LMS/SHP/S05037

Evaluation of the Trench 2 Groundwater Remediation System at the Shiprock, New Mexico, Legacy Management Site

March 2009

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1.0 Introduction

A uranium-vanadium ore processing mill operated near Shiprock, New Mexico, from 1954 to 1968. By September 1986, all tailings and associated materials at the former millsite were encapsulated in a disposal cell built on top of the two existing tailings piles on the site. Groundwater in the area of the millsite was contaminated by multiple inorganic constituents as a result of the milling operations. The Uranium Mill Tailings Remedial Action (UMTRA) Groundwater Project was responsible for characterizing and remediating groundwater at the Shiprock Site (the site). In October 2003, the UMTRA Groundwater Project sites, including Shiprock, were transferred to the U.S. Department of Energy (DOE) Office of Legacy Management (LM). LM now has responsibility for operating the remediation system at Shiprock and must comply with applicable regulations.

The Shiprock Site is located in the northwest corner of New Mexico, about 28 miles west of the City of Farmington (Figure 1) and on the west bank of the San Juan River (Figure 2). The site is divided physiographically into two regions, terrace and floodplain, that are separated by an escarpment. Ground surface elevations on the terrace are generally about 40 feet (ft) higher than comparable land surface elevations on the floodplain. Groundwater beneath the terrace flows within both weathered and competent portions of Mancos Shale bedrock and a few feet of alluvium overlying the shale. Groundwater in the floodplain area flows primarily within alluvium (alluvial aquifer) that was deposited by the river on top of Mancos Shale. The escarpment separating the two regions is an erosion surface of the Mancos Shale, and is referred to in this report as the bedrock escarpment or the Mancos Shale escarpment.

Historically, subsurface contamination originated below the terrace and subsequently migrated in eastward-flowing groundwater toward the floodplain, where it discharged to the alluvial aquifer. Measured water levels in local wells during recent years indicate that groundwater continues to flow from beneath the disposal cell on the terrace to the alluvial aquifer. Water quality data from wells installed on the floodplain indicate that most of the contaminant discharge to the alluvial aquifer occurs near the escarpment, but there is also evidence of discharge of contamination from isolated locations of bedrock beneath the alluvial aquifer and away from the escarpment. The presumed conveyance features for the isolated discharges are fractures in the bedrock that are difficult to clearly identify. The contaminants affecting groundwater in the alluvial aquifer consist solely of inorganic chemicals and include sulfate, nitrate, uranium, and ammonia.

In March 2003, the UMTRA Groundwater Project initiated pump-and-treat remediation of groundwater at the Shiprock Site. During the remediation system's first three years of operation, groundwater was pumped from two vertical wells on the floodplain (Wells 1089 and 1104 in Figure 2), two interceptor drains in the terrace area, and as many as ten vertical wells in the terrace area. In general, the combined pumping rate from the wells and drains has been less than the rate for which the system was designed.

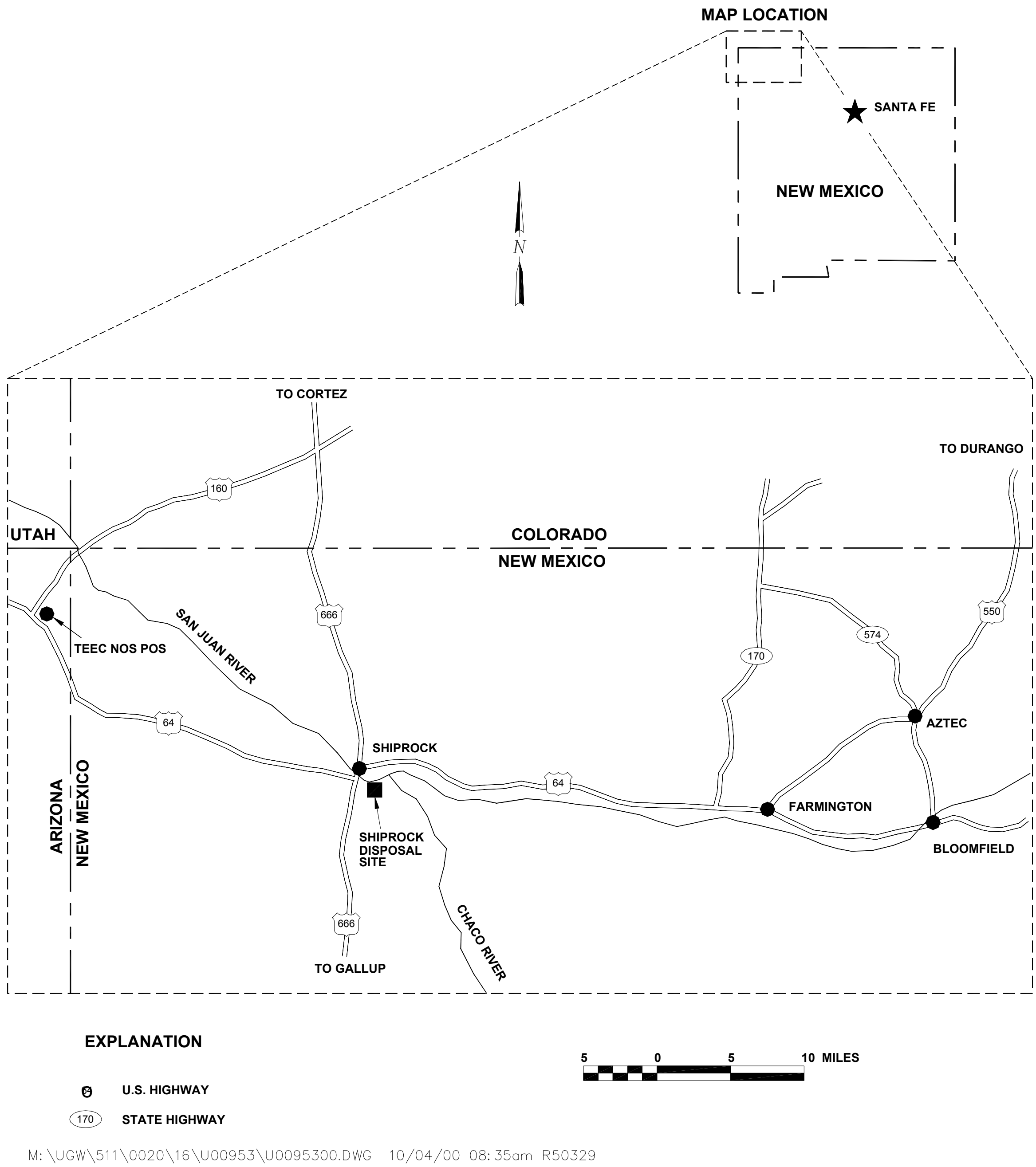

Figure 1. Regional Location Map

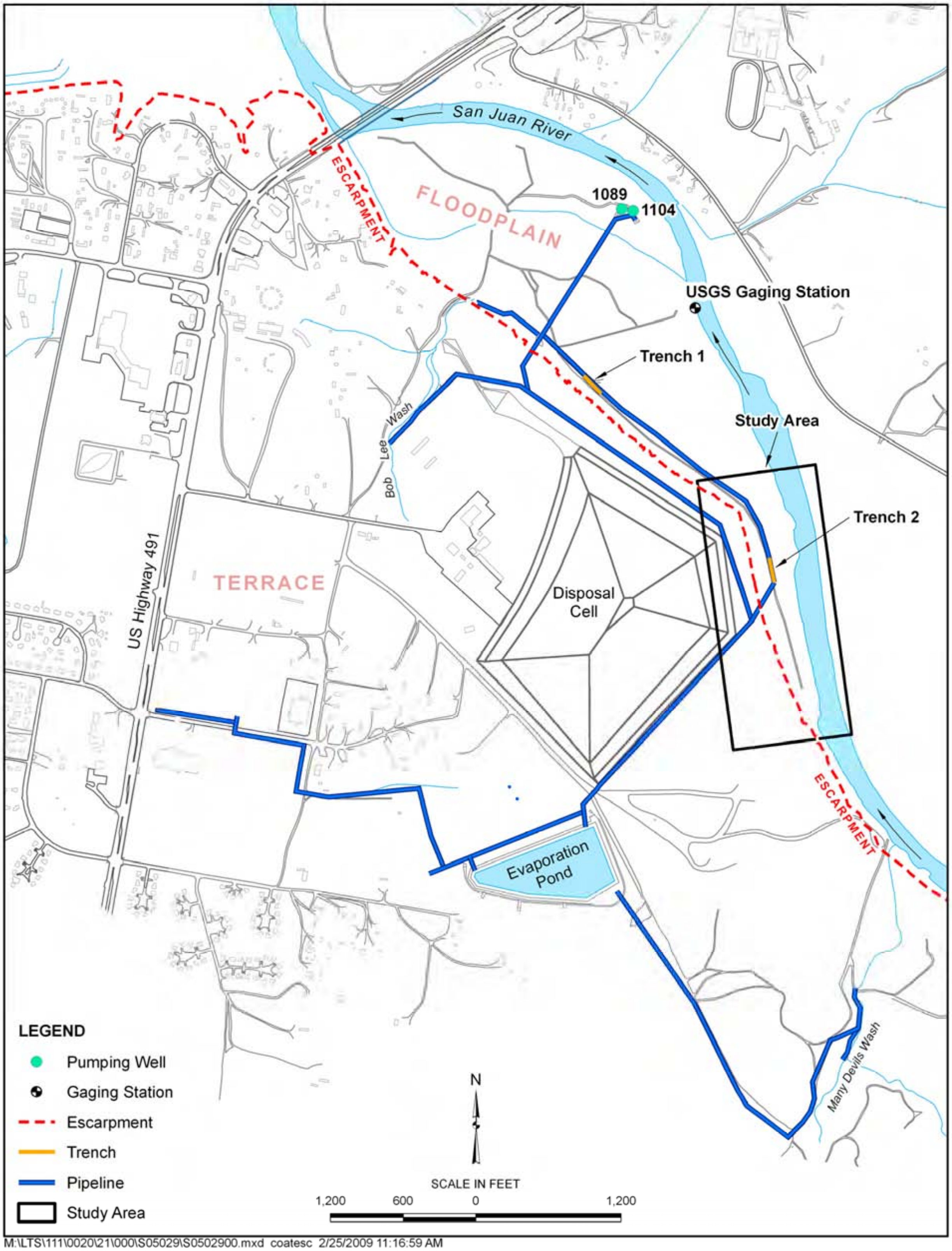

Figure 2. Shiprock, New Mexico, Legacy Management Site

Some of the difficulty in achieving design pumping rates is attributed to groundwater extraction rates at floodplain Wells 1089 and 1104 that are significantly smaller than had been anticipated on the basis of an aquifer pumping test in the alluvial aquifer. One possible explanation for the relatively low pumping rates is the limited saturated thickness of the aquifer in the vicinity of the vertical pumping wells, which generally ranges between 5 and 10 ft. Such water thicknesses limit the available drawdown at extraction wells. Another possible explanation for the lower-than-anticipated pumping rates is well inefficiency, which manifests itself in the form of water levels a short distance outside the well casing that remain substantially above water levels in the casing itself during times of pumping. Such inefficiencies can be caused by the clogging of well screens (or perforations) or the pores of alluvial sediments immediately surrounding the well casings. With the floodplain wells capturing less water than was intended, the potential exists for some contaminated groundwater to bypass the wells and enter the river.

In spring 2006, two additional groundwater withdrawal systems consisting of horizontal wells in excavated trenches (Trench 1 and Trench 2) were installed in the alluvial aquifer near the base of the escarpment (Figure 2). It was believed that the pumping of each of these horizontal wells would result in greater groundwater extraction rates than had previously been achieved at either of the two vertical wells on the floodplain, particularly given that the length of each horizontal well is 200 ft. In addition, there was reason to believe the horizontal wells could be installed in a manner that would render them more efficient than either vertical well. As a consequence, Trench 1 and Trench 2 were expected to intercept much, if not all, of the contaminated water migrating across the Mancos Shale escarpment, thereby reducing the contaminant mass reaching portions of the alluvial aquifer between the bedrock escarpment and the river.

This study presents an evaluation of the Trench 2 remediation system. The system is assessed using several lines of evidence that incorporate hydraulic and water chemistry data collected in the vicinity of the trench since its installation in 2006. A numerical model is also used to improve understanding of flow and transport processes that occur in response to pumping of Trench 2.

2.0 Purpose of Study

The purpose of this study is to evaluate the performance of the Trench 2 system with regard to its ability to achieve remediation of the alluvial aquifer. In meeting this general purpose, the study attempts to meet the following objectives:

1. Assess the ability of the remediation system to remove dissolved mass, particularly contaminant mass, from the alluvial aquifer;
2. Examine the ability of the remediation system to intercept contamination discharging across the Mancos Shale escarpment as well as capture existing contamination in the alluvial aquifer;
3. Develop and apply a numerical model of groundwater flow and contaminant transport in the Trench 2 area to help explain observed groundwater levels and contaminant concentrations in response to pumping from Trench 2;
4. Use collected hydraulic and chemical data from the Trench 2 area and results from the above-mentioned numerical model to assess the adequacy of a hydrogeologic conceptual model that has historically been applied to the Shiprock Site, and make adjustments to the conceptual model if necessary;
5. Assess the potential influence of the San Juan River on flow and transport processes in the alluvial aquifer;
6. Describe the relative hydraulic efficiency of the horizontal well at Trench 2; and
7. Examine the benefits of an on-site, telemetered monitoring system for tracking remediation progress at and near Trench 2.

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3.0 Trench 2 System

The Trench 2 remediation system was installed in the alluvial aquifer during early spring 2006. Test pumping of groundwater was conducted with the system during two separate multi-day periods in April 2006, and continuous pumping of the system began during the first week of May 2006.

As shown in Figure 2, Trench 2 is located about 2,000 ft south-southeast of Trench 1, several hundred ft east of the eastern edge of the Shiprock Site disposal cell and about 130 ft west of the west bank of the San Juan River. Given the trench's location at the base of the bedrock escarpment and its relatively short distance from the river, the remediation system is designed to only influence a relatively narrow strip of alluvial aquifer within the southeast corner of the Shiprock Site. The 200-ft long trench is oriented about 12 degrees west of north (Figure 3). The horizontal well in the trench consists of 4-inch diameter high-density polyethylene pipe, which sits about 12 to 13 ft below ground surface (bgs). Perforations on the underside of the pipe provide the route for groundwater to enter the system (Figure 4) and water in the pipe flows to a sump on the system's north end. Pipe risers connected to the horizontal well are located on the south end of the trench and about midway between the south end and the sump. Two monitoring wells (Ports A and C) sit directly above the well pipe (Figure 3 and Figure 4). Gravel backfill surrounds the well pipe to about 3 ft above its base.

The Trench 2 system is connected to Trench 1 by a water pipeline that parallels the base of the bedrock escarpment (Figure 2). The pipeline extends about 200 ft to the south-southeast of Trench 2, where it then extends up the Mancos Shale escarpment and on to a pond south of the Shiprock disposal cell (Figure 2). The groundwater extracted from the trenches is pumped to the pond where it is treated via evaporation.

To meet the study purpose and objectives listed in Section 2 of this report, a rectangular-shaped study area was established (Figures 2 and 3). The south boundary of the study area is located about 1,000 ft south of the south end of Trench 2, and the north end is about 650 ft north of the trench's northern extent. The south boundary is selected to coincide roughly with where the base of the Mancos Shale escarpment intersects the river, thus pinching off the alluvial aquifer locally.

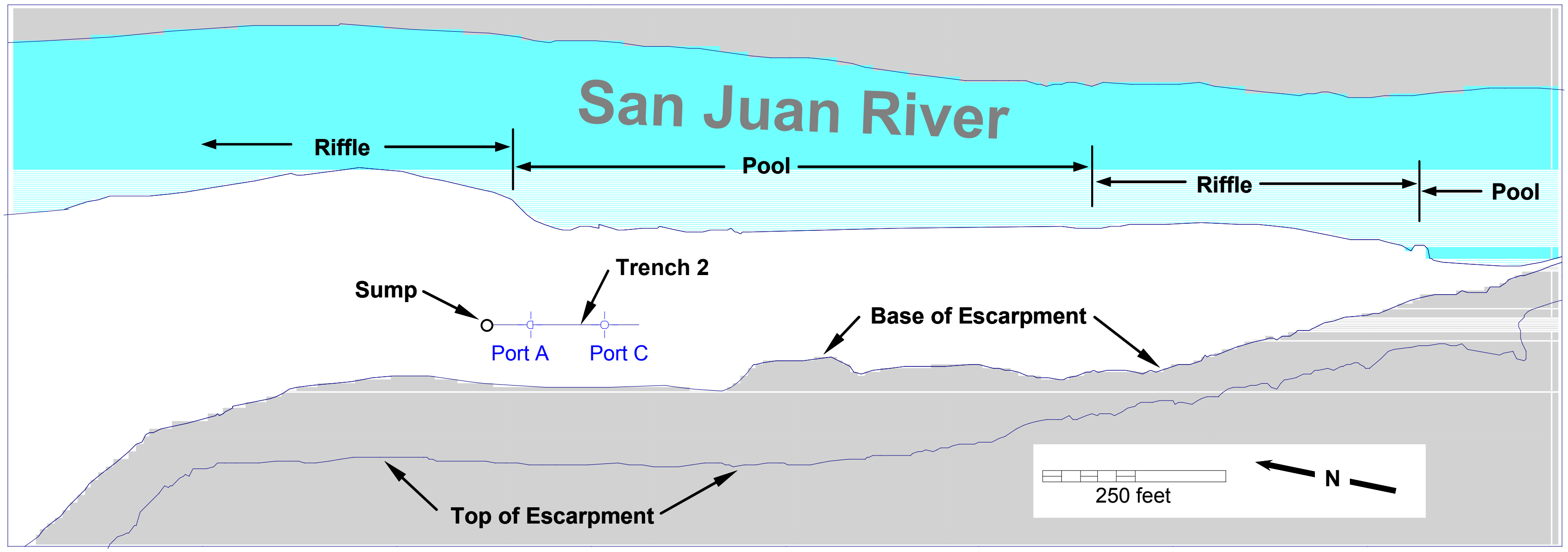

Figure 3. Trench 2 Study Area

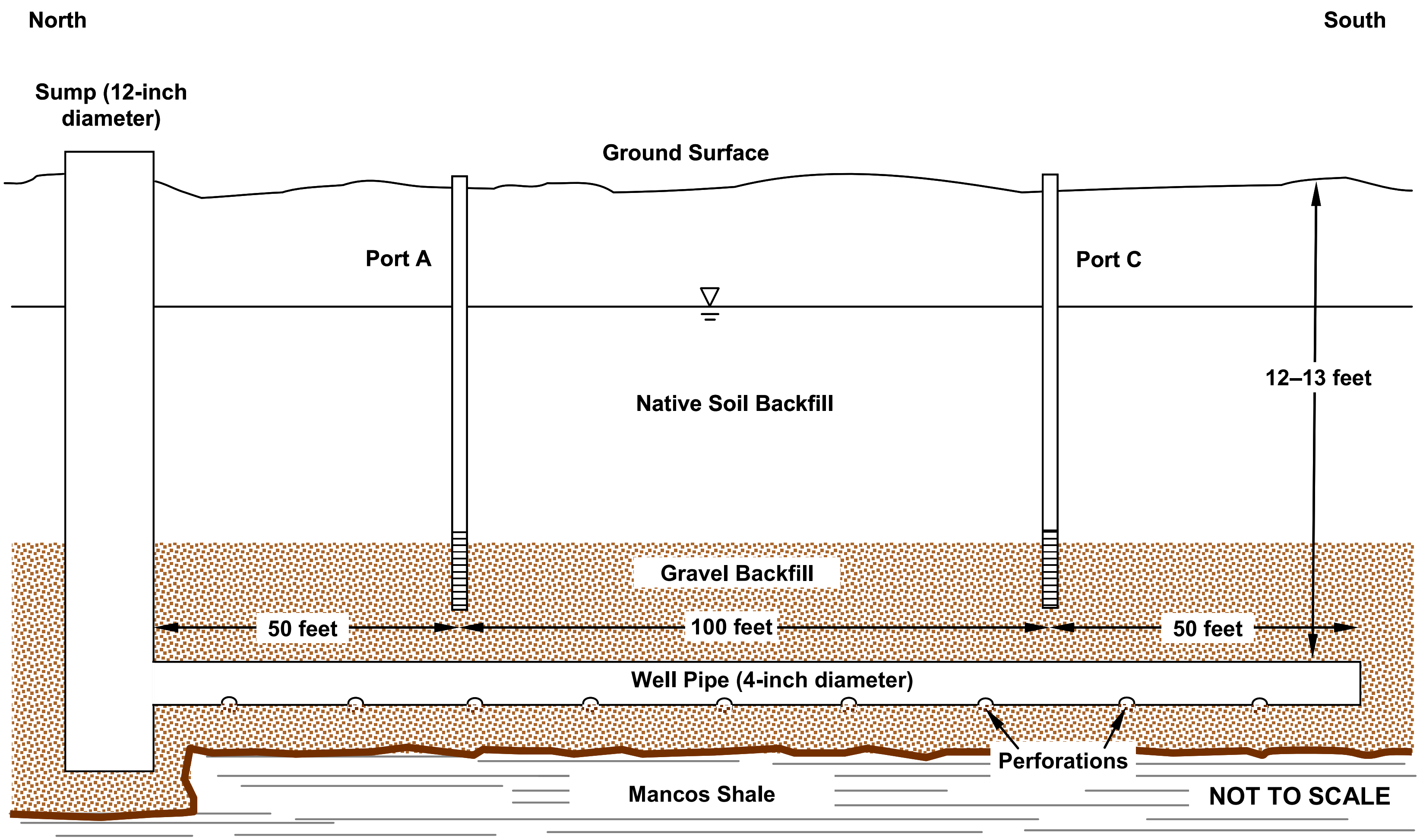

Figure 4. Cross-section Graphic of the Trench 2 Remediation System

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4.0 Groundwater Conceptual Model

