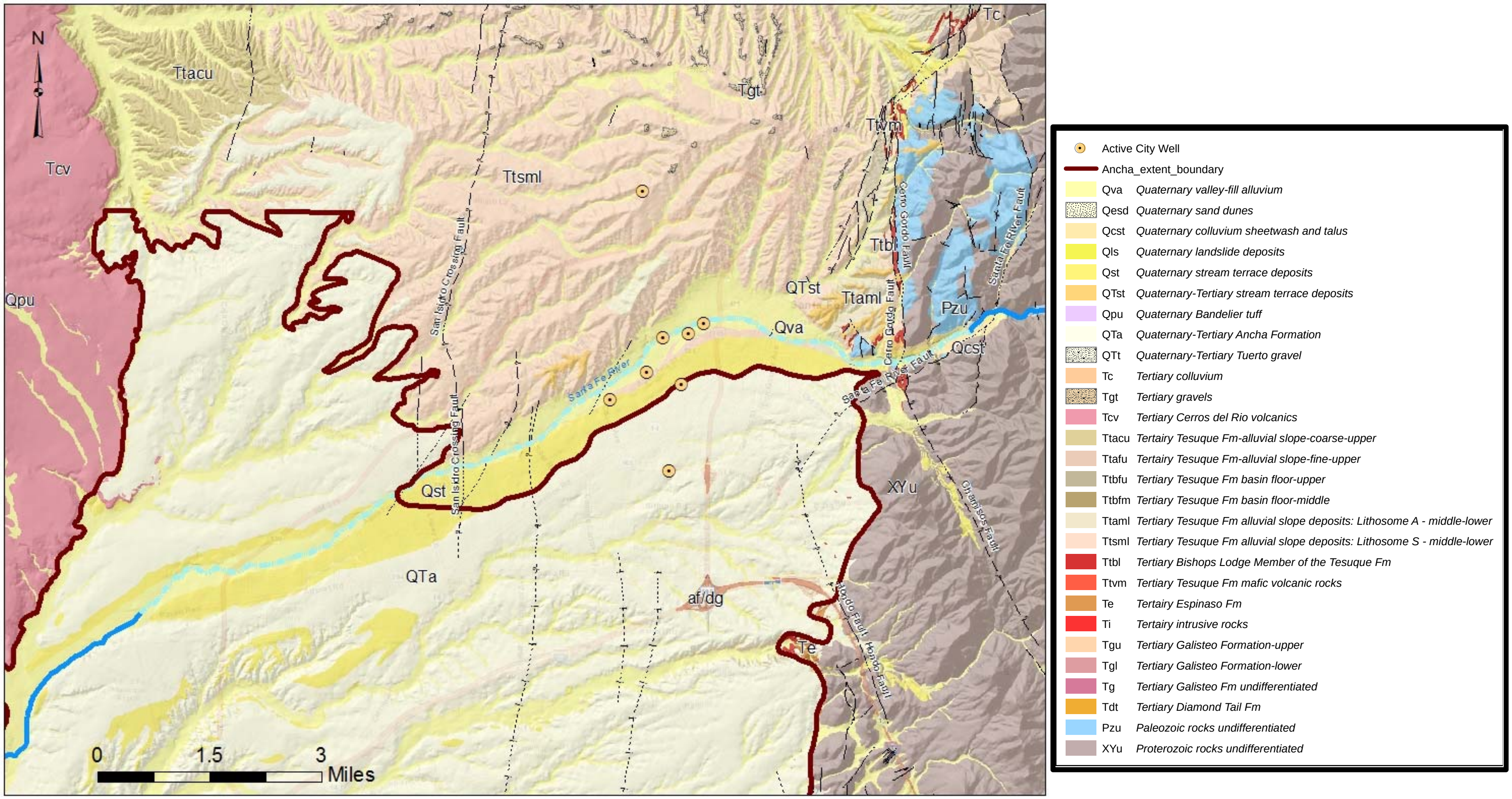

Figure 1. Geologic map in the vicinity of the Santa Fe River (after Koning and Read, 2010).

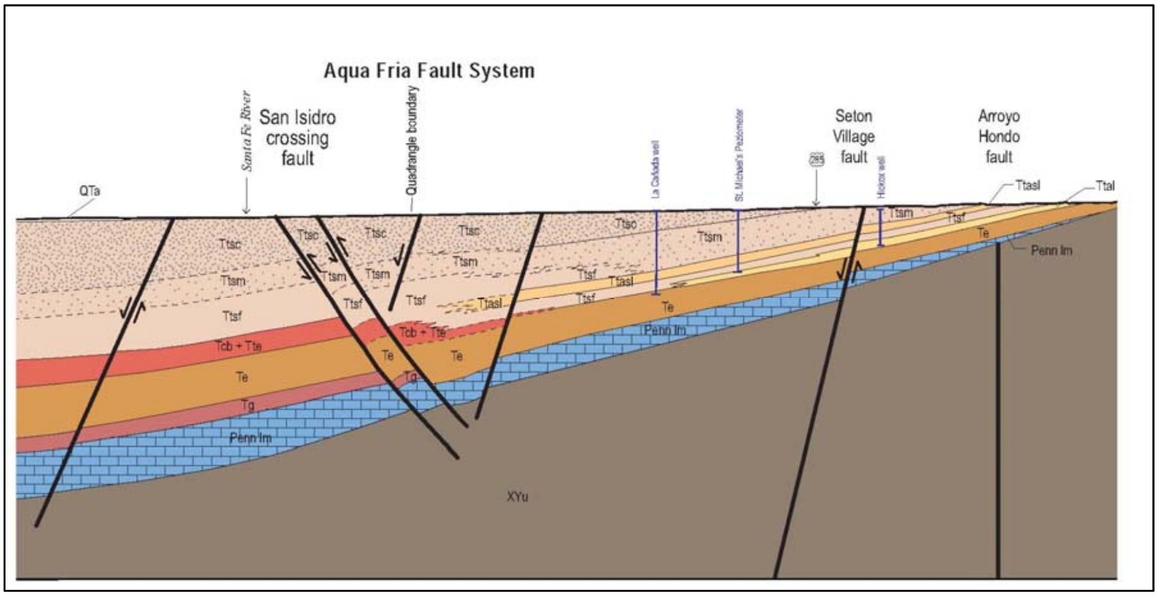

Figure 2. Cross-section of the geologic units beneath the Santa Fe River (Koning and Read, 2010).

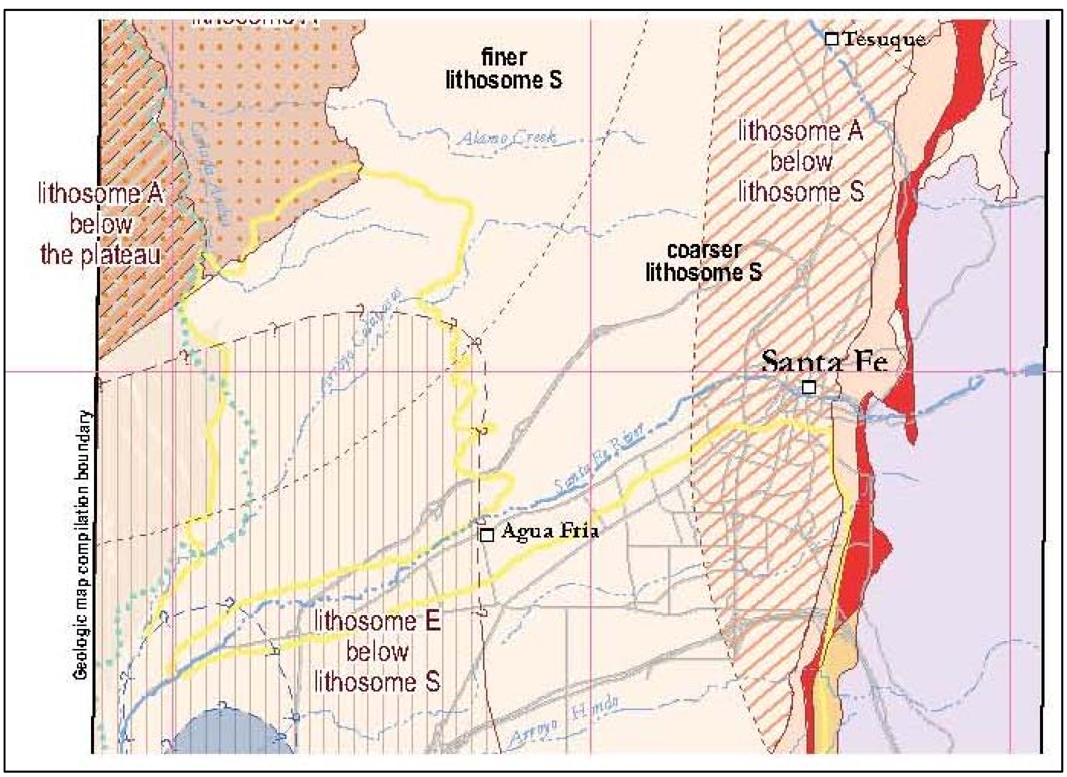

Figure 3. Map of Santa Fe River showing outcrop of lithosomes (after Johnson et al., 2008).

The younger, highly permeable, Ancha Formation underlies the Santa Fe River west and downstream of the San Ysidro fault (and crossing) and is also present south of the Santa Fe River throughout the city (Koning and Read, 2010). The Ancha Formation is described as coarse-grained alluvial slope deposits derived from the southwestern Sangre de Cristo Mountains, together with mostly coarse-grained ancestral Santa Fe River deposits. The Ancha Formation is unsaturated beneath the Santa Fe River upstream of the WWTP (Johnson and Koning, 2012) as shown in Figure 5.

Also beneath the Santa Fe River are disconnected deposits of Quaternary stream terrace deposits (Q_{st}) comprised of sandy gravel and Quaternary valley-fill alluvium (Q_{va}). The quaternary alluvium may have been a separate, perched aquifer prior to the incision and down cutting that has occurred over the past 50 years. The shallow alluvial system may have been about 30 feet thick and served as a reservoir to store infiltrated stream flow to slowly recharge the Tesuque Formation. The alluvium has eroded significantly since the 1970s when the Army Corps of Engineers intentionally removed grade control gabions to increase erosion for the purpose of increasing the flood storage capacity of the river (Grant, 2002). A sewer pipe installed below the Santa Fe River in 1977 at the St. Francis Bridge was suspended 15 feet in the air in 1996 prompting the City to begin restoration work on the river channel.

Figure 4. Outcrop of Lithosome S in the Santa Fe River.