4.1 Background Conditions

This study was planned using a conceptual model of groundwater flow and transport in the alluvial aquifer that was originally developed as part of the Site Observational Work Plan (SOWP) for the Shiprock Site (DOE 1999, 2000). That model was updated in 2004 (DOE 2004), and a few items regarding the exchange of water between the San Juan River and the alluvial aquifer have since been posited for this investigation. The conceptual model attributes the major source of groundwater in the aquifer to losses of surface water from the San Juan River along its west edge. Additional, but less significant, sources of water include infiltration and recharge of precipitation on the floodplain and discharge of bedrock groundwater to the alluvium, particularly near the base of the bedrock escarpment on the west side of the floodplain. Under background, non-pumping conditions, the combined groundwater from these sources flows north-northwestward, parallel to the river and the escarpment. Mixing of the contaminated water from the bedrock discharge with freshwater from local river seepage losses and recharge from on-site precipitation produces a relatively distinct spatial distribution of dissolved constituents within the study area. Specifically, the largest constituent concentrations are observed close to the bedrock escarpment and concentrations decrease quickly with proximity to the river.

In past examinations of floodplain processes, it has been assumed that all of the river water entering the subsurface via seepage losses near the southern end of the floodplain flows only within the alluvial aquifer before it is diverted back to the river near the Trench 1 location. Though it is likely that much of this influent water does remain within the alluvial aquifer before reaching the Trench 1 area, the potential for some of the river-derived groundwater to discharge back to the river within hundreds of feet downstream from where the seepage losses occur is also taken into account in this study. Speculation that these more localized flow patterns occur is based on observation of the distribution of surface water pools and riffles in the reach of the river bordering the study area (Figure 3). In accordance with groundwater flow patterns typically observed in floodplain systems abutting rivers (e.g., Winter et al. 2002), it is assumed in this study that river water typically seeps into an adjacent groundwater system near the downstream end of a pool preceding (upstream of) a riffle and then discharges back to the river near the downstream end of the riffle. Though such a flow pattern may not profoundly affect the flow budget of the affected groundwater system, it is possible that several biogeochemical reactions induced by the mixing of river water with background groundwater in a local “hyporheic” zone (Winter et al. 2002) could be affecting the quality of the water before it reaches the river. The effects of such reactions on the contaminated groundwater entering the floodplain aquifer from the Mancos Shale are worthy of examination.

Figure 5 presents a map view of the conceptual model of groundwater flow in the study area under background, non-pumping conditions, including flow patterns associated with local hyporheic zones. Figure 6 presents an additional view of the background-flow conceptual model in a cross section that traverses the floodplain in the vicinity of Trench 2. This schematic shows that, though most of the contaminated groundwater entering the floodplain alluvium does so via flow in shale bedding planes and fractures intercepting the alluvial aquifer along its west side, additional discharge to alluvium via fractures located closer to the river is possible. This latter conceptualization originates from water chemistry observations made as part of the SOWP (DOE 1999, 2000).

As depicted in Figure 6, the interface between the alluvium and the underlying Mancos Shale can be irregular. It is suspected that pre-historic flows of the river may have incised parts of the bedrock surface, creating paleochannels that were subsequently filled with coarse-grained sediments. The presence of such channels appears quite likely given that alluvial sediments underlying the floodplain consist mostly of relatively clean sands and gravels, which are typically the bedload deposits associated with high-energy environments of rapidly flowing streams and rivers. Characterization efforts at the Shiprock Site have attributed hydraulic conductivities as large as 100 feet per day (ft/day) to these sands and gravels (DOE 1999, 2000). At locations where relatively fine-grained deposits (silts and clays) are observed in the alluvium, they are typically seen in the uppermost 4 to 6 ft of sediment and are likely deposits left by overbank flow when the river occasionally floods. Though hydraulic conductivities of the fine-grained deposits are not explicitly measured, they are expected to be significantly smaller than those attributed to river-derived sands and gravels. During periods of average flow on the river, the top of the saturated zone in the floodplain aquifer tends to lie beneath the shallow silts and clays, but the upper part of the groundwater column does appear to flow within these finer materials during periods of peak river flow in the late spring and early summer.

4.2 Pumping Conditions

Groundwater flow when the Trench 2 system is pumped continuously for several days is conceptualized as converging on the trench from multiple directions (Figure 7). Because of the remediation system's proximity to the river, most of the water collected in the system after several weeks to months of pumping is expected to be induced seepage of surface water by the pumping and its subsequent migration to the trench (Figure 8). Much of the induced river seepage is expected to occur at significant distances south of the trench (Figure 7), from whence groundwater flows in a north-northwestward direction and eventually enters the Trench 2 well pipe. This latter flow pattern occurs because the quantity of water fed to the alluvial aquifer by Mancos Shale discharge is perceived to be much less than the water fed to the alluvium from the river. In association with this pumping-induced flow system, the largest concentrations of dissolved constituents would be observed close to the Mancos Shale escarpment and the lowest concentrations would be seen close to the river. After a sufficient period of pumping, constituent concentrations in alluvial groundwater lying directly between the trench and the river would be largely the same as those observed in river water.

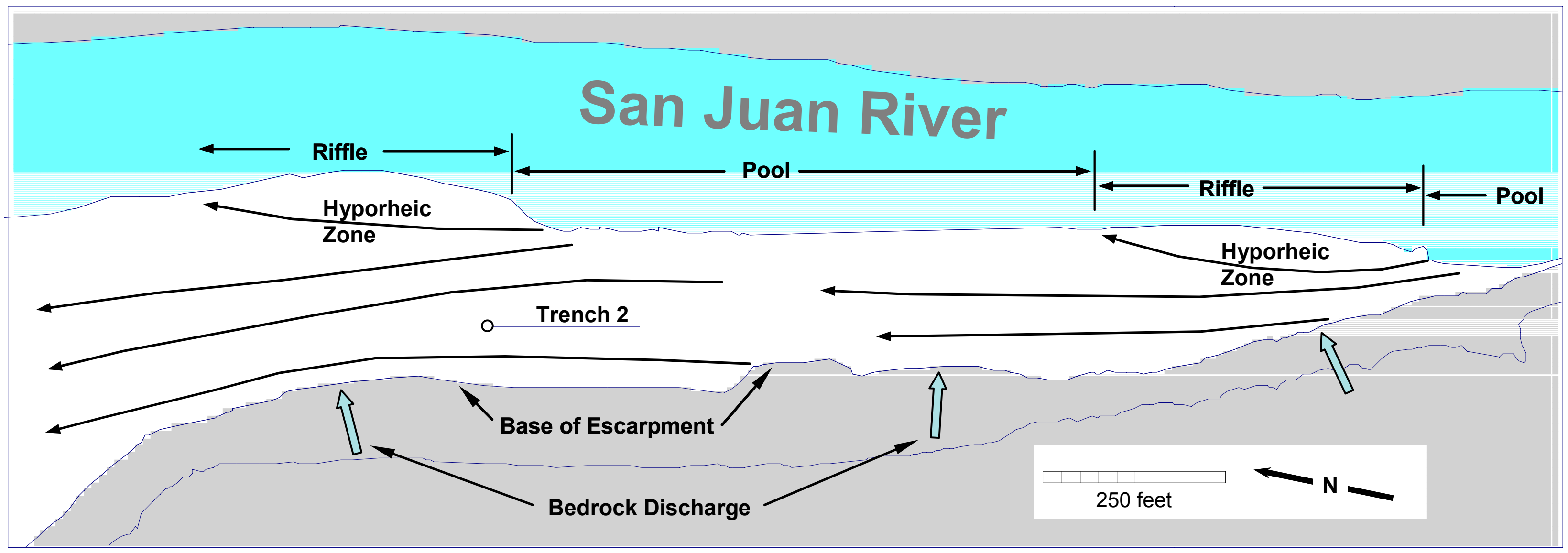

Figure 5. Map View of the Groundwater Conceptual Model for Background (Non-pumping) Conditions

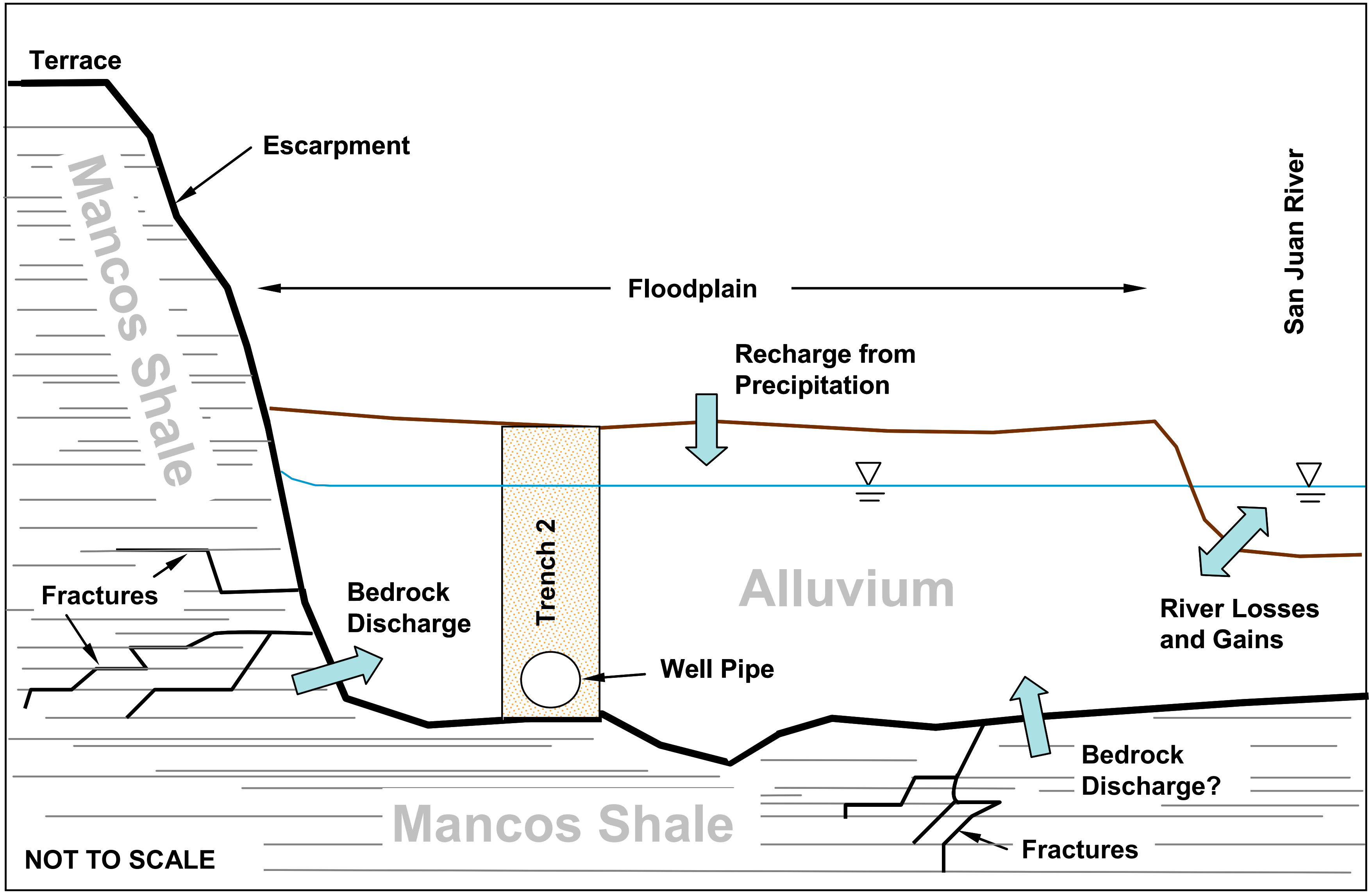

Figure 6. Cross-section View of the Groundwater Conceptual Model for Background (Non-pumping) Conditions

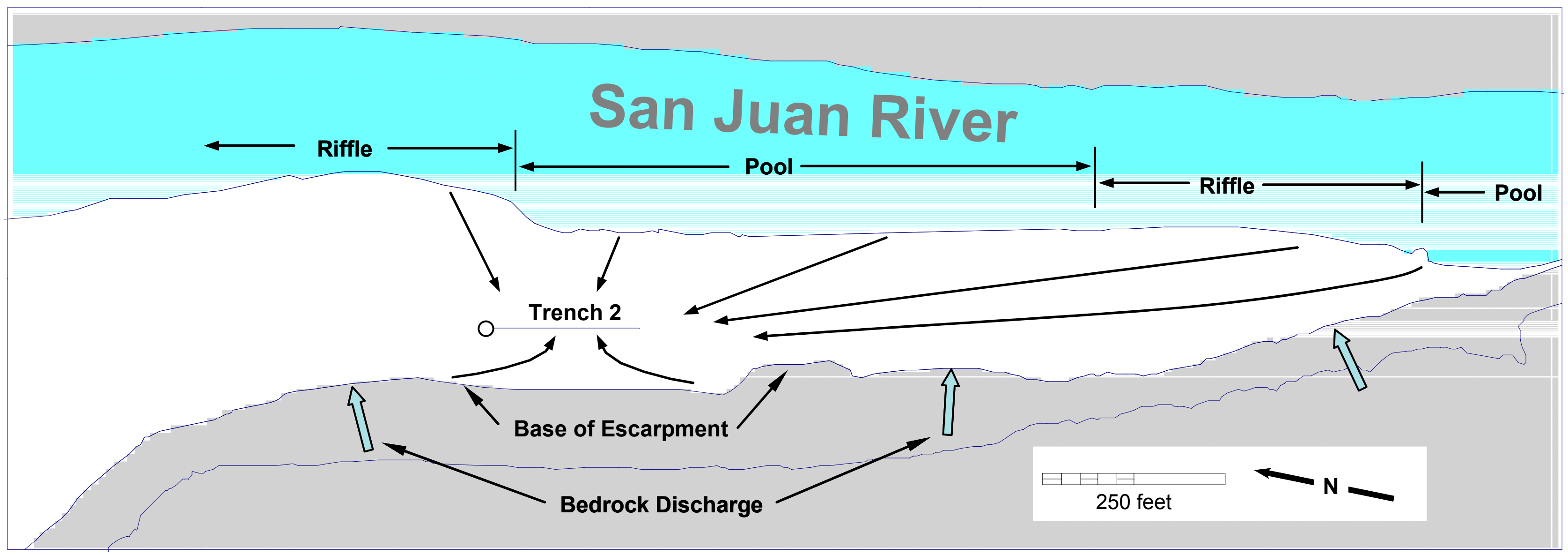

Figure 7. Map View of the Groundwater Conceptual Model as Affected by Trench 2 Pumping

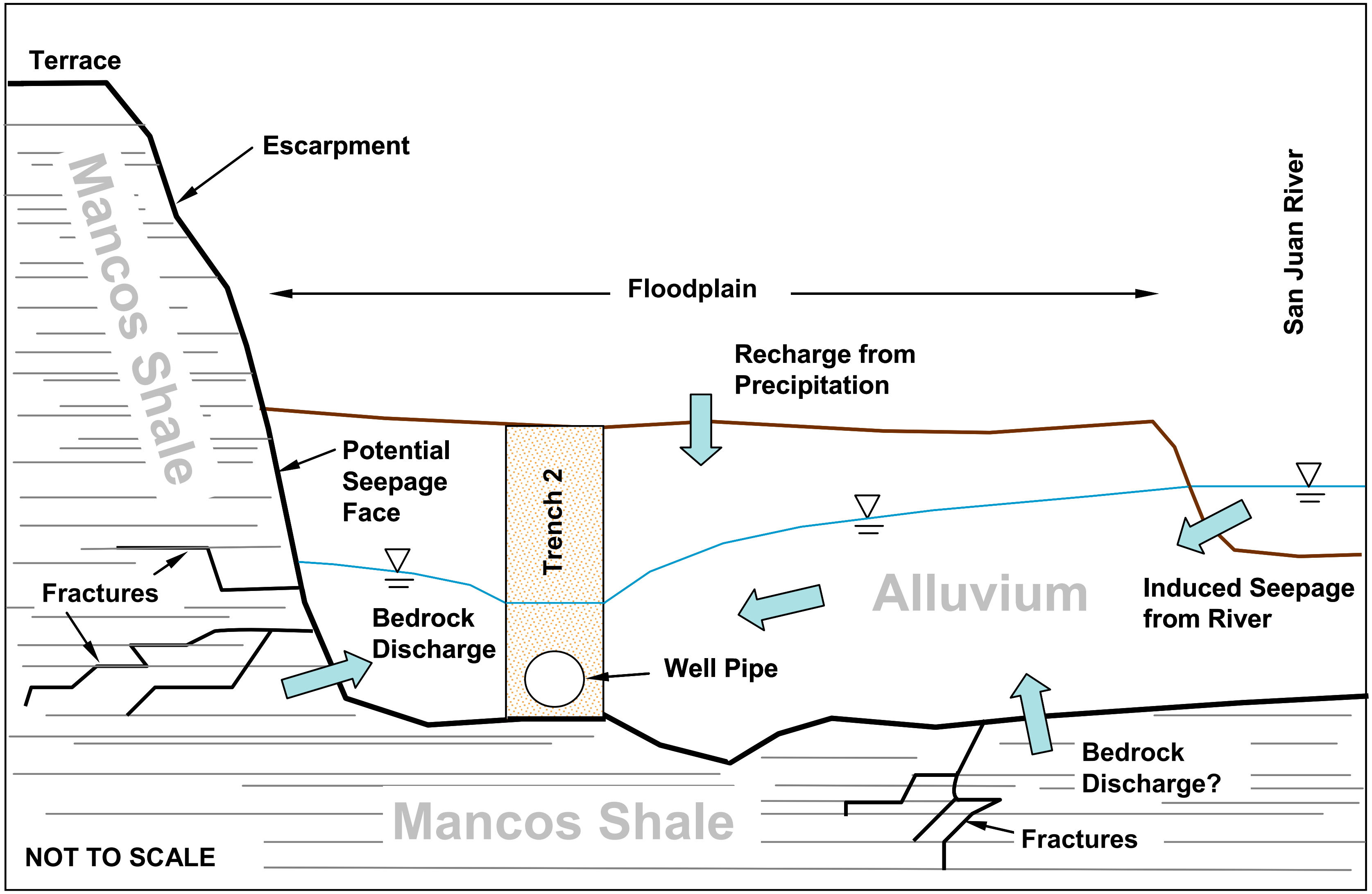

Figure 8. Cross-section View of the Groundwater Conceptual Model as Affected by Trench 2 Pumping

5.0 Information Sources

Numerous sources of information are used to perform this study. The site conceptual model of groundwater flow and transport, as originally discussed in the SOWP (DOE 1999, 2000) and subsequently upgraded (DOE 2004), provides information helpful for selecting locations for monitoring both groundwater levels and water chemistry. A previously developed computer model that accounts for groundwater flow from Mancos Shale beneath the terrace (DOE 2000) provides at least one estimate of the rate with which contaminated terrace groundwater passes from the Mancos Shale to the alluvial aquifer. Variations of this model in a subsequent report by Knight Piesold and Company (Knight Piesold 2002) illustrates how mechanisms for reducing the discharge of contaminated water from the Mancos Shale to the alluvial aquifer could improve overall groundwater quality adjacent to the San Juan River.