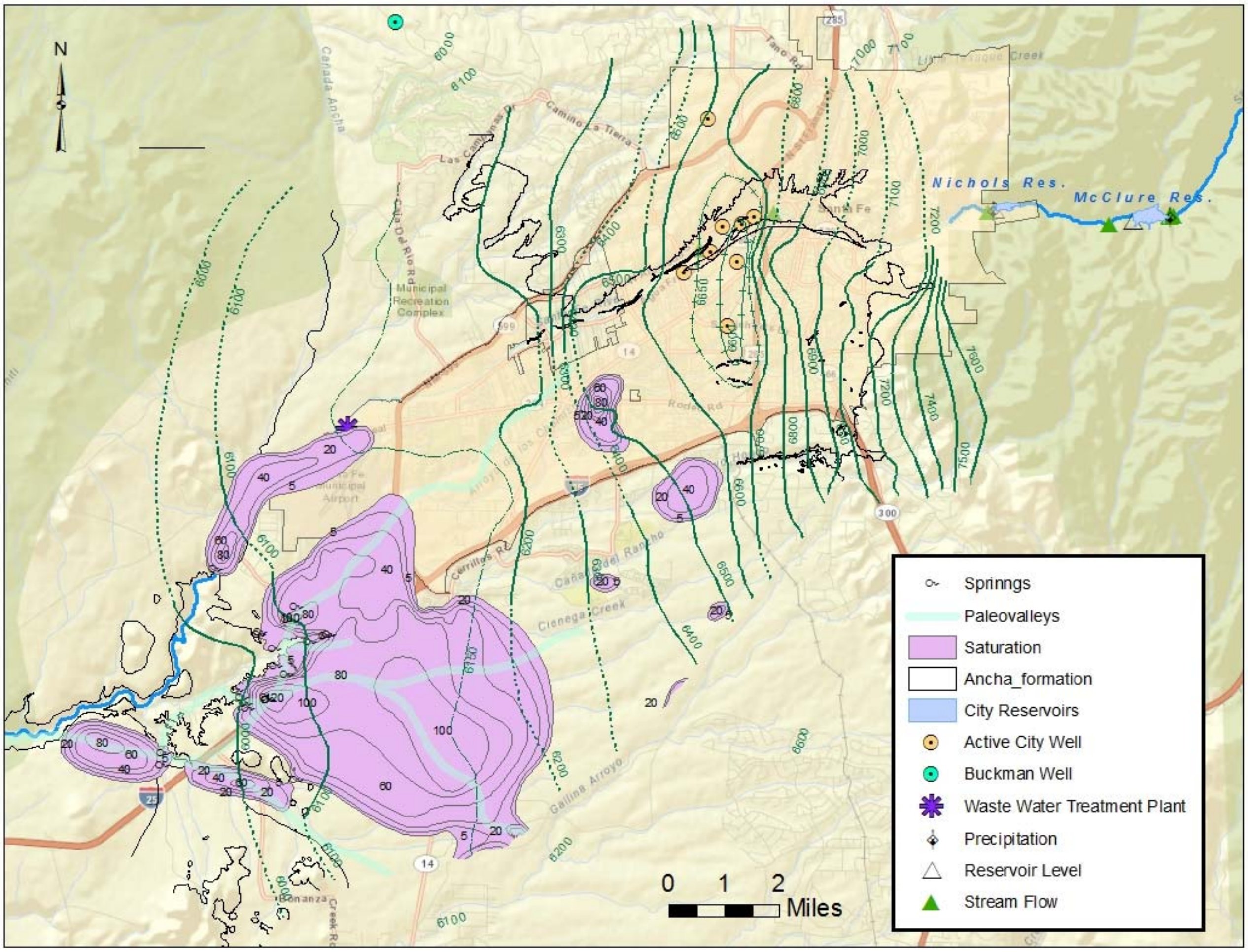

Figure 5. Saturated thickness of the Ancha Formation in the vicinity of the Santa Fe River (after Johnson and Koning, 2012.)

River Infiltration

The Santa Fe River has gaining and losing reaches along its 34 mile length from Nichols Reservoir to the Rio Grande. The reach of interest for this paper is predominately losing. The Santa Fe River loses flow to infiltration, evapotranspiration and diversions from acequias until it reaches the Santa Fe waste water treatment plant (WWTP), where it gains water from effluent. The gaining and losing reaches have been defined by seepage investigations, summarized in Veenhuis, 2008 and Lewis and Borchert, 2009c.

The rate of water lost from stream flow varies based on the amount of flow in the stream. The average rate of loss is approximately 0.4 cubic feet per second (cfs) per mile from Nichols Reservoir to Ricardo Road and 0.2 cfs/mile from Ricardo Road to the WWTP for flows less than 10 cfs (Lewis and Borchert, 2009c). While the rate of loss may vary, a loss of stream flow has been measured in all seepage studies and review of stream gage data.

The amount of water lost to evaporation will vary seasonally and from location to location. Thomas et al., 2000, studied a reach of the Santa Fe River downstream of La Bajada and found that 92 to 98 percent of the stream loss was infiltration and therefore, 2 to 8 percent was evapotranspiration. DBS&A and Watershed West (2002) compared infiltration rates calculated from thermistors with losses measured between flumes during a seepage study and conclude that ET is approximately 5 to 10 percent of the total loss.

Water levels

Water level maps and cross sections of the aquifer beneath the Santa Fe River provide some information about the flow paths between the aquifer and the Santa Fe River. As shown in Figure 6 (modified from Johnson et al., 2004) the regional aquifer is recharged in the east at the mountain front where the water moves towards the west. The 100 feet contours used in Figure 6 and earlier water table maps (Spiegel and Baldwin (1963, Plate 7) and DBS&A (1994, Plate 2)) do not provide enough detail for the reach through town to define the perturbations created by recharge from the Santa Fe River or arroyos. The cone of depression around the City well field shows the significant decline of 140 to 200 feet over the past 50 years. Upstream of La Cienega to about Siler road, the gradient is considerably less steep, as compared to the gradient east of Siler road. The flattening of the water table is an indication that the aquifer is receiving recharge and/or the transmissivity of the aquifer is much greater in this area. Spiegel and Baldwin attributed the flattening of the water table to the much higher transmissivity in the Tesuque Formation in this area, as evidenced by higher yields in wells. The groundwater discharge in the vicinity of La Cienega is evident by the converging flow paths on the La Cienega springs.

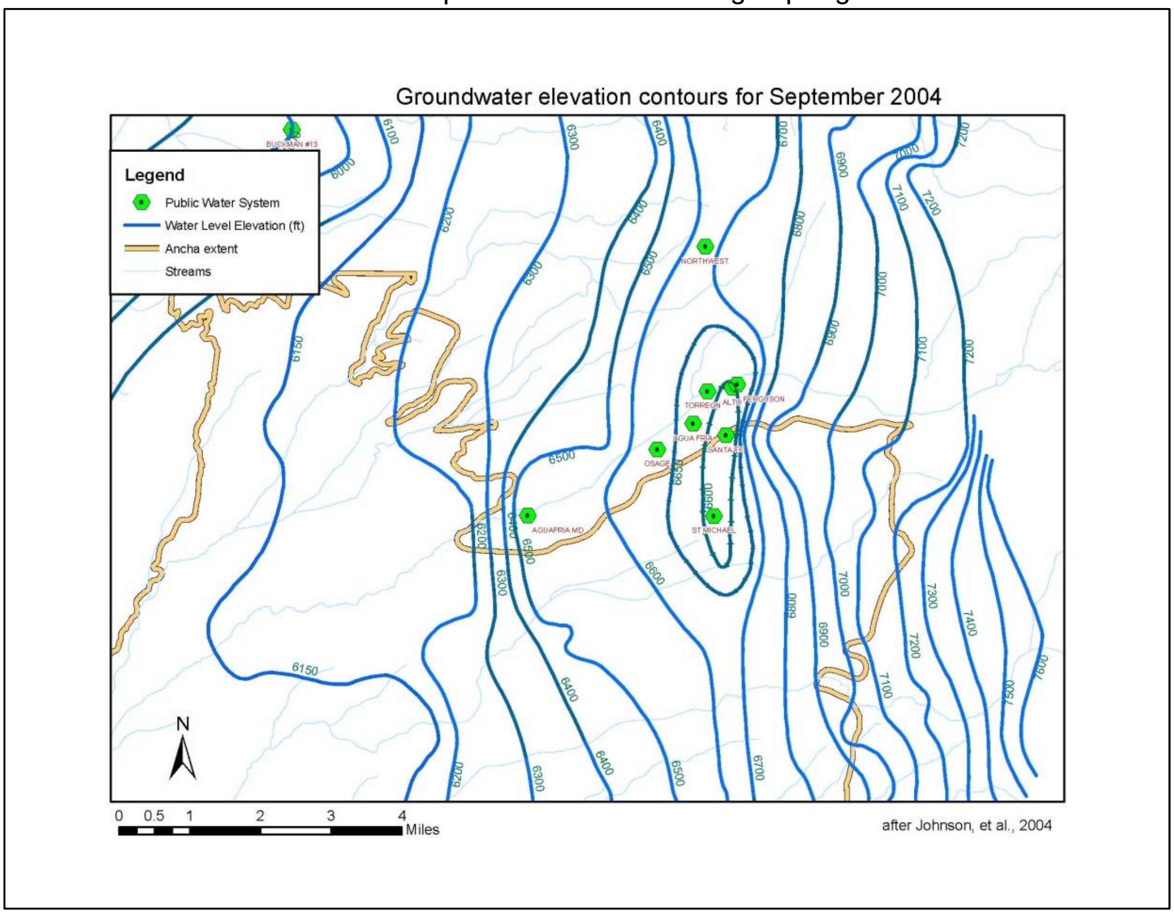

Figure 6. Groundwater elevation contours for September 2004.

Conceptual Models of Fate of Infiltration

While previous studies document the infiltration rates for the reach between Nichols Reservoir and the WWTP (Lewis and Borchert, 2009c, Veenhuis, 2008), the ultimate fate of this water is not well understood. Three conceptual models for how infiltrated water travels in the vadose zone to the water table beneath the Santa Fe River are considered herein and illustrated in Figure 7**.**

Conceptual Model A. Infiltrated water migrates vertically down until intercepted by confining layers within the Tesuque Formation. Water perches on the discontinuous, finer-grained layers and flows both down-dip and vertically, towards the west, ultimately recharging the regional aquifer when the confining layer intercepts the regional water table, relatively distant from the location of infiltration;

Conceptual Model B. Infiltrated water migrates vertically to the regional aquifer from the infiltration point in the stream bed, in which case much of the water infiltrated within the up-town and mid-town reaches stays within the capture zone of the city well field.

Conceptual Model C. Infiltrated water migrates vertically downward within the stream bed alluvium until intercepted by the

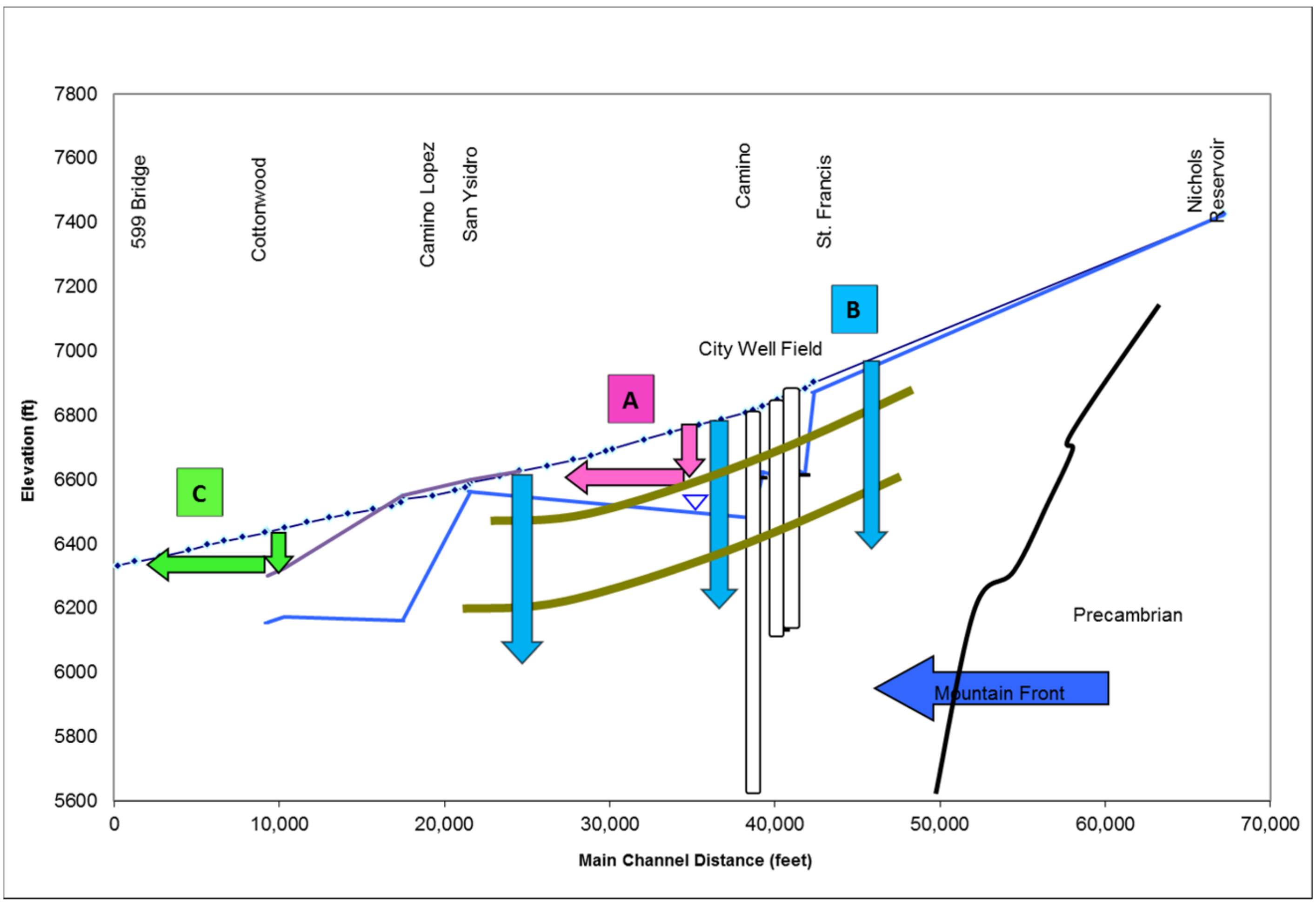

Figure 7. Schematic diagram illustrating the conceptual flow paths for infiltrated water.