The Trench 2 evaluation is based heavily on water level, chemical and other data collected at multiple wells installed in floodplain alluvium around the trench location. Much of the water level data are gathered virtually continuously using sensors installed in the wells, data loggers that store the monitored information, and a telemetering system that transmits the data via telephone back to LM offices in Grand Junction, Colorado. This data collection system is called SOARS, an acronym for System Operation and Analysis and Analysis at Remote Sites. SOARS has provided data from the Trench 2 area since April 2006. Included in the types of data collected and made available through SOARS are groundwater levels, computed hydraulic gradients, pumping rates from the Trench 2 sump, and automated specific conductance measurements made with sensors installed in two wells and the sump.

Fifteen wells in the study area and the Trench 2 sump are monitored as part of SOARS. Most of the monitor wells in this category were installed specifically for the purpose of recording the effects of Trench 2 pumping. Four of the SOARS wells were installed in 2006 and the remaining 11 wells were installed during February 2007 Six wells in the Trench 2 study area are not monitored under SOARS. Water level data are collected at these locations on a periodic basis and placed in an LM database called SEEPro. The SEEPro database also contains construction information for the wells in the study area. Other than the above-mentioned automated specific conductance measurements at two wells and the Trench 2 sump, water chemistry data are collected only periodically during specific sampling events.

Figure 9 shows the locations of the wells that were used to perform this study and Table 1 summarizes construction information for each along with related information for the Trench 2 sump. Figure 9 shows that most of the monitoring locations are within 250 ft of Trench 2. Four wells—608, 609, 1113, and 1114—are located more than 250 ft north of the trench but provide useful information regarding local groundwater flow and transport. Similarly, Well 735, which is more than 750 ft south of the trench and near the study area's south boundary, provides water chemistry data that are considered representative of a mixture of waters from both groundwater discharge across the bedrock escarpment and river losses.

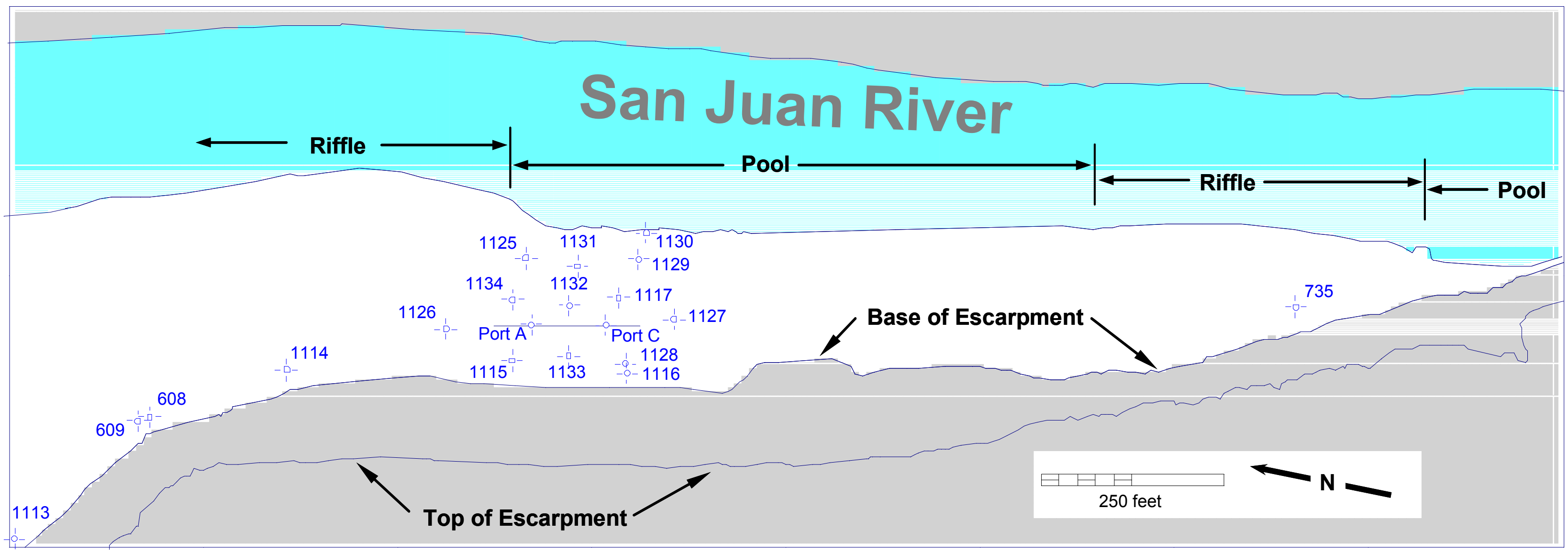

Figure 9. Wells Used to Evaluate Groundwater Flow and Transport in the Trench 2 Study Area

Table 1. Construction Information for Wells in the Trench 2 Study Area

Location	Date Installed	SOARS Location	Northing	Easting	Model x-coordinate	Model y-coordinate	Surface Elevation	Total Depth	Bottom Elevation	Screened Formations[1]	Depth to Bedrock	Bedrock Elevation
			(ft)	(ft)	(ft)	(ft)	(ft amsl)	(ft)	(ft amsl)		(ft)	(ft)
Trench 2 Sump	Apr-06	Yes	2100999.5	251932.4	629.73	293.00	4893.82	~14	~4880	NA	NA	NA
Port A	Apr-06	Yes	2100949.1	251942.9	681.23	292.92	4892.41	~8	~4884.5	Al	NA	NA
Port C	Apr-06	Yes	2100849.3	251963.4	783.07	292.55	4894.67	~10	~4884.5	Al	NA	NA
608	8/29/1985	No	2101434.9	251712.6	158.60	166.83	4891.67	19	4872.67	M	10	4881.67
609	8/30/1985	No	2101450.0	251704.9	142.19	162.42	4890.97	14	4876.97	Al, M	8	4882.97
735	3/26/1993	No	2099904.1	252193.7	1755.41	324.71	4894.53	9	4885.53	Al	NA	NA
1113	6/7/2006	No	2101586.1	251518.5	-29.09	7.78	4896.08	12	4884.08	Al	12	4884.08
1114	6/6/2006	No	2101265.0	251814.8	345.76	232.11	4890.92	12	4878.92	Al	12	4878.92
1115	6/6/2006	Yes	2100964.9	251890.0	654.96	244.41	4893.4	12	4881.4	Al	12	4881.40
1116	6/6/2006	Yes	2100805.0	251905.9	814.71	227.22	4896.39	12	4884.39	Al	12	4884.39
1117	6/6/2006	Yes	2100839.6	252003.7	800.76	330.04	4894.37	12	4882.37	Al	12	4882.37
1125	2/6/2007	Yes	2100974.9	252031.0	673.98	384.46	4893.75	11.57	4882.18	Al	11.57	4882.18
1126	2/6/2007	Yes	2101062.4	251913.9	564.35	287.70	4893.33	12.81	4880.52	Al	12.81	4880.52
1127	2/6/2007	Yes	2100759.4	251990.6	876.62	300.82	4894.81	14.41	4880.4	Al	14.41	4880.40
1128	2/6/2007	Yes	2100812.1	251919.4	810.52	241.91	4895.64	12.11	4883.53	Al	12.11	4883.53
1129	2/6/2007	Yes	2100824.2	252060.5	827.47	382.50	4893.56	10.58	4882.98	Al	10.58	4882.98
1130	2/6/2007	Yes	2100823.7	252111.3	838.43	432.12	4893.29	9.73	4883.56	Al	9.73	4883.56
1131	2/7/2007	Yes	2100903.1	252033.3	744.76	372.04	4892.63	10.55	4882.08	Al	10.55	4882.08
1132	2/7/2007	Yes	2100903.5	251977.9	732.95	317.85	4892.22	11.37	4880.85	Al	11.37	4880.85
1133	2/7/2007	Yes	2100891.9	251909.4	730.33	248.43	4894.42	11.54	4882.88	Al	11.54	4882.88
1134	2/7/2007	Yes	2100980.4	251968.2	655.70	324.12	4893.74	13.46	4880.28	Al	13.46	4880.28
											Average =	4882.1

[1] Al = floodplain alluvium, M = Mancos Shale

~ indicates an estimated value, NA = not applicable

As shown in Table 1, three wells – 608, 609, and 735 – were installed in the study area several years prior to Trench 2 construction. Pre-2006 data from these wells provide some insight into the nature of local groundwater flow and transport prior to changes that may be induced by pumping at Trench 2. Such data are valuable because a reliable conceptual model of pre-remediation conditions is important for assessing the efficacy of the Trench 2 groundwater remedy.

Three information sources in addition to those regarding the monitor wells mentioned above have been very helpful in this study. One of these comprises daily river flows measured at a U.S. Geological Survey (USGS) gaging station on the Shiprock Site, on the west bank of the San Juan River about 2,200 north of (downstream of) Trench 2 (Figure 2). The river flow data are available on the following USGS web site:
(http://waterdata.usgs.gov/nm/nwis/dv/?site_no=09368000&referred_module=sw)

The second consists of chemical data for water sampled from shallow non- well points that were installed in the alluvial aquifer (DOE 1999, 2000) in the late 1980s, prior to the construction of Trench 2. The third consists of water chemistry data from six shallow test pits dug near the base of the bedrock escarpment in 1999 and sampled once at that time. The spatial coordinates of the shallow well points and test pits are listed in Table 2 and their locations are shown in Figure 10.

Graphical analyses of the data assembled for this study are used in subsequent report chapters to conduct most of the evaluation of Trench 2 performance and to characterize groundwater flow in the study area. The numerical model of groundwater flow and associated contaminant transport is used to match much of the collected data with the objective of providing further insight to the remediation system's performance.

Table 2. Shallow Well Points and Test Pits in the Trench Study Area

Location	Date Installed	Northing (ft)	Easting (ft)	Model x-coordinate (ft)	Model y-coordinate (ft)
Well Point 645	Mar-87	2100670.5	252104.62	986.97	394.28
Well Point 646	Mar-87	2100610	252118	1048.93	395.00
Well Point 647	Mar-87	2100547.4	252118.53	1110.36	382.71
Shallow Trench 1015	Dec-99	2099930.3	252175.59	1726.10	312.37
Shallow Trench 1016	Dec-99	2100242.7	252133.61	1411.69	335.16
Shallow Trench 1017	Dec-99	2100569.1	252019.05	1068.78	289.77
Shallow Trench 1018	Dec-99	2100908.3	251924.26	717.34	266.35
Shallow Trench 1019	Dec-99	2101245.2	251837.42	369.75	250.25
Shallow Trench 1020	Dec-99	2101520.1	251622.73	56.77	96.31

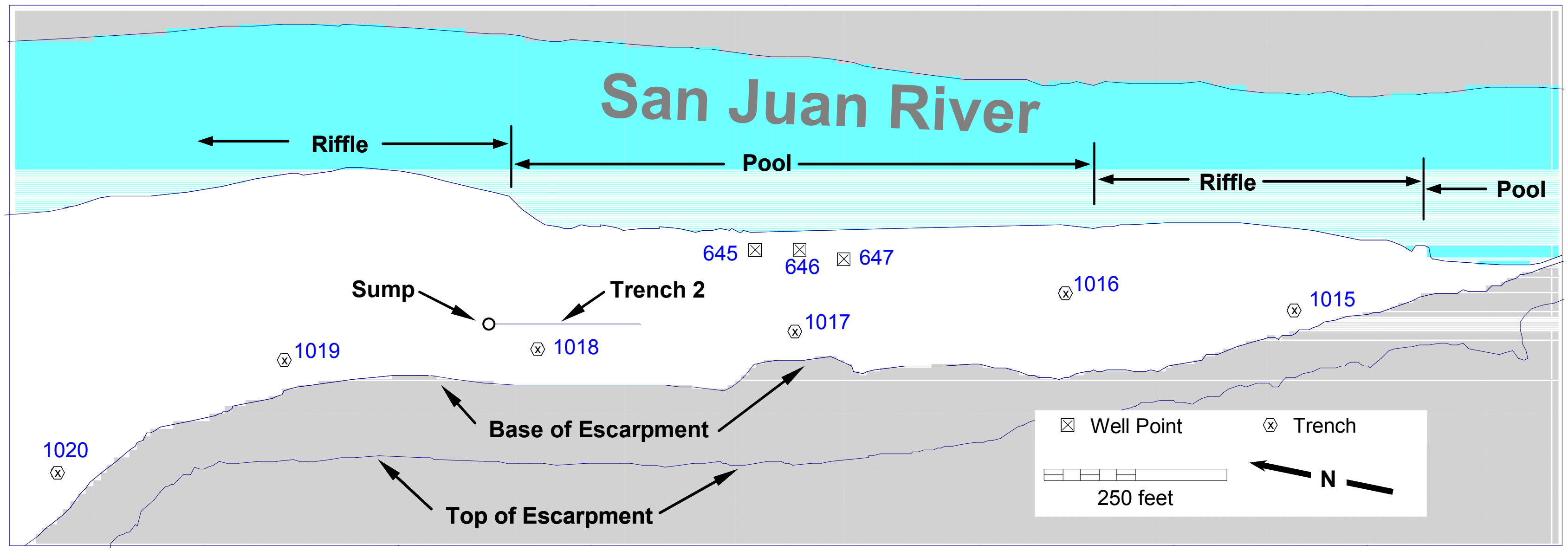

Figure 10. Shallow Well Points and Test Pits in the Trench 2 Study Area Prior to 2006

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6.0 Data Analysis

6.1 Time Horizon

Some of the data examined in this Trench 2 evaluation were collected prior to the installation of the remediation system in early 2006, but the vast majority of the data was collected since pumping of the trench was initiated in April 2006. Data analysis in this and succeeding report chapters covers a period extending through mid-September 2007.

6.2 Groundwater Elevations

6.2.1 Non-pumping Conditions

The groundwater levels that typically occur in the alluvial aquifer during background, non-pumping conditions were identified by examining historical measured water elevations, using units of feet above mean sea level (ft amsl), in Wells 608, 609, and 735 (Figure 9). As previously discussed, these wells were installed prior to 2006 and data have been collected from them over multiple-year time spans. Though additional sources of water level information were considered for this purpose, they were found to either be unreliable indicators of typical water elevations or of limited utility. For example, water levels presented in SEEPro for Well Points 645, 646, and 647 (Figure 10), measured during the years 1987 and 1989, were not used because they were consistently larger than all other levels reported for wells in the study area. The consistently larger elevations reported for the well points suggested that they were based on a datum that differed from the one used for most surveys at the site. Similarly, several water elevations in 2006 and 2007 reported for Well 1114, about 300 ft from Trench 2 (Figure 9), were not considered representative of background conditions because they appeared to be affected by trench pumping. In addition, water level information for Well 1113, at the base of the bedrock escarpment near the north boundary of the study area (Figure 9), was limited to a single value.

A plot of measured water elevations in Wells 608, 609, and 735 from 1985 through mid-September 2007 (Figure 11) illustrated how hydraulic heads in the alluvial aquifer can fluctuate over time and the magnitude of water level differences between the southern and northern parts of the study area. Though Well 608 is screened in the Mancos Shale (Table 1), data for this monitoring site were included in the temporal plot because the length of its record is larger than that for Well 609, which is partially screened in the alluvial aquifer at about the same location. Comparison of water-level measurements at the two wells indicated that they can differ by as much as 0.5 ft, but they generally track each other and are typically about the same value. On the basis of this observation, the decision was made to use the more plentiful Well 608 data to characterize background groundwater elevations about 500 ft north of Trench 2.

Analysis of the data graphically presented in Figure 11 showed that measured groundwater levels elevations at Well 608 varied between 4886.03 and 4889.39 ft amsl between September 1985 and mid-September 2007, and averaged 4887.34 ft amsl. At Well 735, measured water elevations from April 1993 through mid-September 2007 ranged from 4888.35 to 4892.53 ft amsl, and averaged 4889.36 ft amsl. On the basis of these data, it was surmised that groundwater elevations in the near vicinity of Trench 2 have the potential to range from 4886 to 4892 ft amsl.