Ancha/Tesuque contact. The contact acts as a semi-confining layer, because the water flows preferentially to the west (down dip) within the more permeable Ancha Formation along the Ancha/ Tesuque unconformity, eventually recharging the Ancha aquifer. The water may reappear as stream or spring flow in the La Cienega area where the Ancha Formation thins and pinches out. This mechanism is likely occurring downstream of San Ysidro Crossing where the Ancha Formation is present (but unsaturated) beneath the Santa Fe River.

A combination of all of these mechanisms is likely occurring, with one model dominating in a particular reach or area. Recharge to the aquifer also occurs from a deeper component of mountain front recharge which originates from snow melt and precipitation infiltrating through the Precambrian rocks of the Sangre de Cristo Mountains.

Scientific Investigations

A number of investigations have been conducted in the vicinity of Santa Fe that supports any one of these conceptual models. The hydrologic investigations that pertain to the stream/aquifer connection can be grouped into three broad categories: 1) geologic investigations, 2) ground water levels, gradients and water level response, and 3) geochemistry. The investigations are summarized below, along with an explanation of which, if any, of the conceptual models are supported by the investigation.

Geologic Investigations

Geologic investigations in the vicinity of the Santa Fe River have been conducted most recently by the NM Bureau of Mining and Geology (Koning and Read 2010, Johnson et al., 2004, Johnson and Koning, 2012).

The architecture of the basin-fill sediments

The quantity and configuration of sand, gravel, silt and clay (e.g. architecture) within the stream bed material and the underlying aquifer is the primary influence determining the fate of infiltrated stream flow. Koning and Read (2010) mapped the outcrops of the formations and lithosomes within the Santa Fe River, as described above. They describe the structure of the "bedding within the channel-fill complex as laminated to very thin to thick…(up to 1.1 m-thick, but generally less than 60 cm-thick)…Channel-fills are weakly to moderately consolidated and weakly to non-cemented in overall coarser strata". The description of the sediments underlying the Santa Fe River indicate the presence of fine layer sediments, but their extent and thickness are not continuous, such that significant barriers to recharge are not present, which supports conceptual model B.

Additionally, detailed hydrogeologic investigations in the vicinity of groundwater contamination sites, provide insights into the degree of heterogeneity and the dip of the geologic strata. Investigations of contaminated sites have resulted in multiple shallow monitor wells drilled in close proximity to the Santa Fe River in the vicinity of the City wells. For the most part, at all the sites considered, the stratigraphy is difficult to correlate, suggesting a strongly heterogeneous sedimentary system, which supports conceptual model B.

Groundwater flow across faults

The flow of water in the vadose zone and perched and regional groundwater can be impacted by faults by slowing the horizontal movement of water, thereby increasing the amount of water recharged from above. The series of northwest striking faults in the Santa Fe Group appear to be barriers to flow based on evidence from Johnson et al., 2008, Caine et al.,2007, Sigda, 1997 and Sigda and Paul, 2004. Caine et al., 2007 conclude that while faults in the Precambrian crystalline rocks may be conduits to flow, faults in the "poorly lithified basin sediments show pervasive clay-rich cores, fault-localized cements and no well-developed open fractures". Therefore, they suggest that the "intrabasin faults are partial barriers to ground-water flow" in the Española Basin. Based on review of general chemistry of stream and groundwater samples, Johnson et al., (2008) conclude that "changes in the distribution of some chemical ions (barium and magnesium) across the San Ysidro fault are consistent with hydrologic data that suggest the fault is a barrier to horizontal groundwater movement." Sigda (1997) studied the permeability of fault zones with unconsolidated sediments of the Santa Fe Group and found a reduction in permeability along the fault zones due to a "reduction in macroporosity and average grain and pore sizes" and greater abundance of clay. Sigda and Paul (2004) measured the permeability of sediments in the Santa Fe River and found large displacement faults in the vicinity of Aqua Fria, one of which was named the San Ysidro Crossing Fault. They describe the fault as containing "thick clay cores and well cemented zones of deformation bands…"

The impediment of westward movement in the regional aquifer across the San Ysidro fault supports conceptual model B by retaining water which would allow for greater recharge to the vicinity of the City wells.

Water Levels, gradients and water level responses

The water level gradients, both vertical and horizontal, and the water level responses to changes in stream flow, can provide clues to the connection between the stream and the aquifer. The water level changes observed in response to surface water flow in the Santa Fe River and Acequia Madre provide information on the stream-aquifer interaction. Water level declines observed from groundwater pumping also provide information about the stream-aquifer connection. Examination of available groundwater level data supports all conceptual models.

Stream connected monitoring wells

The response of water levels in shallow monitor wells near St. Francis Bridge and the Santa Fe River support conceptual models A and B (DBS&A and Watershed West, 2002). Water is reaching the upper portion of the Tesuque Formation (Lithosome S) in this reach, but it is not known if the water infiltrates several hundred feet to the regional aquifer. Lazarus and Drakos (1995) describe the presence of water in monitor wells near the Santa Fe River. They observed a strong downward gradient and concluded that "Paleochannels incised into the top of the Tesuque Formation control the lateral movement of the groundwater near the recharge areas and become the preferred conduit for shallow, saturated groundwater flow for limited distances away from recharge areas." Their conclusion that "groundwater is present at or below the alluvium/Tesuque Formation contact, and based on available data, is not present as perched water with the alluvium" supports conceptual model B.

Perched shallow aquifer

Spiegel and Baldwin's 1950 water table map shows areas of perched water in the Ancha Formation above the Tesuque Formation in the vicinity of Santa Fe well field. Although Johnson et al., 2004, have concluded that the Ancha is not saturated in this area today, such perched aquifers are an indication that in the early 1950s, the Santa Fe River and the deeper Tesuque Formation were disconnected, which would support conceptual model A.

Acequia –groundwater connection

Finch and Watson, 1995, describe a water level increase in response to the release of water to Acequia Madre and Acequia Cerro Gordo as the result of a 1991 court order.

They state that the "observed water levels in monitor wells located along the Acequia Madre at the Baca Street Site (Santa Fe Well) have increased at a rate of 4 to 12 feet per year, depending on the proximity of the well to the point where surface water enters the unlined ditch at St. Francis Street. This indicates a positive effect on recharge to the aquifer…" However, without the details on the depths of wells and the hydrographs for these wells it is uncertain if the response is due to flow in the acequia or the cessation of pumping the Santa Fe Well (which stopped pumping in1992 due to contamination of the well), If the response in water levels in these deeper wells is due to recharge from the acequias this would support conceptual Model B. If the response if from cessation of pumping, then no conclusion can be drawn about recharge pathways.

Horizontal Gradients

The regional horizontal flow in the Ancha and Tesuque aquifers if from east to west as shown in Figure 5. Areas where the gradient is disturbed can indicate changes in permeability, thickness and flow paths, such as the marked flattening of the gradient downstream of the San Ysidro Crossing fault. This change in gradient is attributable to several factors. First of all, the fault behaves as a barrier to flow as discussed previously. Secondly, the Ancha-Tesuque contact is downstream of the fault, which has a displacement of up to 1,000 feet (Johnson et al., 2008, pg. 14). The Ancha Formation is comprised of much coarser, weakly consolidated sediments than the underlying Tesuque Formation, which may play an important role in recharge from the Santa Fe River. Because the hydraulic conductivity is much higher in the upper portions of the Tesuque Formation, the gradient becomes less steep. Recharged water in this reach would preferentially remain in the more permeable sections of the Tesuque formation which is the path of least resistance, supporting conceptual model C. Water infiltrating downstream of the San Ysidro fault is unlikely to provide any recharge to the City's in-town wells, that are completed in the deeper Tesuque Formation.

Further downstream, groundwater near the WWTP is creating a mound most likely from the WWTP discharges, which would have little impact to the City's in-town wells.

Vertical gradients

The direction of the vertical gradient in an aquifer can be an indication of the source of recharge. Wells with strong upward vertical gradients are receiving significant recharge from the deeper zones; If the first water tapped is under artesian pressure, this would indicate very little recharge from directly above. The downward gradient would indicate a source of recharge from above, or a declining water level due to pumping.

The vertical gradient in the groundwater has been calculated from a series of well nests located throughout the City (Figure 8). A negative vertical gradient indicates a downward gradient and a positive number indicates an upward flow. Well nests located close to the Santa Fe River show a downward gradient (Alto Street well nests, Fairgrounds and NMOSE County Well nest), whereas, water level data from well nests (USGS SF-1 wells at San Mateo, Las Campanas, and Archery wells) shows an upward gradient.

Figure 9 shows the profile of the water table and the elevation of the Santa Fe River. MW10 located between the Santa Fe River and Alto Street is intermittently wet which indicates a vertical recharge pulse (conceptual model B) or water temporarily perched on a less permeable layer (conceptual model A).

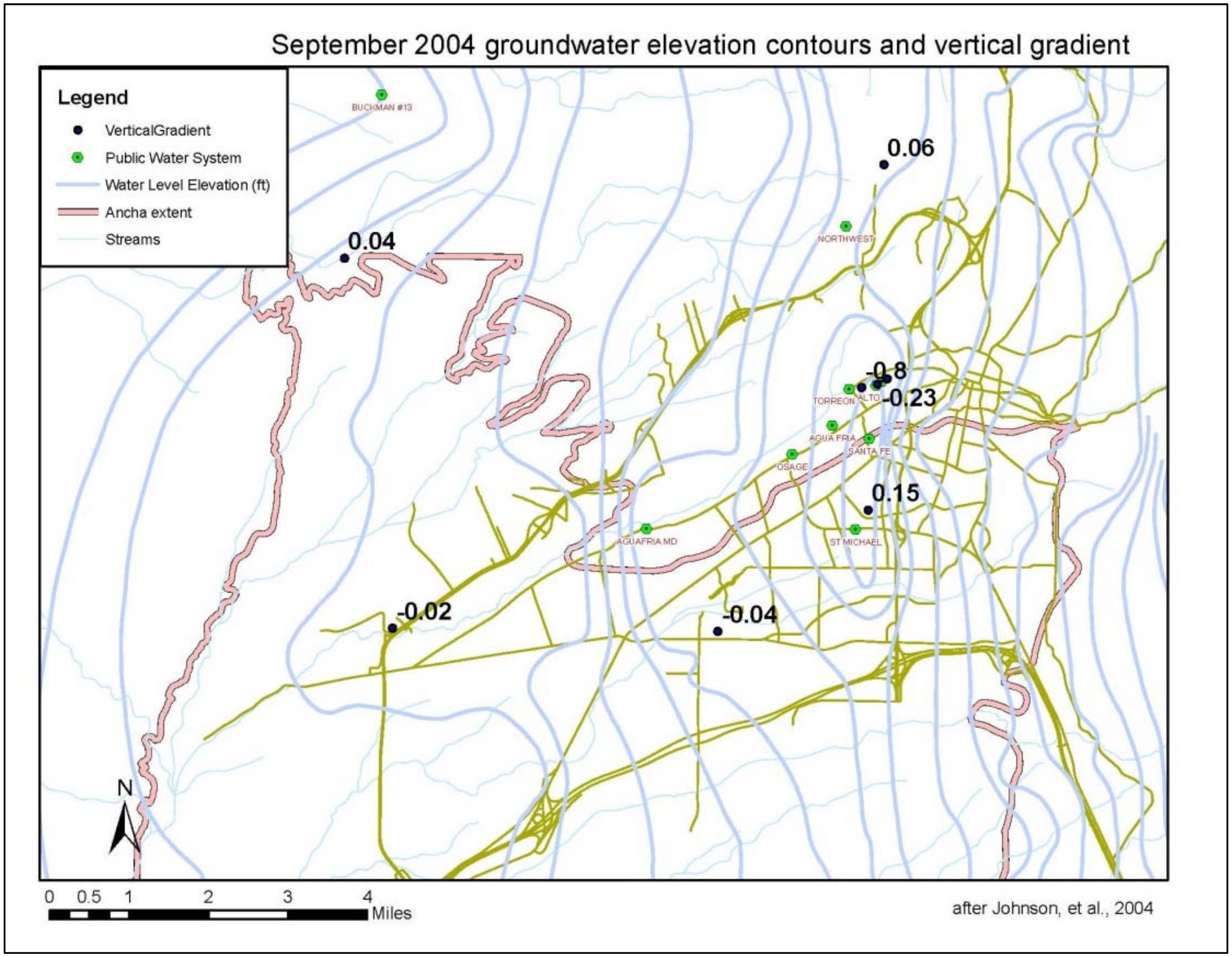

Figure 8. September 2004 groundwater elevation contours and vertical gradient.