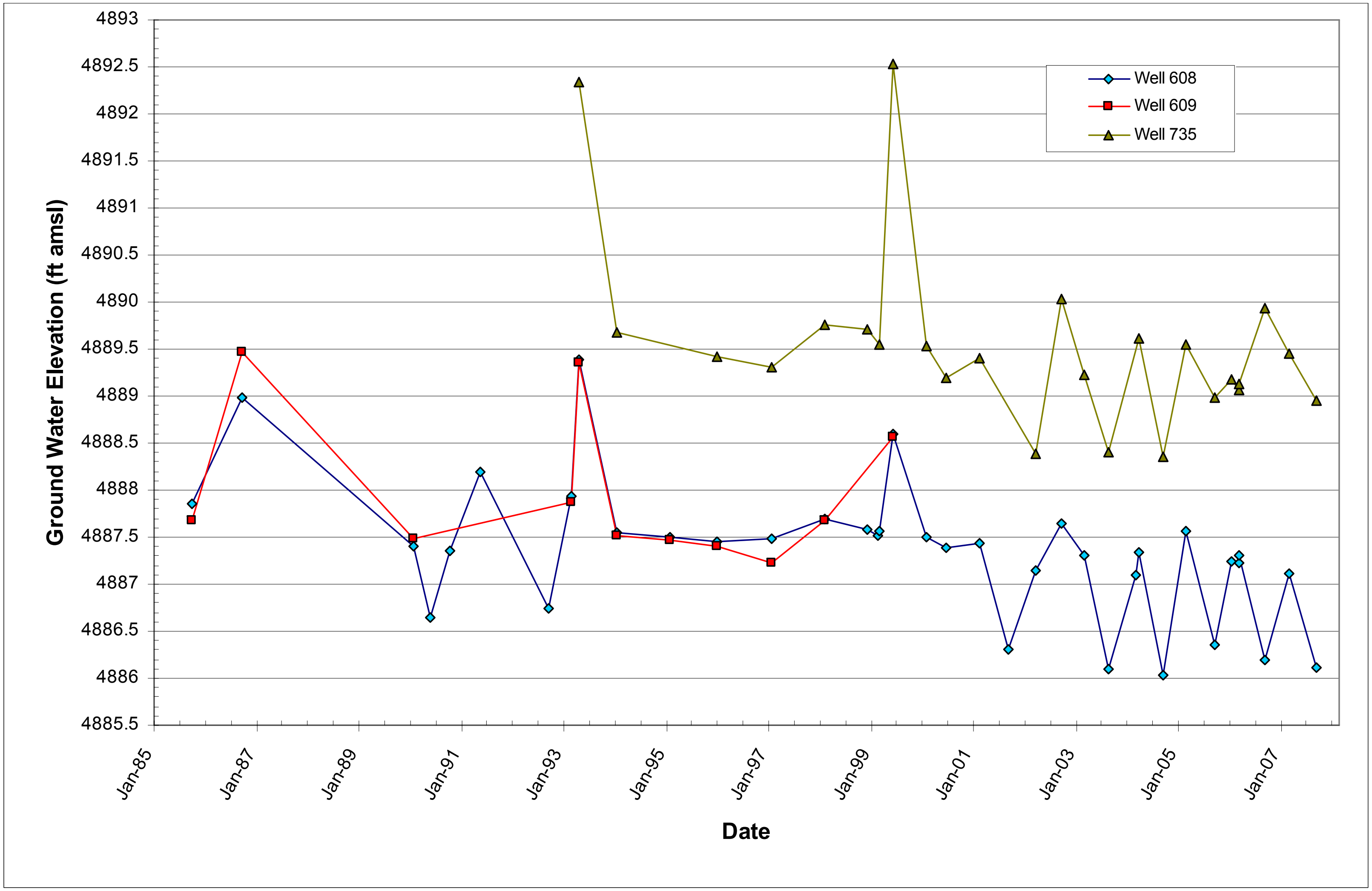

Figure 11. Measured Water Elevations in Wells 608, 609, and 735 from 1985 to mid-September 2007

Further analysis of measured water elevations collected at Wells 608 and 735 revealed that, when the data were collected at both wells during individual sampling events, the difference in their water levels ranged from 1.24 to 3.93 ft. Dividing these respective differences by the approximate distance between Well 608 and 735 (1,610 ft) resulted in computed hydraulic gradients between the wells ranging from 0.00077 and 0.00244 (dimensionless). Such a large range in hydraulic gradient suggested that variable flow conditions in the river and between the river and alluvial aquifer had the potential to radically change flows through the aquifer between the northern and southern boundaries of the study area.

6.2.2 Pumping Influences

To assess possible groundwater elevations in the vicinity of Trench 2 during times of pumping, daily water levels at two locations during 2007 were examined. The first set of data was drawn from Well 1130, on the west bank of the river and directly east of the trench (Figure 9), and was limited to days when the remediation system was being pumped. The second data set was based on continuously collected water levels at Port A, located directly over the trench. The tabulated results showed that water elevations varied from 4887.64 to 4892.32 ft amsl on the river's west bank, and from 4884.97 to 4888.83 ft amsl at Port A. Differences between the average daily water levels on days when both wells were monitored ranged from 1.50 to 3.70 ft, and averaged 2.83 ft. These latter results suggested that, during periods of relatively high pumping rate, the difference in hydraulic head between the river east of the trench and the trench area itself could be as large as 4 ft.

6.3 Bedrock Elevations

Well logs were used to determine top-of-bedrock (i.e., top of the Mancos Shale) elevations at the locations of several of the wells used in the study. In some cases, these elevations were reported explicitly in the well logs; at others, particularly in cases where the well was installed using a Geoprobe, field reports suggested that the local bedrock elevation could be estimated from the total well depth, as drilling was terminated upon encountering the hard bedrock surface. Because the reported total depths for many of the wells drilled using the Geoprobe method were rounded to the nearest foot, the top-of-bedrock elevations derived from such depths could only be considered approximate. Nonetheless, inspection of both the reported and derived bedrock elevations helped provide insight regarding potential groundwater flow conditions in the area.

The resulting elevations, listed in Table 1, indicate that the local bedrock surface beneath the floodplain in the vicinity of Trench 2 can vary by as much as 4 ft. The spatial distribution of these elevations, shown in Figure 12, suggests that some of the lowest elevations occur in the near-vicinity of the trench and some of the highest elevations occur close to west bank of the river and near the escarpment. Though these results might indicate that a paleochannel is aligned with the trench, it is difficult to translate the trends shown in Figure 11 to areas located away from the trench.

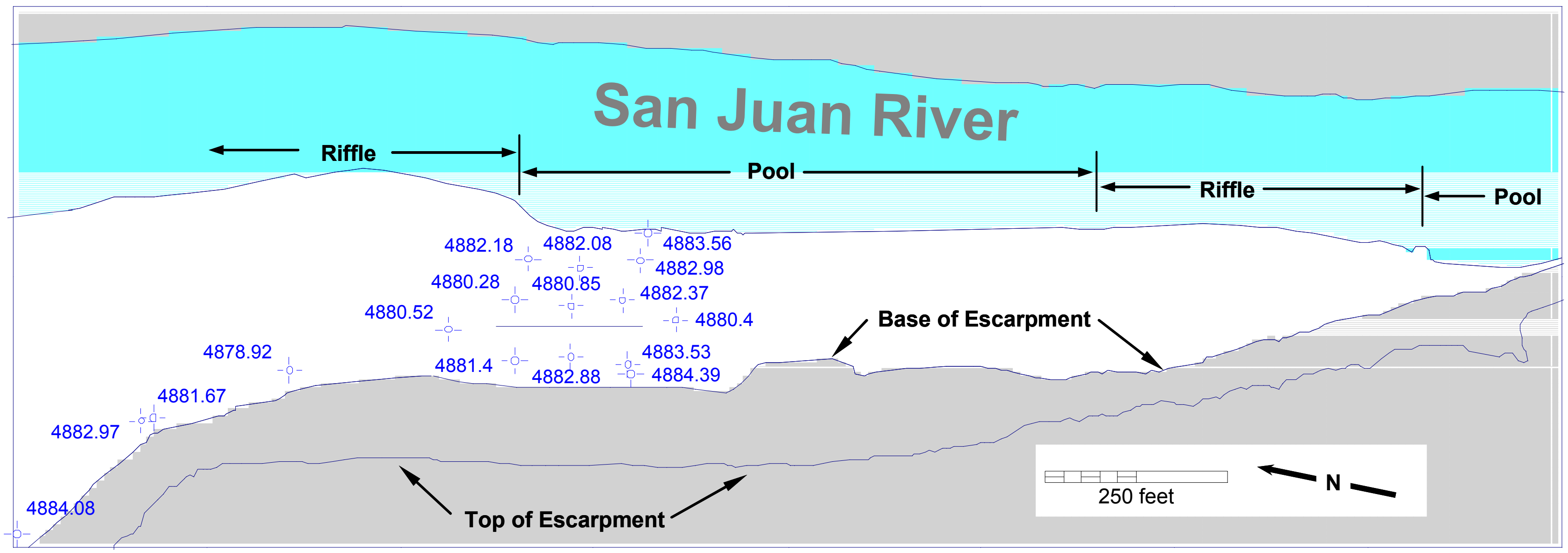

Figure 12. Estimated Bedrock Elevations (ft amsl) in the Trench 2 Study Area

Assuming that the elevation of the top of the saturated zone in the vicinity of the trench averages about 4,889 ft amsl, the top-of-bedrock elevations shown in Table 1 indicated that the saturated thickness of the aquifer under average flow conditions could vary from about 5 to 9 ft. Despite the fact that increases in water elevation accompany periods of high river flow in the late spring and early summer, these limited thicknesses inferred that the capacity for groundwater flow would vary significantly between areas where the bedrock surface is relatively deep and those where it is relatively shallow. Such flow variations would occur in response to spatial differences in saturated thickness even if alluvial sediments comprising the floodplain aquifer were relatively homogeneous.

6.4 Hydraulic Evaluation

Both automated data collection and manual measurements of physical parameters made it possible to evaluate groundwater hydraulics in the Trench 2 area. The information stemming from automated monitoring systems included water level data collected at five-minute intervals at several observation wells, pumping rates on five-minute intervals at the Trench 2 sump, and water stage measurements at the USGS river gaging station located a short distance north of the study area (Figure 2). Water levels at wells and the Trench 2 pumping rates were translated into daily average values for the purposes of this study, and surface water variations were tracked using reported average daily river flows.

Periodic manual measurements of water level dating back to as early as December 2006 are presented in Table A-2, Appendix A. Tabulations of daily water levels at several wells for the period between March 28, 2007 and September 14, 2007 are presented in Table A-1, Appendix A. Table B-1 in Appendix B lists computed average daily pumping rates at the Trench 2 sump between April 6, 2006 and September 15, 2007 and average daily flows of the San Juan River during the same time span.

6.4.1 Non-Pumping Conditions

Groundwater levels measured under non-pumping conditions were examined to ascertain whether conceptualized background groundwater flow patterns (Figure 5) were representative of the Trench 2 study area. In most cases, the data relied upon for this assessment was taken from Wells 608, 609, and 735 because these wells were the only local monitoring locations that were available prior to the start of Trench 2 pumping. However, some additional indications of background groundwater conditions were found in continuously collected water level data near Trench 2 over an 18-day period (April 13, 2007 through May 1, 2007), during most of which Trench 2 was not pumped. The little bit of pumping that did occur during this period took place on April 27, at which time the average daily flow was limited to 0.48 gallons per minute. Manual measurements of water level were also made at 16 wells during this period on April 30 and May 1.

Inspection of these data did indeed indicate that hydraulic gradients were oriented parallel to the river and the escarpment at times when no pumping occurs in the Trench 2 study area. Because the available information consisted of measured water levels either at the numerous wells centered around Trench 2 horizontal wells or in vertical wells at scattered locations in the study area, it was impossible to discern whether groundwater discharge to the river occurs locally, such as at the downgradient ends of each of the potential local hyporheic zones identified in Figure 5 or elsewhere.

6.4.2 Effects of Pumping

Inspection of monitored water levels at the numerous wells surrounding Trench 2 at times when the trench was pumped during 2006 and 2007 indicated that, as conceptualized, groundwater flow was convergent toward the trench when the remediation system was operational. However, lack of data near the river both northeast and southeast of the trench made it impossible to estimate the total river reach over which surface water seepage into groundwater was induced by trench pumping. It was expected that subsequent groundwater modeling would help to provide estimates of the spatial distribution of these processes.

6.4.3 Remediation System Efficiency

Evaluation of the hydraulic efficiency of the Trench 2 system was achieved by comparing continuously collected water levels in the system sump on the trench's north end with simultaneous water levels measured at Port A. As shown by the location of Port A in Figures 3 and 9 (approximately 50 ft south-southeast of the sump) and indicated by its approximate depth (Figure 4 and Table 1), changes in groundwater level at this well would be expected to closely track those measured in the sump if the system was working as expected. It was anticipated, however, that the Port A water levels would slightly exceed those at the sump because the gravel fill surrounding this well's screen (Figure 4) provides groundwater to the well pipe feeding the sump. If the water levels measured at Port A differed from those in the sump by just a few tenths of a foot, it could be concluded that there was little resistance to flow from groundwater into the well pipe via its perforations, and that the system was relatively efficient. Alternatively, differences of a foot or more between the simultaneously measured sump and water elevations would indicate that the system was inefficient.

As shown in Figure 13, the two sets of water level data did indicate that the system is relatively efficient. Changes in water level at Port A did track those at the Trench 2 sump between March 28, 2007 and September 14, 2007, and Port A water elevations were typically only about 0.2 to 0.4 ft above the sump equivalents. The largest differences between the two water elevations tended to be observed when water levels were at their lowest, which were also the times at which pumping rates were at their greatest. Such a result was expected given that friction losses increase with increasing groundwater velocities.

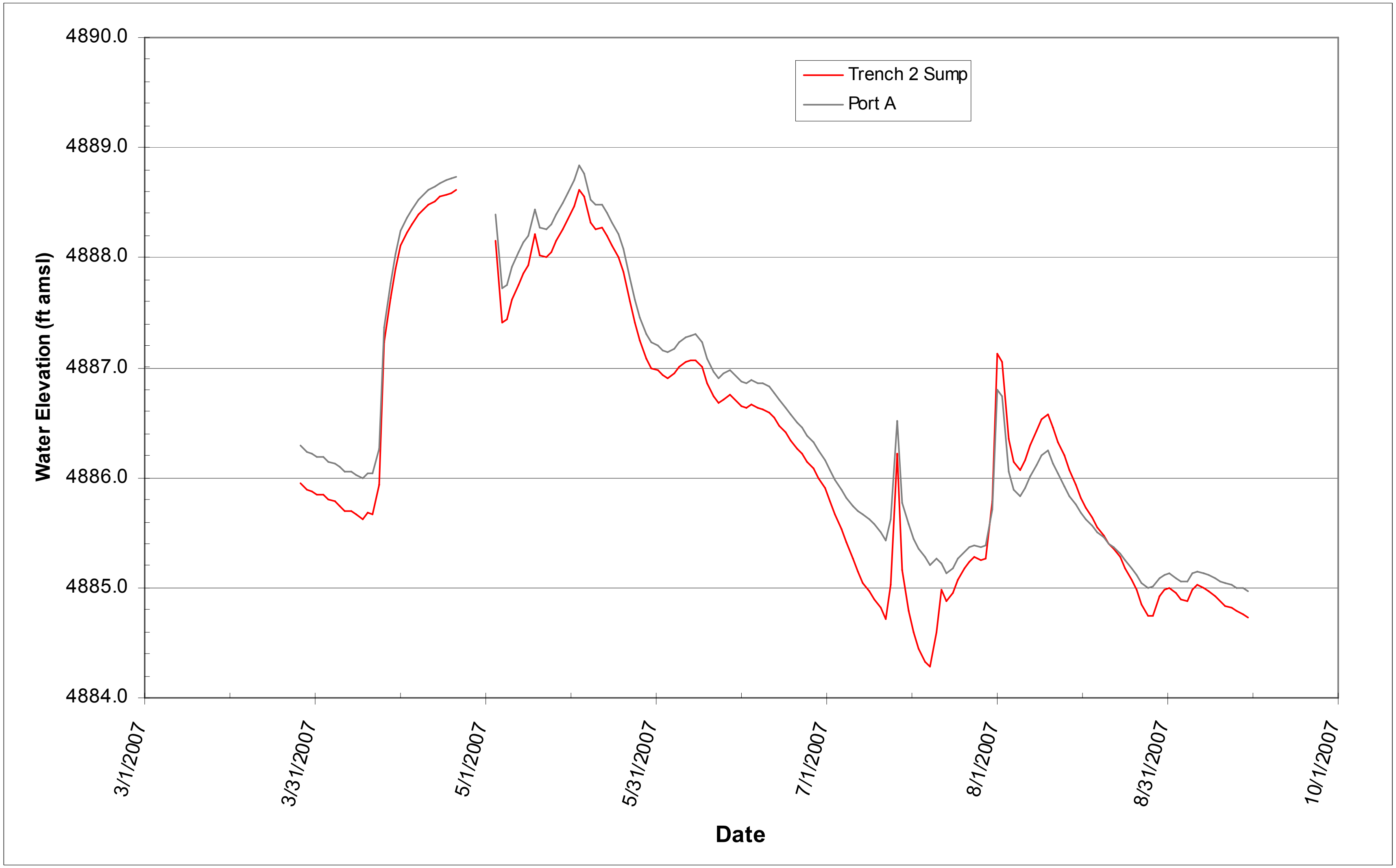

Figure 13. Measured Water Elevations at the Trench 2 Sump and Port A

Of some interest is the fact that Figure 13 shows water levels in the sump being unexpectedly higher than those at Port A during a several-day period in July 2007. Recalibration of the sensors used to measure groundwater elevations at these locations was necessary at the time so that water levels at Port A, as expected, were larger than those in the sump.

6.4.4 River Influences on Groundwater Levels

Groundwater levels measured in the Trench 2 Area during the study period showed that water elevations in wells clearly rise and fall in response to changes in the stage of the San Juan River, which is positively correlated to flow in the river. Manual measurements of water level in wells installed in 2006 (Ports A and C, Wells 1113-1117) (see Table A-2, Appendix A) showed such responses to corresponding mean daily river flows (Table B-2, Appendix B), as did the automatically recorded water levels in wells installed in spring 2007 (Wells 1125-1134) (see Table A-1, Appendix A). Though it was impossible to measure the effects of changes in river stage on the quantity of water flowing through the floodplain aquifer at any given time on the basis of measured water levels alone, it was expected that computer modeling of the groundwater system at selected times within or over multi-month periods exhibiting river flow variations would likely help to identify the effects. To facilitate such modeling, both in this investigation and possibly in future studies, the relationship between water levels in Well 1130, which is located on the west bank of the river east of Trench 2 (Figure 9), and daily average river flows was analyzed.

The close proximity of Well 1130 to the river suggested that it could be used similarly to a stilling well at a river gaging station that monitors instantaneous stage in the river, such that the combination of stage and flow data comprised a flow rating curve (Mosley and McKerchar 1992). This similarity was partly attributed to the fact that water levels in the well would typically be mediated by river stage, thus making them less susceptible to decreases when Trench 2 was being pumped in comparison to wells located closer to the trench. To further examine this possibility, a plot was prepared of average daily river flows and corresponding water levels in Well 1130 for the period between March 1, 2007 and September 15, 2007. The resulting graph, shown in Figure 14, clearly indicated a correlative relationship between the two data sets, but the relationship appeared to change with time. That is, the same river flow at different times tended to result in noticeably different measured water levels in Well 1130.

The changing relationship between near-river groundwater elevation and river flow was further examined in a scatter plot of Well 1130 water levels and average daily river flow (Figure 15), from which potential flow rating curves could be discerned. Inspection of this plot showed that data collected between March 27, 2007 and July 14, 2007 resulted in flow rating information that was distinctly different from similar information associated with dates after July 14, 2007. Furthermore, variations of as much as 0.5 ft in Well 1130 water levels for the same river flow in the pre-July 15 data suggested that factors such as temporally varying riverbed permeability during the spring and early summer of 2007 may have significantly affected water levels in the well. Nonetheless, it did appear that the data represented in Figure 15 could be used to develop two separate rating curves that would be helpful in developing numerical models of groundwater flow in the study area.