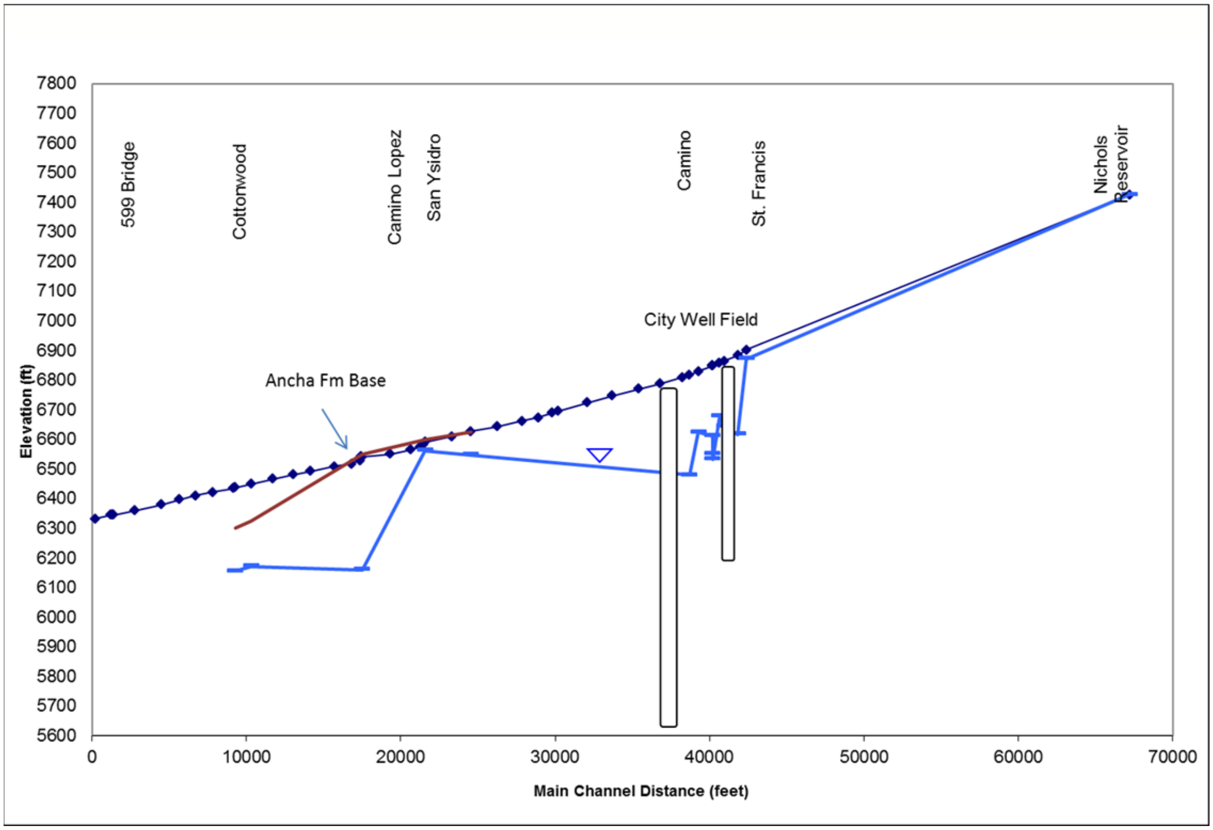

Figure 9. Cross section of the Santa Fe River channel and groundwater elevation.

Geochemistry

The chemistry of surface and groundwater can provide clues to the inter-connection between the stream and aquifer and is the subject of numerous investigations. Some of the investigations were focused on groundwater contamination from anthropogenic sources and others were focused on the natural ground water quality and temperature to specifically assess the connection between stream and aquifer.

Groundwater Contamination Investigations

Groundwater contamination in City wells indicates a travel time of less than a few decades for recharge to reach the aquifer. Yet, such evidence is not conclusive, as contamination can travel down the borehole (annulus) of unsealed domestic or monitoring wells. Contaminants have reached the Santa Fe Well (also known as the Baca Street well), located adjacent to Acequia Madre, about a half-mile south of the Santa Fe River, and the Alto well, and located adjacent to the Santa Fe River (NMED, 2008).

Chlorinated solvents and petroleum products (such as PCE, TCE, DCE, EDC and CTET) have been detected in monitor wells completed in various depths beneath the Baca Street site and in the Santa Fe Well. The groundwater pathway has not been fully characterized (NMED 2008), nor has the source of the plumes. However, the presence of contamination in zones above the Santa Fe Well has been determined from monitor wells completed to depths of 435 feet and therefore recharge is occurring from the surface to the aquifer, but the pathway is not well understood. The Santa Fe Well is screened from 200 to 725 feet, thus contaminants could migrate deeper into the aquifer through the well bore. Furthermore, the numerous domestic wells (817 identified by NMED) within a 4 mile radius may increase the vertical hydraulic conductivity between any stratified layers within the Tesuque Formation (NMED 2008). The presence of contamination at depth in the groundwater does indicate migration through the Tesuque Formation, supporting conceptual model B, but it is not conclusive whether this occurs through the heterogeneous layers or via anthropogenic pathways (e.g. wells).

Geochemical Fingerprinting

General Chemistry

DBS&A and Watershed West, 2002 conducted geochemical sampling of groundwater. Samples from monitor wells in the reach between Camino Alire and St. Francis Bridge and Santa Fe River water were tested for major cation and anion chemistry. They also reviewed existing available data for the Santa Fe River and City wells and prepared Stiff and Piper diagrams. Geochemistry in groundwater from deep wells could be explained by mixing with water from the Santa Fe River; however, recharge from the mountain block could also explain the observed chemistry. While they conclude that “the Santa Fe River is strongly connected with the groundwater system”, the authors are not distinguishing between interaction with the shallow perched groundwater and the deeper groundwater system. None of the methods disproved or proved the connection of the regional aquifer with the Santa Fe River.

Calcium to Sodium Ratios

Johnson et al., 2008 examined groundwater chemistry from 236 locations in the Southern Española Basin. They found that “calcium-bicarbonate water is dominate in the eastern half of the basin and grades westward into more sodium-rich waters, consistent with down-gradient chemical evolution by cation exchange along regional ground water flow paths” . The relatively high ratio of calcium to sodium on the western half of the aquifer beneath Santa Fe indicates a relatively short residence time and supports conceptual model B. Johnson et al., 2008 found that “groundwater in the center of the basin, in the vicinity of the Santa Fe River and Arroyo Hondo, has the lowest concentrations of TDS and major ions reflecting the influence of channel infiltration and recharge”. Elevated chloride and chloride to bromide ratios in shallow wells beneath urban areas of Santa Fe are consistent with anthropogenic sources.” They conclude that “significant infiltration occurs along the length of the Santa Fe River.”

However, in a later abstract, Johnson and Koning (2009) conclude that “lithosome S was probably deposited on an alluvial fan by an ancestral Santa Fe River…that allows for high rates of westward ground water flow and infiltration of Santa Fe River surface water west of the San Ysidro Crossing fault-indicated by TDS, Ca/Na ratios, SO4/CL ratios and a water-table mound centered over the river channel.” The presence of lithesome S beneath the Santa Fe River supports conceptual model C.

Chloride mass balance and Oxygen and Deuterium

Anderholm (1994) sampled the Santa Fe River and groundwater for chloride and stable isotopes of hydrogen and oxygen to estimate recharge. Using a chloride mass balance method, he concluded that the recharge from the Santa Fe River basin was 2,900 acre-feet per year. However, the area where this recharge occurs is not clearly stated, but described as from both “mountain-stream channel recharge” and “subsurface inflow from the mountains” (Anderholm, 1994). Most of this recharge occurred from winter precipitation based on the relation between stable isotopes of hydrogen and oxygen.

Manning and Keating (2008) report on findings of a numerical groundwater modeling effort that incorporated the geochemical data collected from wells, surface water and springs. They found that waters in the Southeast zone (which includes the Santa Fe area) "have locally elevated chloride concentrations, probably due to mixing with human-impacted waters", which supports a relatively short travel time to the regional aquifer. They also found "younger ages associated with the major surface water sources" suggesting that recharge in the form of stream loss is occurring beneath even intermittently flowing arroyos, which supports conceptual model B

Tritium, C-14, Noble gas and Temperature

Manning 2007 explains that "recharge temperatures computed from noble gas concentrations can constrain recharge elevation, which can be used to distinguish water recharge in the mountains from water recharge on the basin floor." He found that "noble gas recharge temperatures indicate that ground water in the Southeast zone [near Santa Fe] contains a significant fraction of mountain-block recharge, commonly 20-50% or more." The remainder of the recharge occurs as basin floor recharge (i.e. seepage loss from streams). Tritium and carbon14 concentrations also indicate that basin-floor recharge is occurring in the Espanola Basin. However, the tritium concentrations west of Santa Fe indicate that the recharge takes tens of years to traverse the unsaturated zone. Manning found the highest chloride, sulfate and TDS concentrations near Santa Fe, which he concludes are due to anthropogenic sources such as sewage effluent and road salt. Manning's work supports conceptual model B.

Groundwater Temperature

Johnson et al., 2008 measured groundwater temperature in 236 locations and found that the coldest groundwater was observed in the mountain block and beneath the Santa Fe River in the regional aquifer. They conclude that the cold temperatures "likely reflects recent recharge originating at higher elevations or from direct infiltration of mountain runoff along the Santa Fe River" which supports conceptual model B.

Conclusions and Recommendations

Stream losses in the Santa Fe River recharge the regional aquifer beneath the Santa Fe River through all of the pathways represented by the three conceptual models. Some of the water is reaching confining layers and migrating down dip to recharge the aquifer further to the west (conceptual model A), some water is migrating vertically and reaching the regional aquifer locally (conceptual model B) and some water is flowing preferentially along the contact between the Tesuque and Ancha Formations and recharging more permeable sections of the Tesuque Formation downstream of the San Ysidro Crossing (conceptual model C). The precise amount following each of the recharge pathways will vary depending on the extent and magnitude of flows in the Santa Fe River. The timing to reach the regional aquifer will vary depending on the depth to water beneath the river and the permeability and stratification of layers in the vadose zone. Nevertheless, many of the City wells are currently positioned to benefit from seepage from releases to the Santa Fe River. The Ferguson, Alto, Torreon, Agua Fria, and Osage wells are all located within a few hundred feet from the Santa Fe River. The travel time and amount of seepage that would reach the wells will vary depending on the amount of water available for recharge and the depth to water. The depth to the water table in the regional aquifer beneath the Santa Fe River in the vicinity of the City wells is several hundred feet, created by the cone of depression around the City wells. If pumping from the wells were reduced for a period of time, the water levels could recover and the travel time to recharge the wells would be reduced.

The problem is complex and perhaps best suited to numerical modeling of the saturated and unsaturated flow. Enhanced data collection to provide model input would help to improve the numerical characterization of the complex system. To determine the travel time for Santa Fe River seepage to reach existing City wells, it is recommended that pressure transducers in the nested monitor wells adjacent to the Alto Well be installed to monitor water level response to flow in the Santa Fe River. This well nest has four wells that are drilled to depths of 160 (MW-9), 280 (MW-4), 415 (MW-3) and 480 (MW-2) feet below ground surface. The water level data should be collected for multiple years to establish a pattern of water level response. MW-10, located between the Santa Fe River and Alto Street should also be monitored for water level data.

To improve the understanding of the groundwater flow paths beneath the Santa Fe River, a detailed water level map should be prepared based on non-pumping water levels. Both shallow and deep wells should be monitored to examine both horizontal and vertical flow patterns. Ideally, water levels could be measured in as many wells as possible and repeated during different conditions.

With greater detail on water level responses obtained from the well nest and detailed water level map, the information could be used to calibrate a groundwater model that simulates the stream-aquifer connection.

Measurement of water budget components such as stream flow and pumpage in the vicinity of the city well field would be critical for future model calibration or a flow net analysis. Therefore, continued measurement of stream flow at the St. Francis Bridge and at a location downstream near the San Ysidro crossing is recommended. Return flow from Acequia Madre should also be measured if a new gage is installed near the San Ysidro Crossing (downstream of the Ricardo Road location). Production rates from City wells are currently monitored, but an assessment of pumping of other wells, such as domestic wells, should be conducted. A thorough review of well logs from monitoring wells could be performed to map the clay, sand and gravel layers within the Tesuque Formation in the vicinity of the Santa Fe River. Data from aquifer tests should be reviewed to inform and potentially revise aquifer parameters in groundwater modeling efforts.

Aside from water right constraints and potential protests that could arise in drilling additional wells, from a hydrologic perspective, the best location to recover any river losses would be towards the west side of town, west of the San Ysidro Crossing Fault in Township 16N Range 8E and south along the Santa Fe River.

Any location downstream of the WWTP where the depth to water is relatively shallow would provide an immediate connection between groundwater and surface water and allow for recovery of river losses.

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