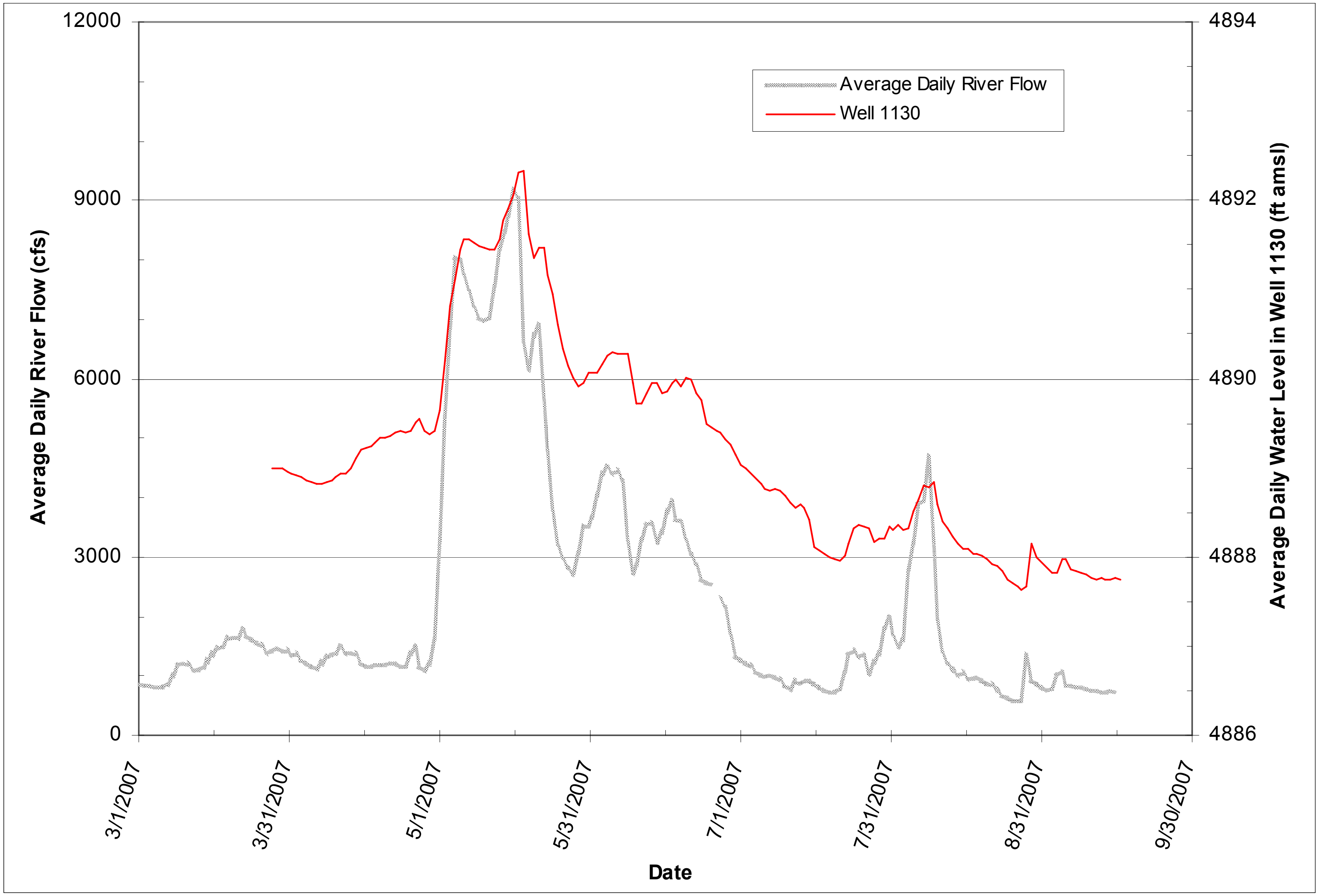

Figure 14. Average Daily Flows in the San Juan River and Water Elevations in Well 1130

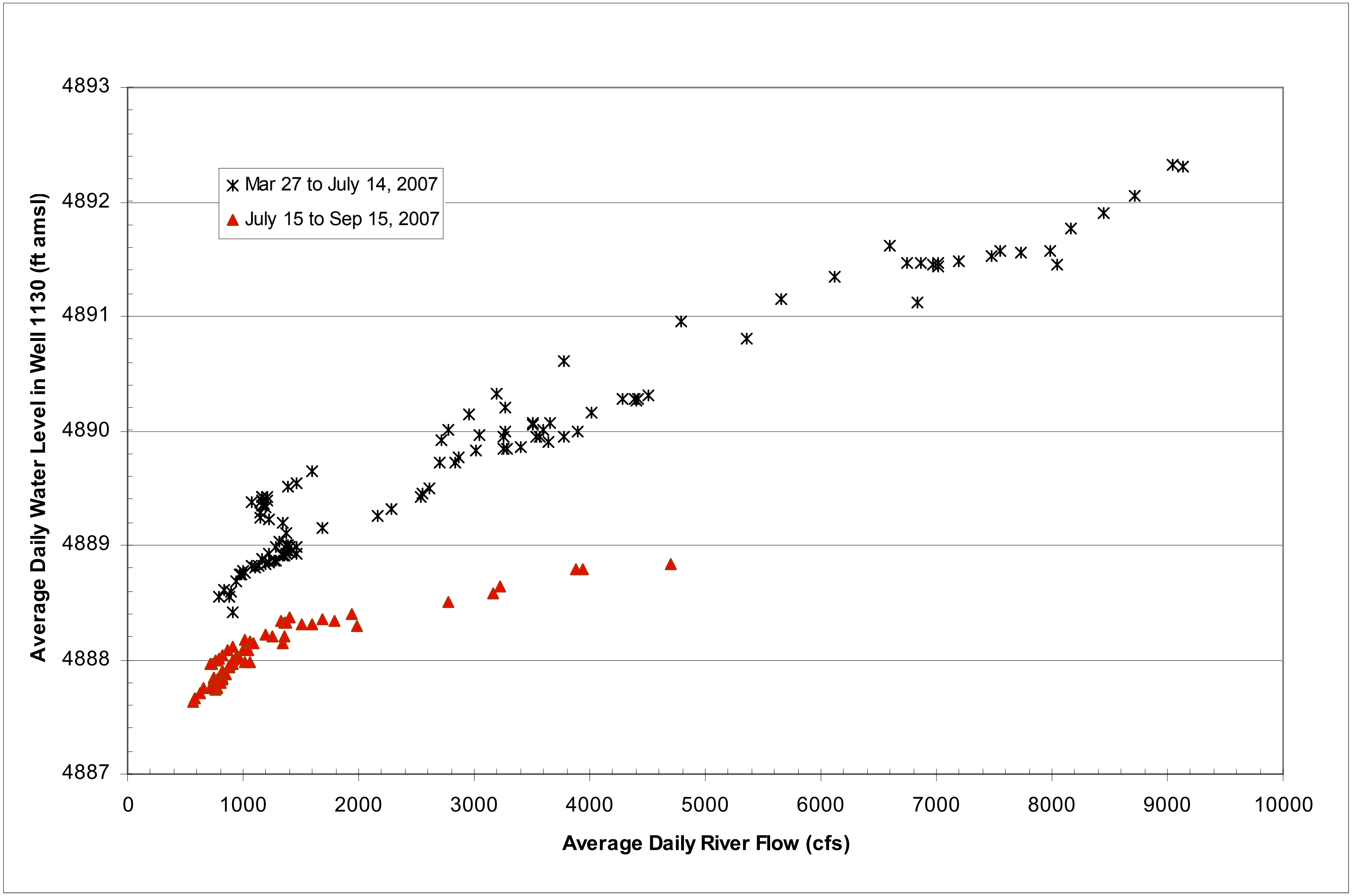

Figure 15. Scatter Plot of Average Daily Water Elevations in Well 1130 and Average Daily Flows in the San Juan River

The two apparent rating curves were used to surmise how groundwater elevations near Trench 2 could vary during periods of "average" flow in the river. The average daily discharge of the San Juan River at the Shiprock gaging station is 2,150 cfs. Inspection of Figure 15 indicated that, during the spring and summer of 2007, this flow could have been associated with groundwater elevations near the west bank of the river that ranged from about 4888.4 ft amsl to 4889.4 ft amsl.

6.5 Water Chemistry

Groundwater chemistry and river quality data collected from as far back as the late 1980s as well as more recent chemical data specifically associated with Trench 2 monitoring were examined to evaluate the applicability of the site conceptual models presented in Sections 4.1 and 4.2 and graphically portrayed in Figures 5 through 8. This evaluation took into consideration measured concentrations of dissolved groundwater constituents during periods of no pumping at Trench 2 to see whether discharge of Mancos Shale groundwater on the west side of the floodplain produced generally larger concentrations near the Mancos Shale escarpment and gradually decreasing concentrations toward the east and the river. Temporal plots of constituent concentrations over multi-month time spans at the various wells designed to monitor Trench 2 performance were used to assess both gradual and relatively rapid effects that trench pumping had on water chemistry.

6.5.1 Non-Pumping Conditions Prior to 2006

The spatial distribution of groundwater salinity under background, non-pumping conditions was evaluated by examining specific electrical conductance (specific conductance) at several monitoring locations that were present before the installation of Trench 2. These locations consisted of Wells 608, 609, and 735 (Figure 9), three shallow well points (645, 646, 647) near the river (Figure 10), and six test pits (1015 through 1020) near the base of the bedrock escarpment (Figure 10). Electrical conductance was used for this purpose because specific conductance serves as an indicator of summed dissolved constituent concentrations. Studies of natural water chemistry (e.g., Hem 1989) have shown that total dissolved solids (TDS) concentrations in units of milligrams per liter (mg/L) can be estimated by multiplying measured specific conductances in units of millisiemens per centimeter (mS/cm) by 700.

In accordance with the site conceptual model of background groundwater chemistry in the aquifer (Section 4.1), specific conductance prior to implementation of the Trench 2 remediation system was hypothesized to be largest near the Mancos Shale escarpment and decrease quickly toward the river. A tabular summary of pre-2006 specific conductance data (Table 3) and a map view of those data (Figure 16) showed that this was generally the case. Wells 608 and 609 and five of the shallow test pits (1016 through 1020), which are located near the base of the escarpment (Figure 9), ranged from about 6 to 38 mS/cm. In contrast, specific conductance values measured at well points 645, 646, and 647, each near the river's west bank, ranged from about 0.3 to 1.8 mS/cm. At Well 735, located south of Trench 2 in the area where the southernmost pool on the river is likely to contribute surface water to the alluvial aquifer (Figure 16), specific conductance values spanned a large range (2 – 24 mS/cm). This observation suggested that salinity of groundwater in vicinity of Well 735 varied with time, reflecting the mixing of different proportions of bedrock-derived contaminated water and relatively fresh water

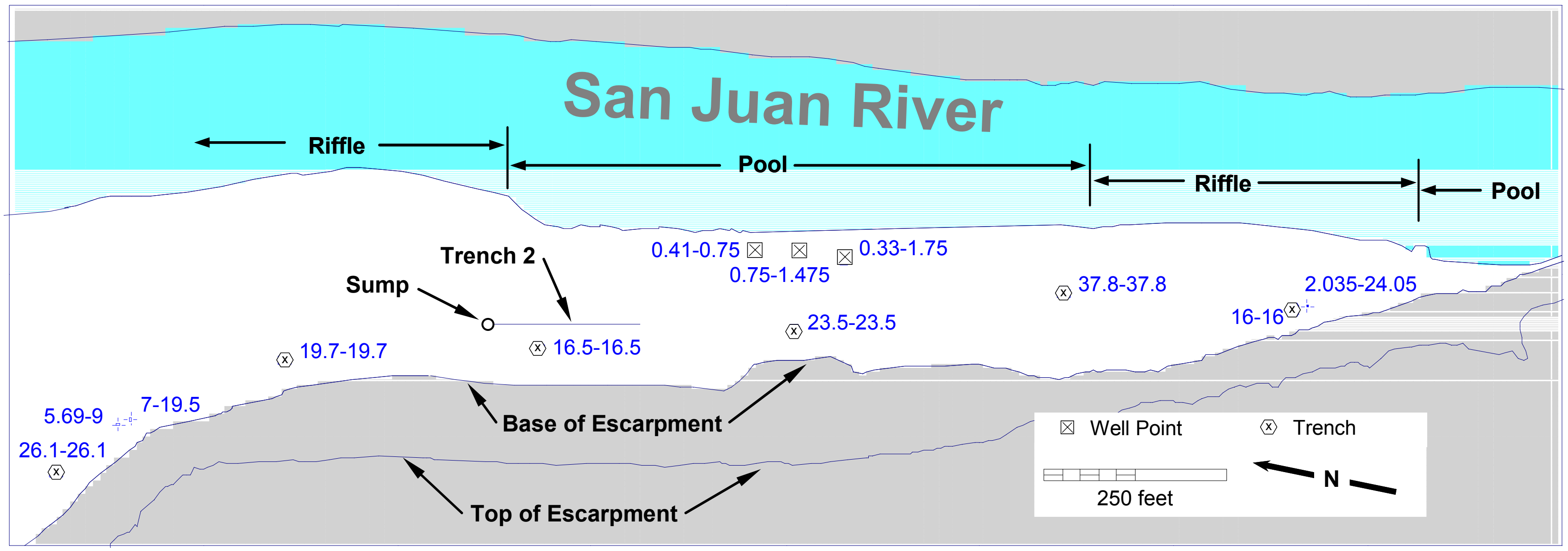

Figure 16. Ranges of Specific Conductance (mS/cm) Measured Prior to 2006

from the river. Test Pit 1015, which was excavated close to Well 735 (Figure 16) and sampled once in December 1999 (Table 3), had a specific conductance value of 16 mS/cm, suggesting that the proportion of contaminated water affecting this locale at the time was relatively large.

Table 3. Summary of Pre-2006 Water Chemistry Data

Location	Time Period	Number of Sampling Events	Specific Conductance (mS/cm)		Sulfate (mg/L)		Uranium (mg/L)	
			Range	Mean	Range	Mean	Range	Mean
Well Points								
645	Mar-87 to Apr-89	4	0.410-0.750	0.621	165-1480	571.8	0.011-0.066	0.027
646	Mar-87 to Apr-89	4	0.750-1.475	1.149	388-914	707.6	0.032-0.088	0.061
647	Mar-87 to Apr-89	4	0.330-1.750	1.111	114-1740	977.6	0.014-0.251	0.141
Shallow Test Pits								
1015	Dec-99	1	16-16	16.0	4000-4000	4000	0.13-0.13	0.13
1016	Dec-99	1	37.8-37.8	37.8	31500-31500	31500	3.23-3.23	3.23
1017	Dec-99	1	23.5-23.5	23.5	15250-15250	15250	1.52	1.52
1018	Dec-99	1	16.5-16.5	16.5	12250-12250	12250	1.23-1.23	1.23
1019	Dec-99	1	19.7-19.7	19.7	15500-15500	15500	1.98-1.98	1.98
1020	Dec-99	1	26.1-26.1	26.1	14750-14750	14750	1.81	1.81
Wells 608, 609, and 735								
608	Sep-85 to Sep-05	32	7-19.5	13.88	6570-15400	11781.1	1.7-3.73	2.29
609	Sep-85 to Jan-95	4	5.69-9	7.40	4850-13400	9532.5	1.4-3.04	2.22
735	Apr-93 to Sep-05	23	2.035-24.05	9.06	707-15000	4749.9	0.023-1.25	0.18

Examination of pre-2006 concentrations of groundwater constituents in the alluvial aquifer confirmed that the major contaminants included sulfate, nitrate (NO_3), uranium and ammonia (NH_3). Of those constituents that contributed most to specific conductance (and, therefore, TDS concentration), the most abundant, in order of decreasing concentration, were sodium, magnesium, calcium, and potassium. The most abundant anions, in order of decreasing concentration, were sulfate, nitrate (NO_3), bicarbonate, and chloride. Though the Mancos Shale contains gypsum, which is a source of sulfate, observed large concentrations of this constituent in the alluvial aquifer have indicated that it is a legacy contaminant from site milling operations. Similarly, nitrate concentrations that have historically exceeded the UMTRA maximum contaminant limit (MCL) for this anion of 44 mg/L by more than two orders of magnitude have led to its classification as a contaminant of concern.

In general, the spatial distributions of groundwater contaminants in the alluvial aquifer have tended to mirror the distributions exhibited by specific conductance. This was observed, for example, in summaries of pre-2006 concentrations for sulfate and uranium in the Trench 2 study area (Table 3). The largest concentrations were primarily observed in areas close to the bedrock escarpment (at Wells 608 and 609 and Test Pits 1016 through 1020) and the lowest concentrations were observed at the shallow well points (645, 646, and 647) close to the San Juan River. Sulfate and uranium concentrations at Well 735, in the southern part of the study area, tended to span the full range of values for these parameters seen at the escarpment and near the river. Single measurements of sulfate and uranium concentration at Test Pit 1015, which was dug near Well 735, were intermediate in value (Table 3) between the two extremes observed for these parameters at the escarpment and the river.

All pre-2006 data examined to characterize background trends in water chemistry in the study area indicated that significant spatial variability in specific conductance and a variety of dissolved constituents existed at any one time along the length of the aquifer, which in turn inferred that the mass influx of dissolved constituents from the Mancos Shale could vary spatially. Similarly, relatively large changes in specific conductance between sequential sampling events at a given location indicated that the mass influxes had the potential to vary with time as well.

6.5.2 Effects of Trench 2 Operation

6.5.2.1 Water Chemistry in 2006 and 2007

Chemical data from groundwater samples collected at wells during operation of the Trench 2 system in 2006 and 2007 provided evidence of how constituent concentrations in the study area changed in response to groundwater pumping. In general, dissolved constituent concentrations decreased as pumping progressed, though the decreases were occasionally interrupted by temporary increases. The largest concentration decreases with time were most apparent at wells located close to the escarpment, where concentrations tended to be large under background, non-pumping conditions. In contrast, concentration decreases at wells located closer to the river were more subtle, especially given that dissolved constituent levels at these locations were inclined to be small under background conditions due to influxes of freshwater from the river. Overall, examination of the monitored groundwater chemistry indicated that the Trench 2 system performed well in removing contaminant mass from the alluvial aquifer and, in so doing, reduced the size of contaminated areas between the bedrock escarpment and the San Juan River.

A temporal plot of measured specific conductance at monitor wells installed prior to 2007 (Figure 17) was initially used to illustrate the general behavior of dissolved constituents in floodplain groundwater, both prior to and after the start of Trench 2 pumping in April 2006. This figure showed conductance data not only for wells that were installed during 2006 (Wells 1113-1117, Ports A and C) but also at wells that existed prior to 2006 (Wells 608 and 735). To assess the effects of changes in groundwater extraction on specific conductance, the daily pumping rate (in units of gallons per minute [gpm]) from the Trench 2 sump was added to the plot.

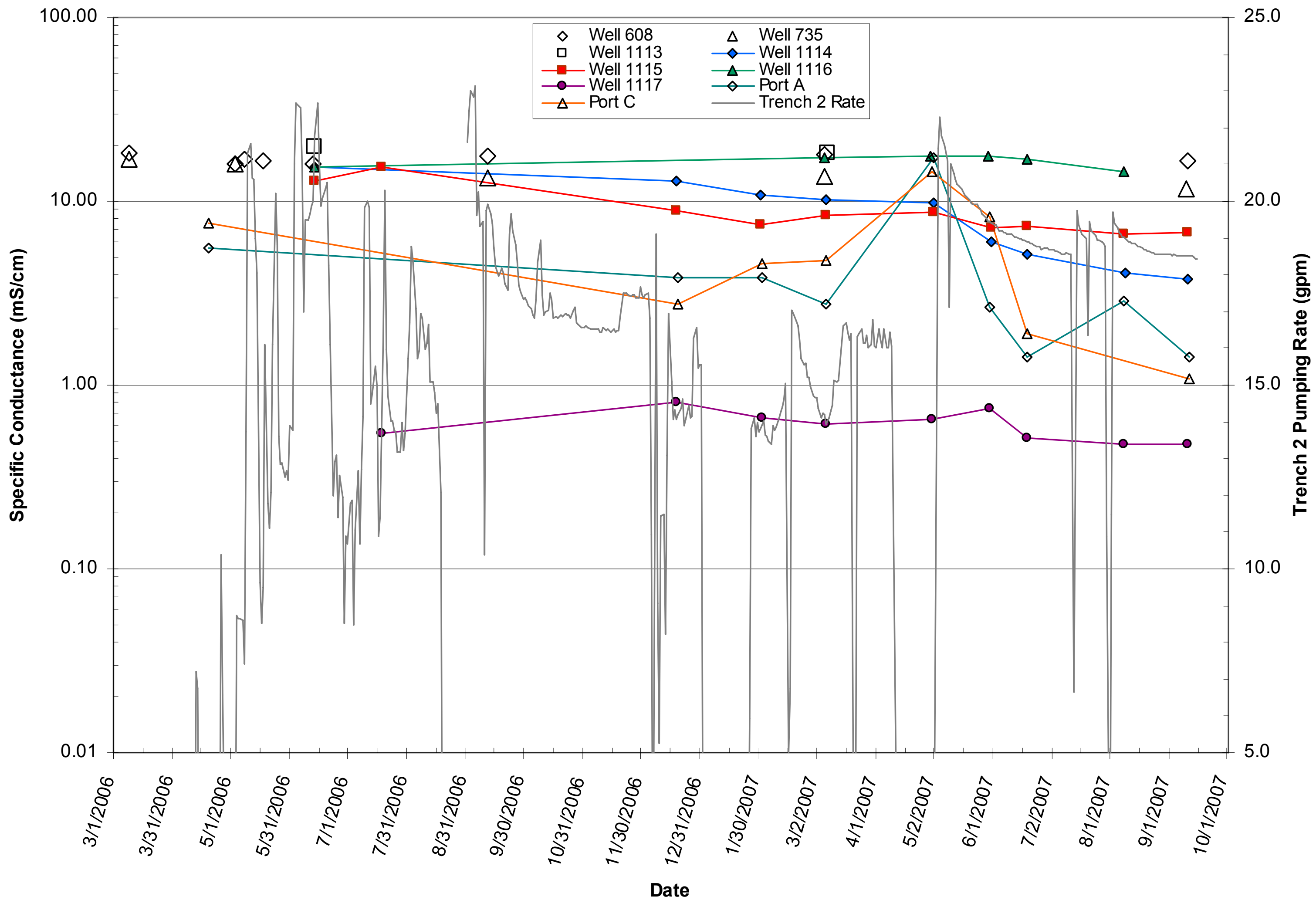

Figure 17. Specific Conductances at Wells Installed Prior to 2007

With the exception of Well 1117 and Ports A and C, the monitoring locations represented in Figure 17 are located within just a few tens of feet from the bedrock escarpment, the apparent source area for site-related contaminants in the alluvial aquifer. Accordingly, these locations tended to exhibit relatively large specific conductance values when they were first measured in 2006. For example, specific conductance in Well 608, near the base of the escarpment and about 500 ft north-northwest of Trench 2 (Figure 9), was 18.25 mS/cm in March 2006, prior to the start of pumping. Similarly, a specific conductance of 16.8 mS/cm was measured in March 2006 at Well 735, which lies about 30 ft east of the escarpment and 1,000 ft south of the trench. Wells 1114, 1115, and 1116, located within 30 ft of the escarpment and within 300 ft of the trench, had specific conductances of about 13 to 15 mS/cm in June 2006, about 2 months after the start of pumping.

In further agreement with the conceptual model presented in Section 4.2, specific conductance at wells located more than 50 ft away from the bedrock escarpment were typically smaller than conductances observed in wells closer to the escarpment. Ports A and C, which overlie Trench 2 about 80 ft east of the escarpment, had specific conductances of 5.6 and 7.6 mS/cm, respectively, on April 19, 2006, before significant continuous pumping of the trench began. Moreover, other than an apparent spike in salinity in April and May 2007, specific conductance at these two locations tended to remain below 5 mS/cm during sampling events through September 2007. Because the first water chemistry data for Well 1117 (120 ft east of the escarpment) were not collected until mid July 2006, it was difficult to determine background specific conductances for this location. However, relatively consistent specific conductance values of about 0.5 to 0.8 mS/cm measured at this well during the mid-July event and subsequent sampling events (Figure 17) suggested that dissolved solids concentrations here under non-pumping conditions were significantly lower than those observed at Trench 2, about 40 ft to the east.

Temporal fluctuations in specific conductances over the spring 2006-summer 2007 period were of interest because they showed how dissolved constituent concentrations might change at various locations in response to decreases in the trench pumping rate. In general, the fluctuations appeared to be stronger at wells located closest to the trench. This was apparent at Ports A and C, which exhibited sharp increases in specific conductance between early March 2007 and early May 2007 (Figure 17), apparently in response to a shutdown in trench pumping that occurred from April 13 through May 1. This suggested that dissolved solids concentrations had the capacity to increase relatively quickly when pumping was stopped, at least in the near vicinity of the trench. In the case of Ports A and C, it also appeared that a relatively rapid increase in dissolved mass when pumping stopped was capable of increasing specific conductance to levels that were greater than those that occurred under background conditions in April 2006. The processes that made this latter phenomenon possible were unclear.

Of the wells installed prior to 2007 and monitored routinely between spring 2006 and summer 2007, only Well 1114 exhibited continuously decreasing specific conductance values (Figure 17), apparently in response to pumping of Trench 2. The location of this well, about 290 ft north-northwest of the Trench 2 sump (Figure 9), appeared to play a role in preventing specific conductance increases when pumping either decreased or stopped, such as the increases that were observed at Ports A and C in April and May 2007. Though the logarithmic scale used to prepare the temporal plot in Figure 17 tended to visually damp the steady decreases in salinity at Well 1114, the total measured drop in specific conductance at this location was significant - from about 18 mS/cm in June 2006 to less than 4 mS/cm in September 2007. Specific conductances at Well 1115, which is closer to the trench than Well 1114 (about 50 ft west of Port A) also tended to show gradual decreases between spring 2006 and summer 2007, but mild increases were observed at this well between June and July 2006, and between early February and May 2007. Decreases in well pumping either shortly before or during these two latter periods were the apparent causes of the mild increases in specific conductance at Well 1115.

The specific conductances shown for Wells 1116 and 1117 in Figure 17 suggested neither well was significantly affected by Trench 2 pumping. At Well 1116, this observation was probably attributable in part to the well's close proximity to the bedrock escarpment (~ 20 ft away), in that continuous discharge of groundwater across the escarpment quickly replenished any contaminant mass that was being removed from the subsurface by pumping. In addition, the conceptual model of groundwater flow patterns under pumping conditions, as illustrated in Figure 7, suggested that contaminated groundwater located adjacent to the escarpment and south of Well 1116 would replace some of the water drawn away from the well location by the trench. In contrast, the apparent lack of salinity change at Well 1117 in response to pumping was likely attributable to the fact that specific conductance was already as low as 0.5 mS/cm when the well was first sampled in June 2006. Any river water that was subsequently drawn into this location, per the conceptual model shown in Figure 7, was likely to have specific conductances of about the same magnitude.

With minor exceptions, similar behavior to that for specific conductance at wells installed in 2006 was also observed with the major ionic constituents that contribute to specific conductance. Graphical demonstrations of this were developed using temporal plots of concentration for the cation sodium (Figure 18) and the anions sulfate and nitrate (Figures 19 and 20, respectively). The behavior of sodium at Well 1117, located just east of Trench 2 was somewhat anomalous, as its concentration inexplicably increased from 180 to 950 mg/L between mid-July 2006 and mid-December 2006. Concentrations of the contaminants uranium and ammonia also exhibited similar behavior to that for specific conductance between March 2006 and mid-September 2007 (Figures 21 and 22), including temporary increases in concentration in early May in response to an 18-day period of non-pumping beginning in mid-April. Additional plots of anion and cation concentrations over the spring 2006–summer 2007 period, presented in Appendix C, generally illustrated the same temporal behavior.

Though all temporal plots of chemical parameters monitored at wells installed prior to 2007 (Figures 17 through 22) showed evidence that Trench 2 pumping resulted in dissolved mass reductions in the alluvial aquifer, the logarithmic scale used in these graphs made it difficult to discern the relative magnitude of the reductions. To develop rough estimates of concentration decreases, a table was prepared listing chemical parameter changes observed at six of the wells between the time they were first sampled in 2006 and when they were last sampled prior to September 15, 2007. The results, presented in Table 4, suggested that mass reductions over the study period were potentially as large as 80 to 90 percent in some locales and moderate in others. As expected, most of the wells that exhibited the largest decreases were those that exhibited relatively high values of chemical parameters to begin with (Wells 1114 and 1115, and Ports A and C) and were, therefore, susceptible to significant dissolved mass losses. An exception to this general observation occurred at Well 1116, which, for reasons given earlier, appeared to be quickly replenished with contaminated groundwater discharge across the escarpment. Though most of the chemical parameter changes listed in Table 4 indicated decreases in dissolved mass over time, a few did indicate minor increases (e.g., uranium at Well 1116 and specific conductance at Well 1117). In general, this tabular summary indicated that, despite occasional fluctuations in water chemistry, the Trench 2 remediation system successfully reduced contaminant mass in the study area during its operation through summer 2007.

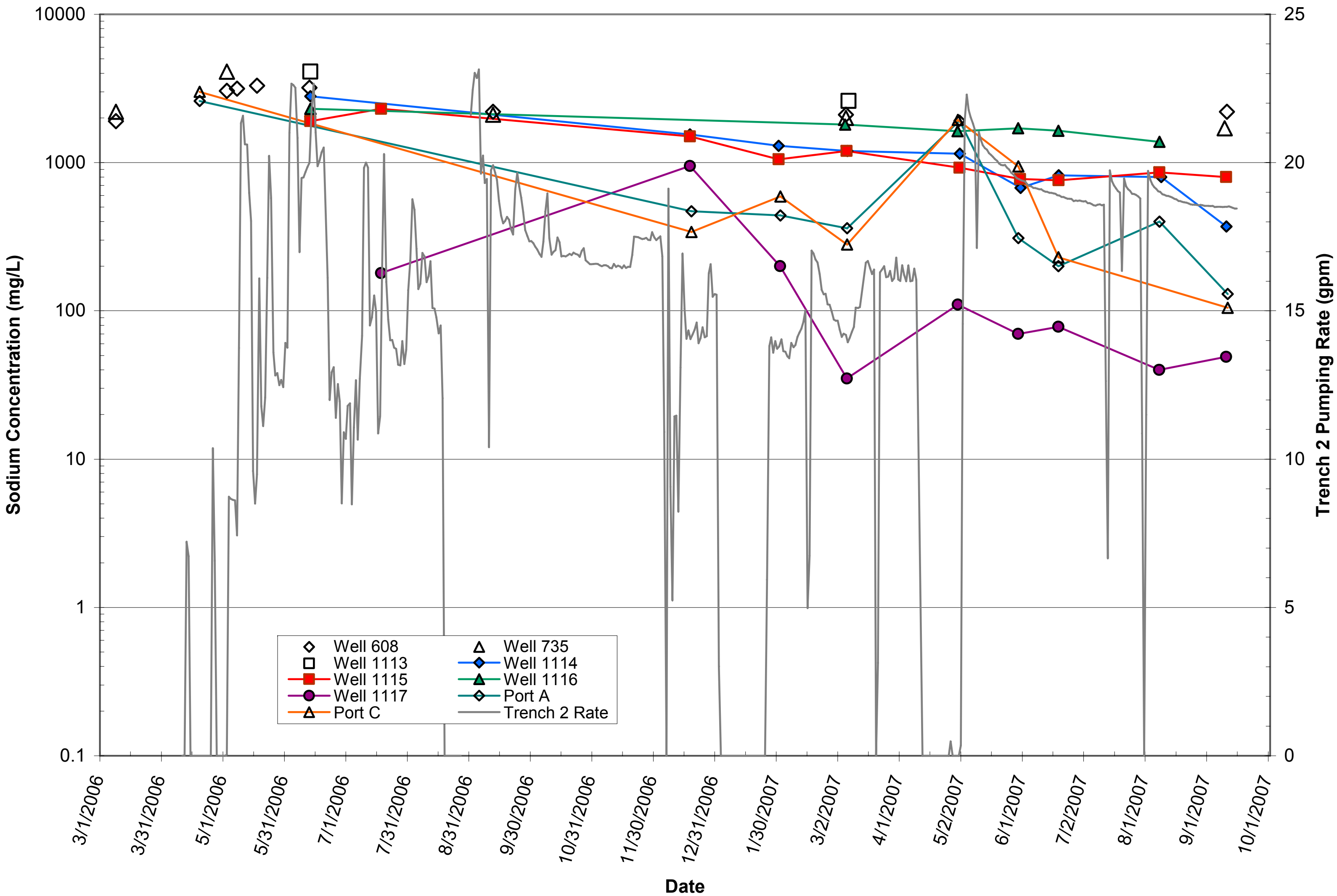

Figure 18. Sodium Concentrations at Wells Installed Prior to 2007

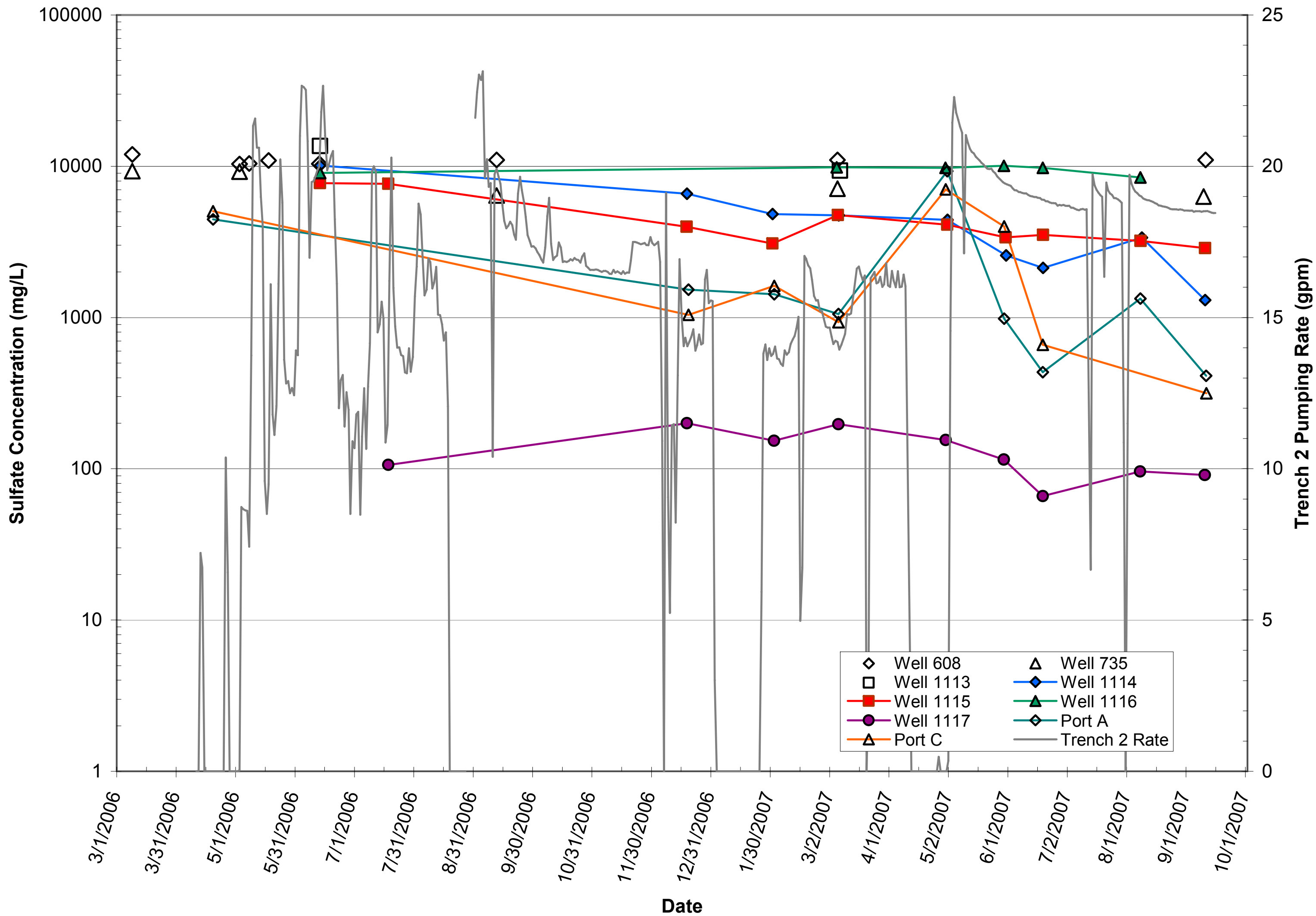

Figure 19. Sulfate Concentrations at Wells Installed Prior to 2007

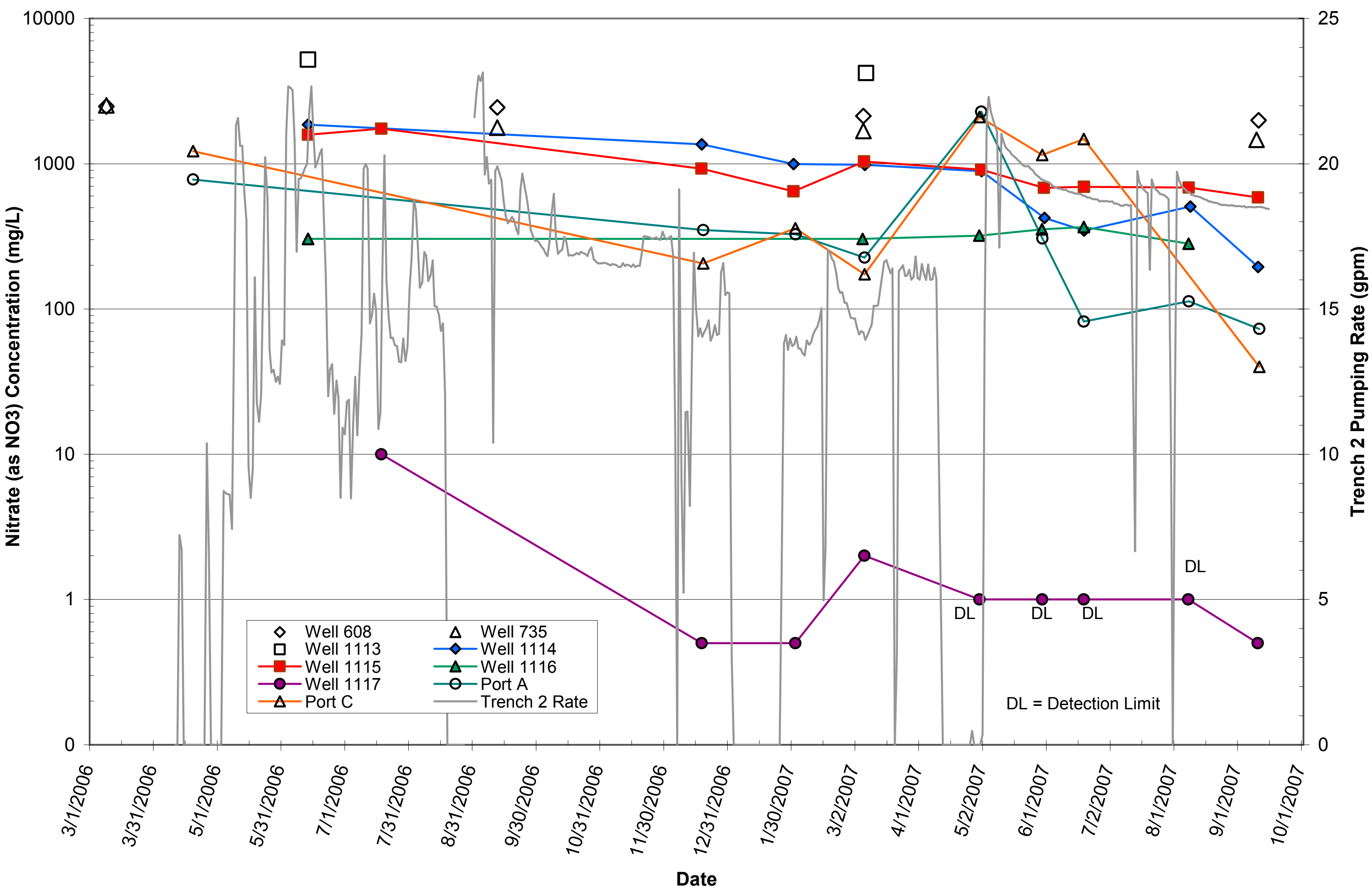

Figure 20. Nitrate (as NO_3) Concentrations at Wells Installed Prior to 2007

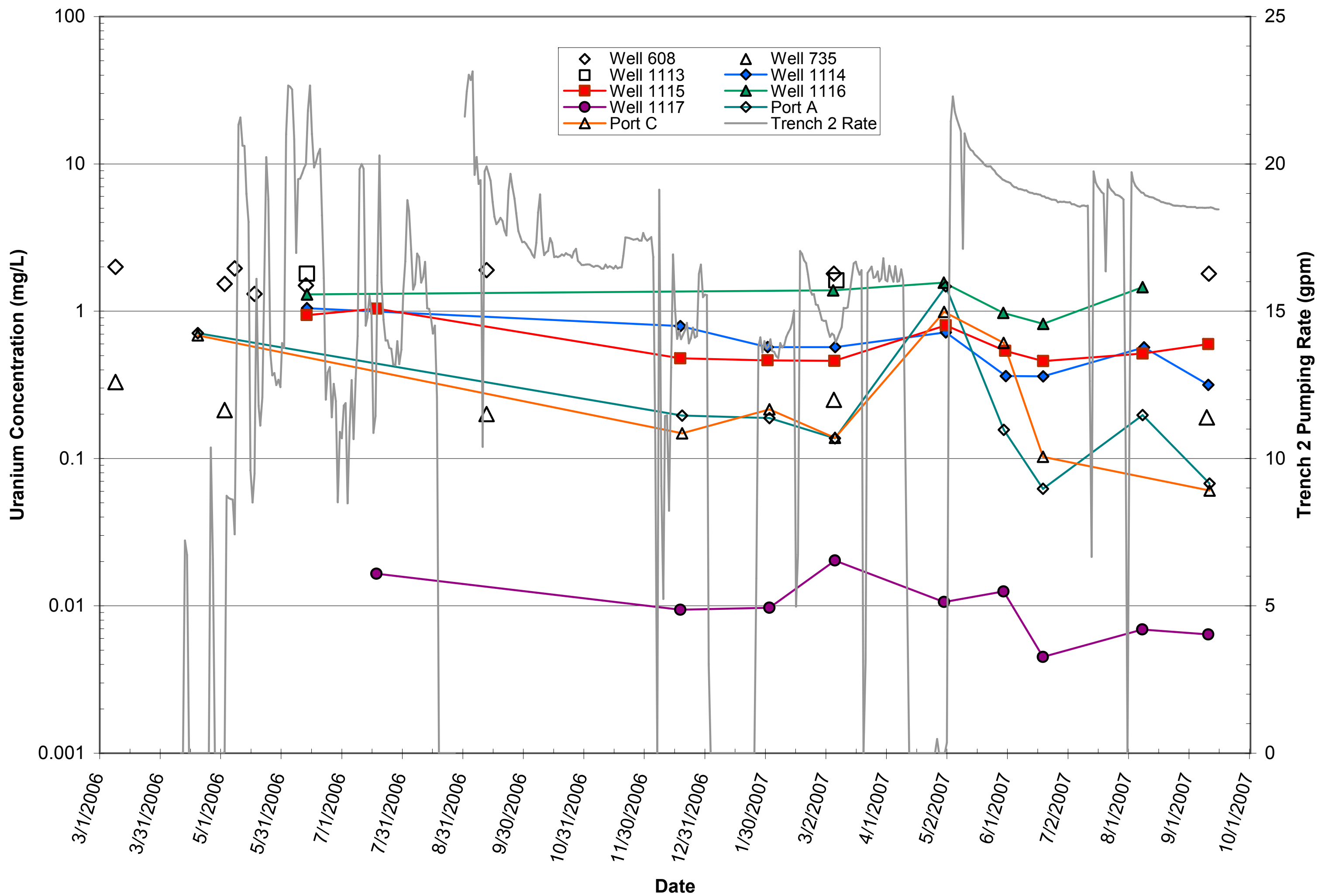

Figure 21. Uranium Concentrations at Wells Installed Prior to 2007

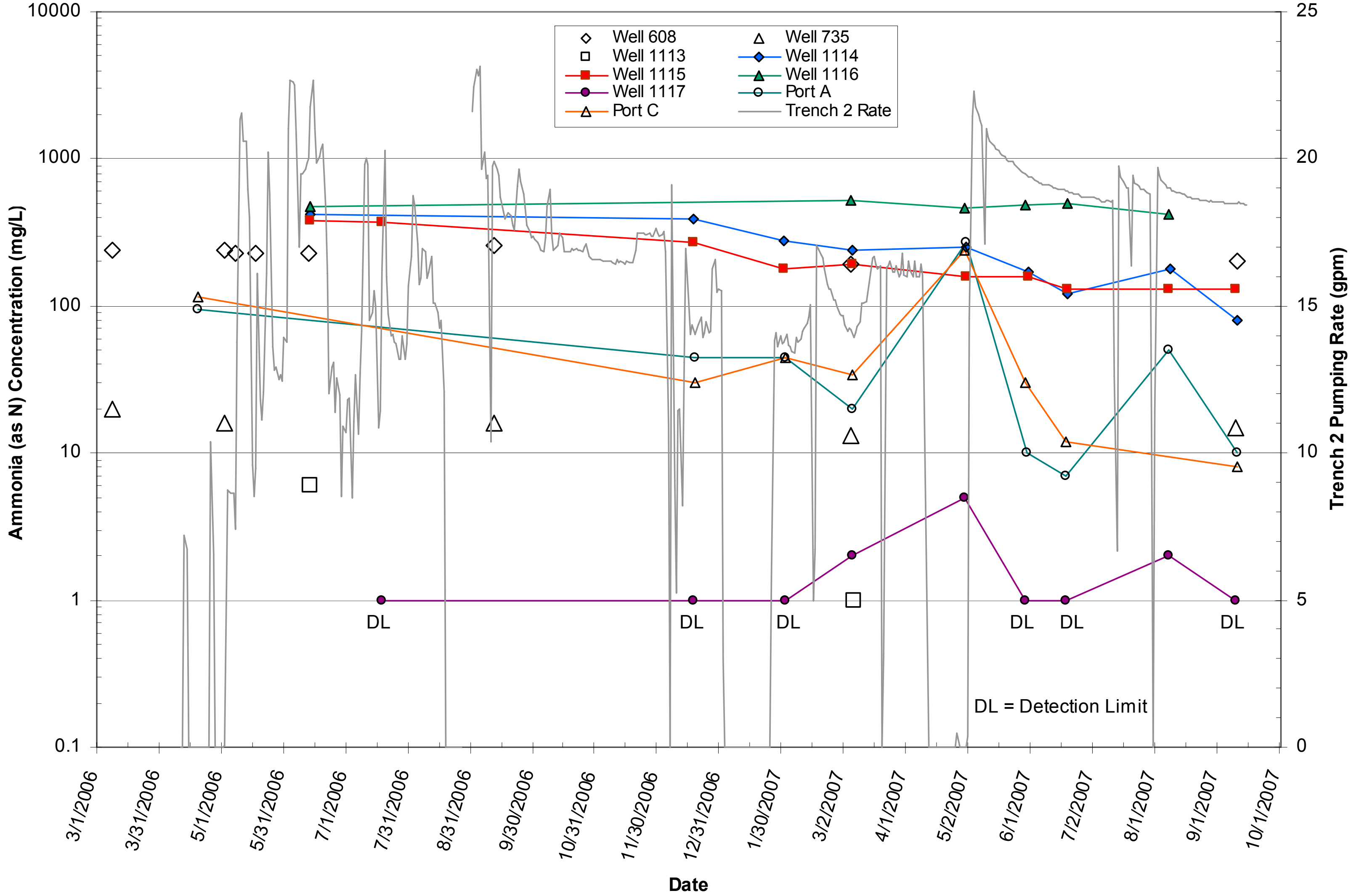

Figure 22. Ammonia (as N) Concentrations at Wells Installed Prior to 2007

Table 4. Initial and Final Chemical Parameters at Wells Monitored From Spring 2006 to Summer 2007

Parameter	Port A		Port C		Well 1114		Well 1115		Well 1116		Well 1117	
	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date
Salinity												
Initial Specific Conductance (mS/cm)	5.62	4/19/2006	7.62	4/19/2006	15.29	6/13/2006	12.98	6/13/2006	15.37	6/13/2006	0.444	7/18/2006
Final Specific Conductance (mS/cm)	2.9	8/8/2007	1.91	8/8/2007	4.05	8/9/2007	6.6	8/8/2007	14.61	8/8/2007	0.472	8/8/2007
Change (mS/cm)	-2.72		-5.71		-11.24		-6.38		-0.76		0.028	
Percent Change	-48.4		-74.9		-73.5		-49.2		-4.9		6.3	
Cations												
Initial Sodium (mg/L)	2600	4/19/2006	3000	4/19/2006	2800	6/13/2006	1900	6/13/2006	2300	6/13/2006	180	7/18/2006
Final Sodium (mg/L)	400	8/8/2007	230	8/8/2007	800	8/9/2007	860	8/8/2007	1380	8/8/2007	40	8/8/2007
Change (mg/L)	-2200		-2770		-2000		-1040		-920		-140	
Percent Change	-84.6		-92.3		-71.4		-54.7		-40.0		-77.8	
Initial Magnesium (mg/L)	950	4/19/2006	800	4/19/2006	1900	6/13/2006	2000	6/13/2006	1800	6/13/2006	25	7/18/2006
Final Magnesium (mg/L)	175	8/8/2007	125	8/8/2007	360	8/9/2007	430	8/8/2007	1350	8/8/2007	25	8/8/2007
Change (mg/L)	-775		-675		-1540		-1570		-450		0	
Percent Change	-81.6		-84.4		-81.1		-78.5		-25.0		0.0	
Anions												
Initial Sulfate (mg/L)	4454	4/19/2006	5051	4/19/2006	10093	6/13/2006	7742	6/13/2006	9046	6/13/2006	106	7/18/2006
Final Sulfate (mg/L)	1332	8/8/2007	660	8/8/2007	3373	8/9/2007	3202	8/8/2007	8422	8/8/2007	96	8/8/2007
Change (mg/L)	-3122		-4391		-6720		-4540		-624		-10	
Percent Change	-70.1		-86.9		-66.6		-58.6		-6.9		-9.4	
Initial Nitrate (mg/L)	780	4/19/2006	1218	4/19/2006	1859	6/13/2006	1585	6/13/2006	2580	6/13/2006	10	7/18/2006
Final Nitrate (mg/L)	113	8/8/2007	1477	8/8/2007	508	8/9/2007	684	8/8/2007	2305	8/8/2007	1*	8/8/2007
Change (mg/L)	-667		259		-1351		-901		-275		NA	
Percent Change	-85.5		21.3		-72.7		-56.8		-10.7		NA	
Additional Contaminants												
Initial Uranium (mg/L)	0.709	4/19/2006	0.685	4/19/2006	1.048	6/13/2006	0.939	6/13/2006	1.298	6/13/2006	0.0165	7/18/2006
Final Uranium (mg/L)	0.197	8/8/2007	0.102	8/8/2007	0.567	8/9/2007	0.516	8/8/2007	1.454	8/8/2007	0.0069	8/8/2007
Change (mg/L)	-0.512		-0.583		-0.481		-0.423		0.156		-0.0096	
Percent Change	-72.2		-85.1		-45.9		-45.0		12.0		-58.2	
Initial Ammonia (as N) (mg/L)	95	4/19/2006	115	4/19/2006	420	6/13/2006	380	6/13/2006	475	6/13/2006	1	7/18/2006
Final Ammonia (as N) (mg/L)	50	8/8/2007	12	8/8/2007	180	8/9/2007	130	8/8/2007	420	8/8/2007	2*	8/8/2007
Change (mg/L)	-45		-103		-240		-250		-55		NA	
Percent Change	-47.4		-89.6		-57.1		-65.8		-11.6		NA	
Average Percent Change	-70.0		-70.3		-66.9		-58.4		-12.4		-27.8	

* Value at detection limit; NA = not applicable

6.5.2.2 Chemistry at Wells Installed During 2007

The water chemistry history at wells installed in spring 2007 provided less information regarding alluvial aquifer responses to groundwater extraction than the history for previously installed wells. Nevertheless, data analyzed from six of these wells placed relatively close to Trench 2 helped to further characterize the temporal changes of dissolved mass in the alluvial aquifer. Two of the wells (Wells 1132 and 1134) were located between the trench and the river, two additional wells (Wells 1128 and 1133) were located directly between the trench and the bedrock escarpment, and the remaining two were located almost directly north (Well 1126) and south (Well 1127) of the two ends of Trench 2.

A temporal plot of specific conductance measured at the six wells during spring and summer 2007 (Figure 23) provided information on groundwater salinity during this period. This graph indicated that the largest conductances, ranging from about 6 to 17 mS/cm, were typically observed at Wells 1128 and 1133, the two locations between the trench and the escarpment. The lowest conductances, on the order of 0.4 to 1.2 mS/cm, were consistently observed at Wells 1127, 1132, and 1134. With the exception of one sampling event in early March 2007, specific conductances at Well 1126 were typically 3 to 4 times smaller than those observed at the two near-escarpment wells and 4 to 5 times larger than those at the lowest conductance wells. This pattern generally followed expected trends, wherein the largest salinities would occur close to the escarpment and total dissolved mass would decrease with proximity to the river.

The fact that specific conductances at Well 1126 were significantly larger than those at Well 1127 was of interest because the two wells are located about the same distance from the bedrock escarpment (65 to 85 ft), albeit at opposite ends of Trench 2. The apparent difference in salinity in the two areas suggested that dissolved constituent mass at Well 1127 was diluted more heavily by influxes of river water in response to trench pumping than was the dissolved mass at Well 1126. This hypothesis was examined further using a flow and transport model of the study area (Section 7.4.2.2).

As with wells that were present during and prior to 2006, specific conductance appeared to fluctuate between sampling events at the wells installed during 2007 (Figure 23). Fluctuations in wells located between Trench 2 and the river (Wells 1132 and 1134), where conductances were relatively small throughout spring and summer 2007, were minor and might have simply reflected a natural variability in salinity rather than distinct responses to changes in pumping rates from the trench. A slight increase in conductance of about 0.25 mS/cm between early March and late April 2007 at Well 1127, directly south of Trench 2, possibly represented a rebound in salinity due to the pumping shutdown that occurred over the last half of April, but this was difficult to confirm. However, a distinct decrease in specific conductance of more than 13 mS/cm at Well 1126 (directly north of Trench 2), between the same two sampling events (Figure 23), followed by an increase of about 2.5 mS/cm in late May, did appear to be related to changes in pumping rate. Because this latter response was opposite to the conductance rebound observed in early May at Ports A and C in response to the pumping shutdown in April, it suggested that salinity at Well 1126 was affected by processes that were noticeably different from those influencing groundwater directly over the trench and south of it. Possible reasons for the Well 1126 responses were further examined with the previously mentioned model of the study area (Section 7.4.2).

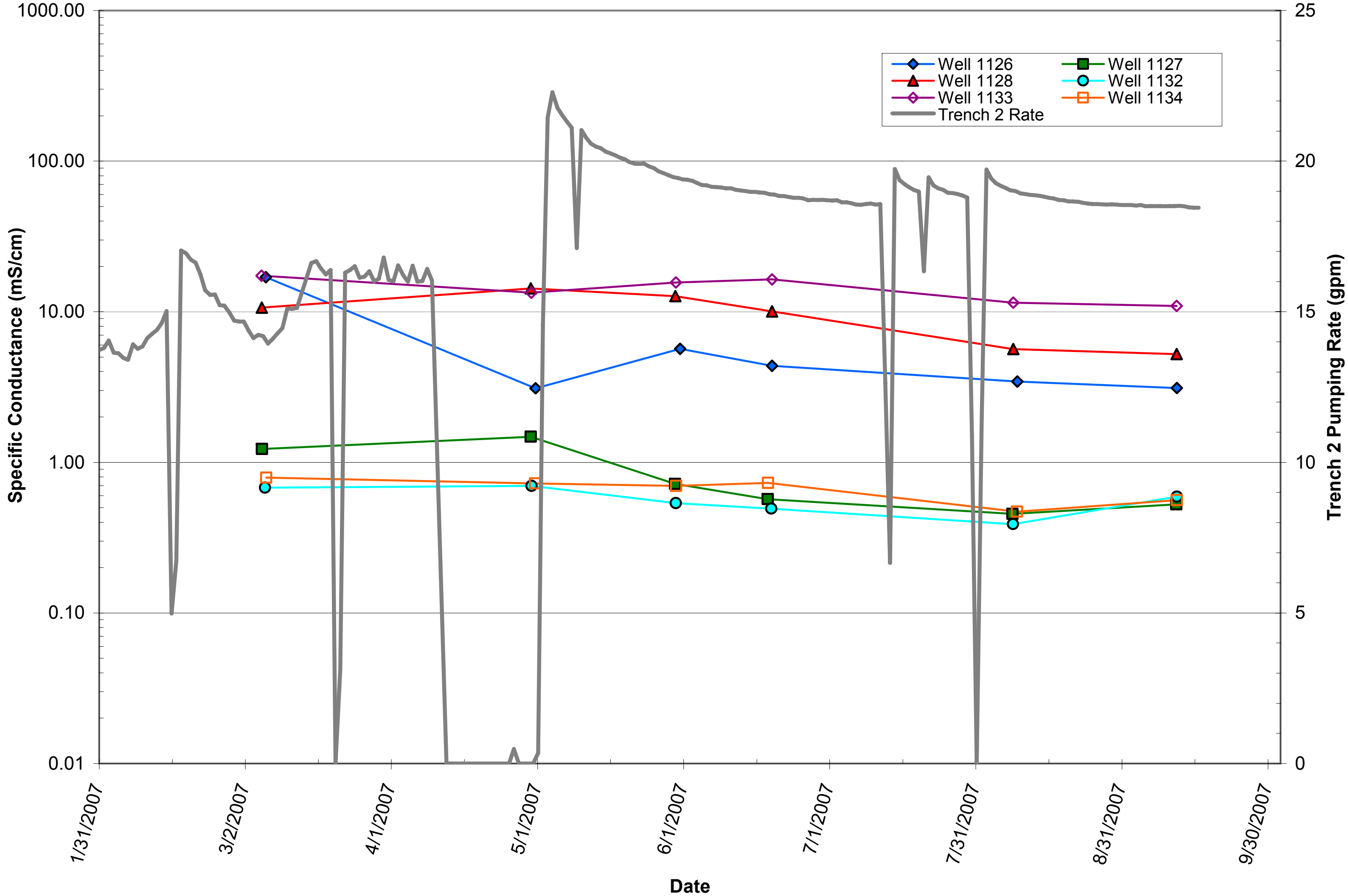

Figure 23. Specific Conductances at Near-Trench Wells Installed During 2007

To further assess the temporal behavior of dissolved constituents at near-trench wells installed in 2007, plots of sodium, sulfate, nitrate, uranium and ammonia (Figures 24 through 28, respectively) were developed for the same six locations used to prepare Figure 23. Each of these graphs illustrated temporal behavior that was similar to that for specific conductance. That is, the largest concentrations were typically observed at near-escarpment wells (Wells 1128 and 1133), the lowest were measured at wells between Trench 2 and the river (Wells 1132 and 1134) and at Well 1127 south of the trench, and Well 1126 usually exhibited concentrations that were between the highest and lowest values. Concentration fluctuations occurred at most locations, and for all constituents, Well 1126 showed a distinct decrease in concentration between early March and late April 2007. Again the latter behavior indicated that the response in Well 1126 to the pumping shutdown in April was opposite to the previously discussed concentration increases at Ports A and C during this time span. Temporal concentration plots for additional cations and anions at the wells installed during 2007 were developed, as presented in Appendix D.

In an effort to discern whether groundwater extraction at Trench 2 during spring and summer 2007 was contributing substantially to mass removal from the alluvial aquifer, changes between initial measured chemical parameters and final measured concentrations were calculated for the above-mentioned six wells installed in 2007 (Table 5). Despite the approximate nature of this assessment, the tabulated results did infer that the Trench 2 system was removing significant amounts of dissolved mass from the alluvial aquifer during the first three quarters of the year. Estimated average percent decreases in concentration during this time generally ranged from about 30 to 90 percent.

6.5.2.3 Chemistry of Trench 2 Discharge

Temporal plots of the concentrations of significant cations and anions in groundwater extracted from Trench 2 (Trench 2 discharge) between April 2006 and summer 2007 (Figures 29 and 30, respectively) indicated that the greatest share of dissolved mass was removed from the alluvial aquifer during the first three months of pumping. Though concentrations of each constituent and manual measurements of specific conductance (also shown in the plots) fluctuated greatly during the initial three months, none of these chemical parameters subsequently reached magnitudes as large as those observed at the start of pumping in April 2006. As illustrated in the temporal plots, sodium and magnesium were the most prominent cations collected by the remediation system, and sulfate and nitrate were the two most prominent anions. These latter observations showed that the remediation system was removing groundwater that reflected relative ionic abundances seen at surrounding wells. The magnitudes of manually measured specific conductances in the discharge, ranging from a high of about 10 mS/cm to a low of about 2 mS/cm, suggested that the remediation system was collecting both contaminated water near the escarpment and non-contaminated water originating in the river. Fluctuations in concentration were observed for specific conductance and for each cation and anion in the discharge throughout the study period.

The concentrations of the contaminants uranium and ammonia in Trench 2 discharge also fluctuated significantly during the spring 2006-summer 2007 period (Figure 31). Despite the fluctuations, substantial differences between initially measured concentrations for these constituents in April 2006 and corresponding final measured values in September 2007 indicated that large amounts of their mass had been removed from the alluvial aquifer by the remediation system.

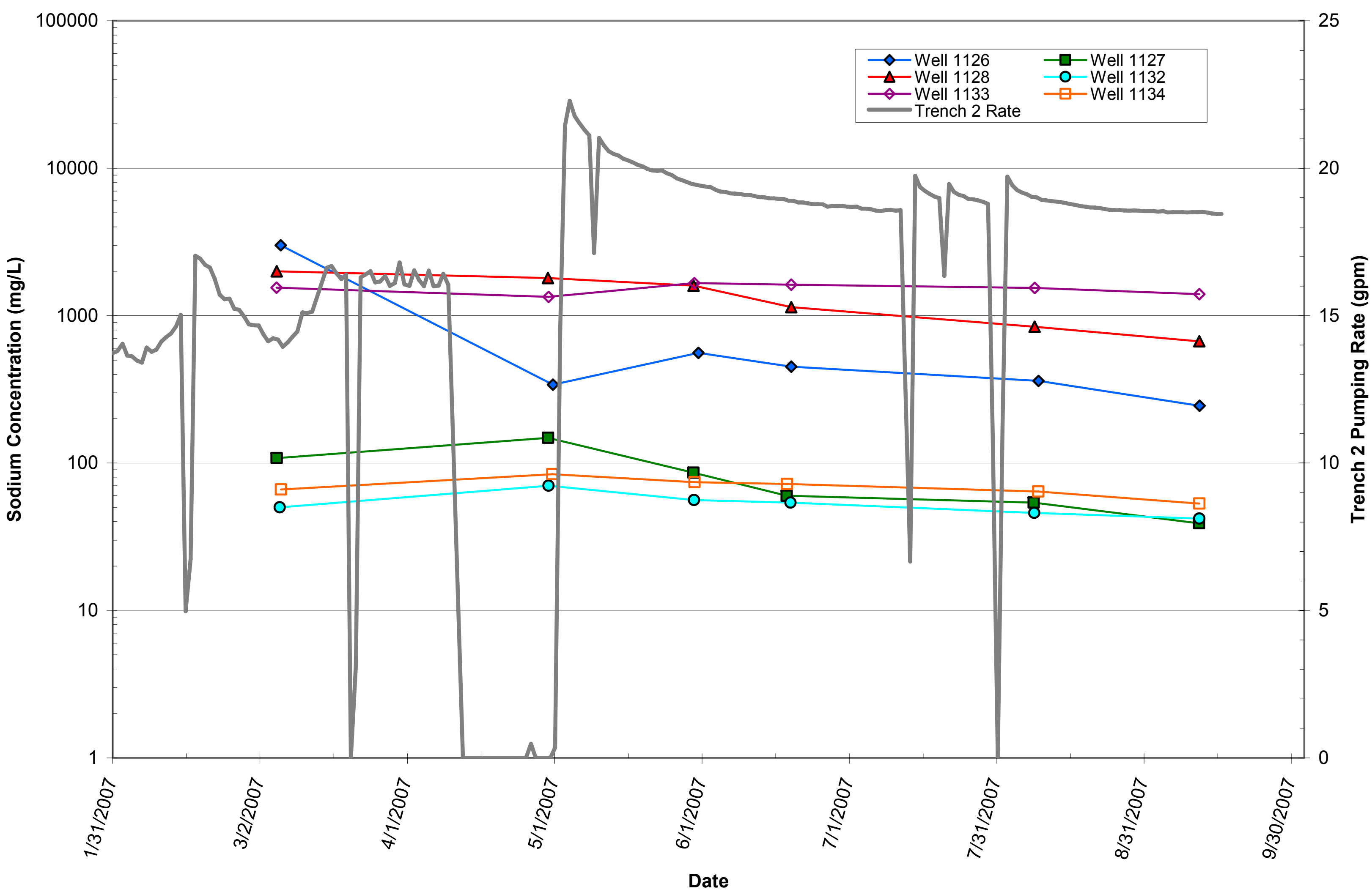

Figure 24. Sodium Concentrations at Near-Trench Wells Installed During 2007

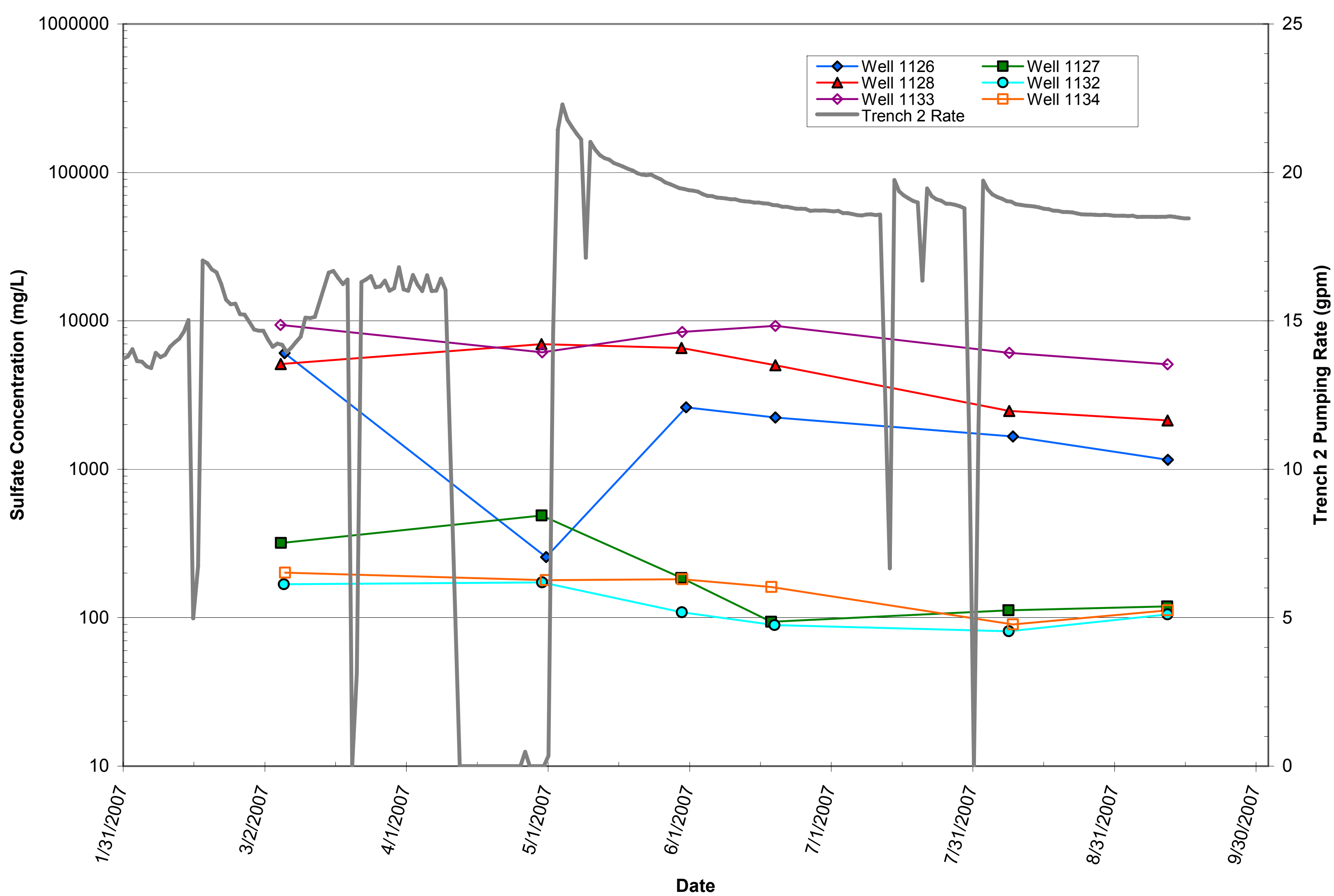

Figure 25. Sulfate Concentrations at Near-Trench Wells Installed During 2007

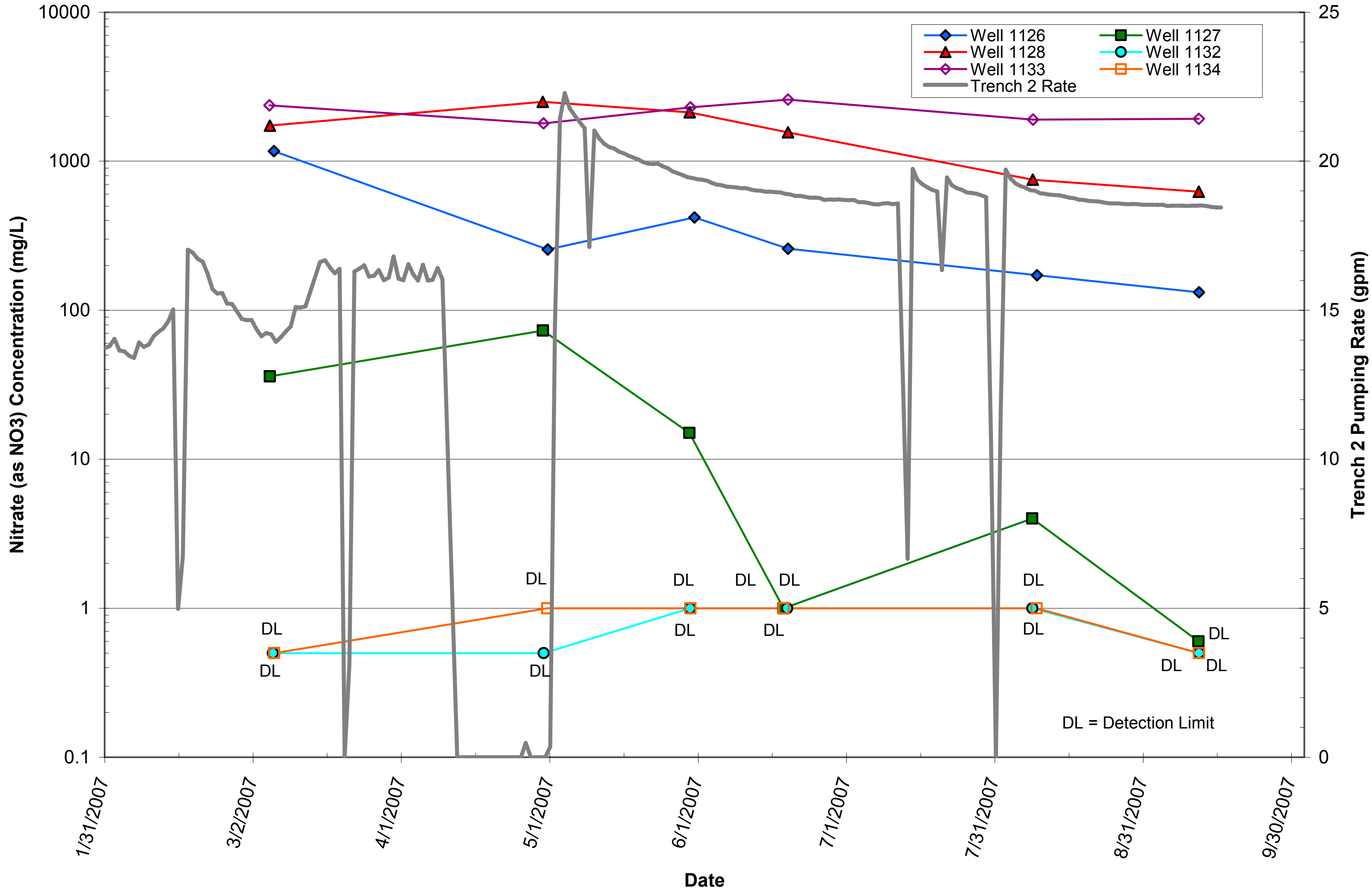

Figure 26. Nitrate (as NO_3) Concentrations at Near-Trench Wells Installed During 2007

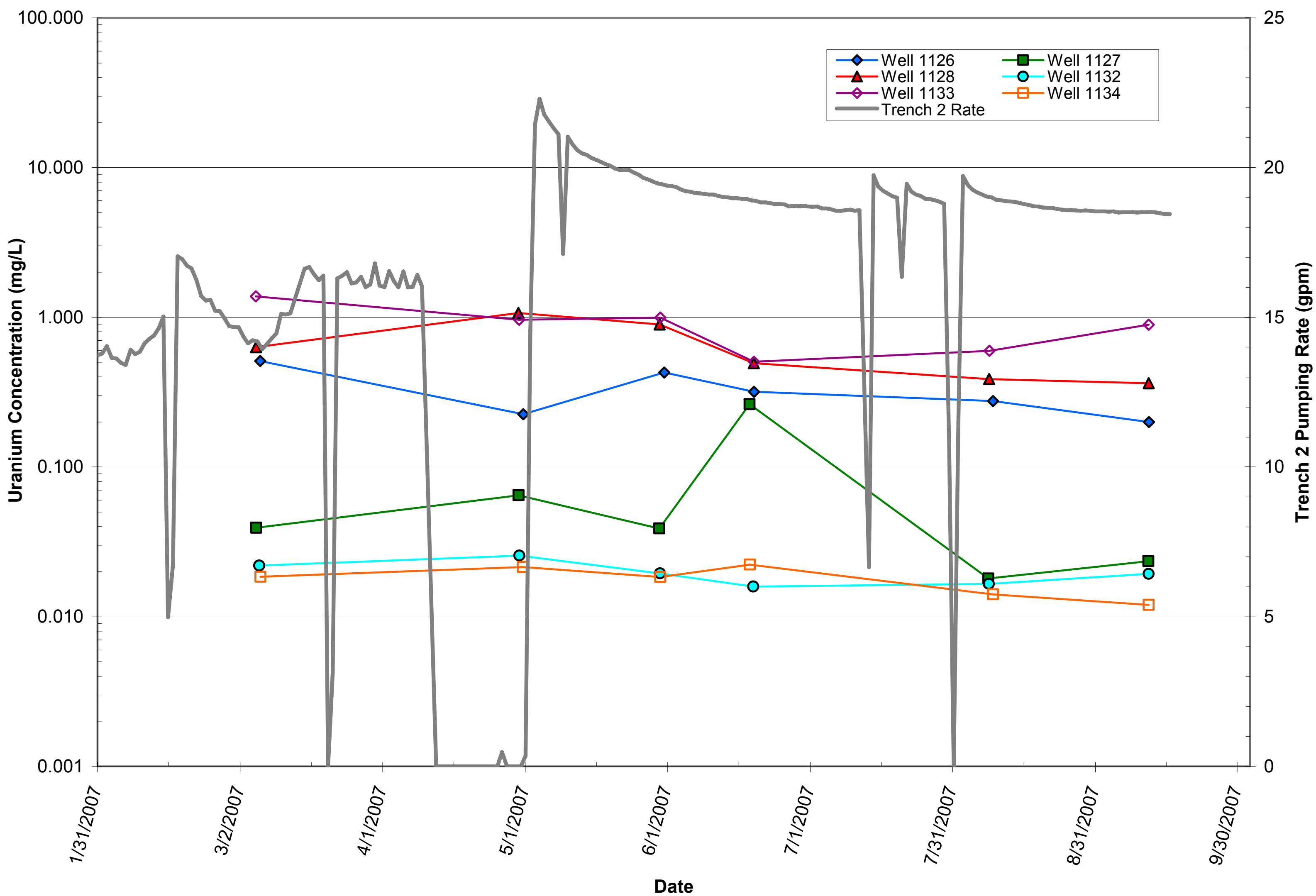

Figure 27. Uranium Concentrations at Near-Trench Wells Installed During 2007

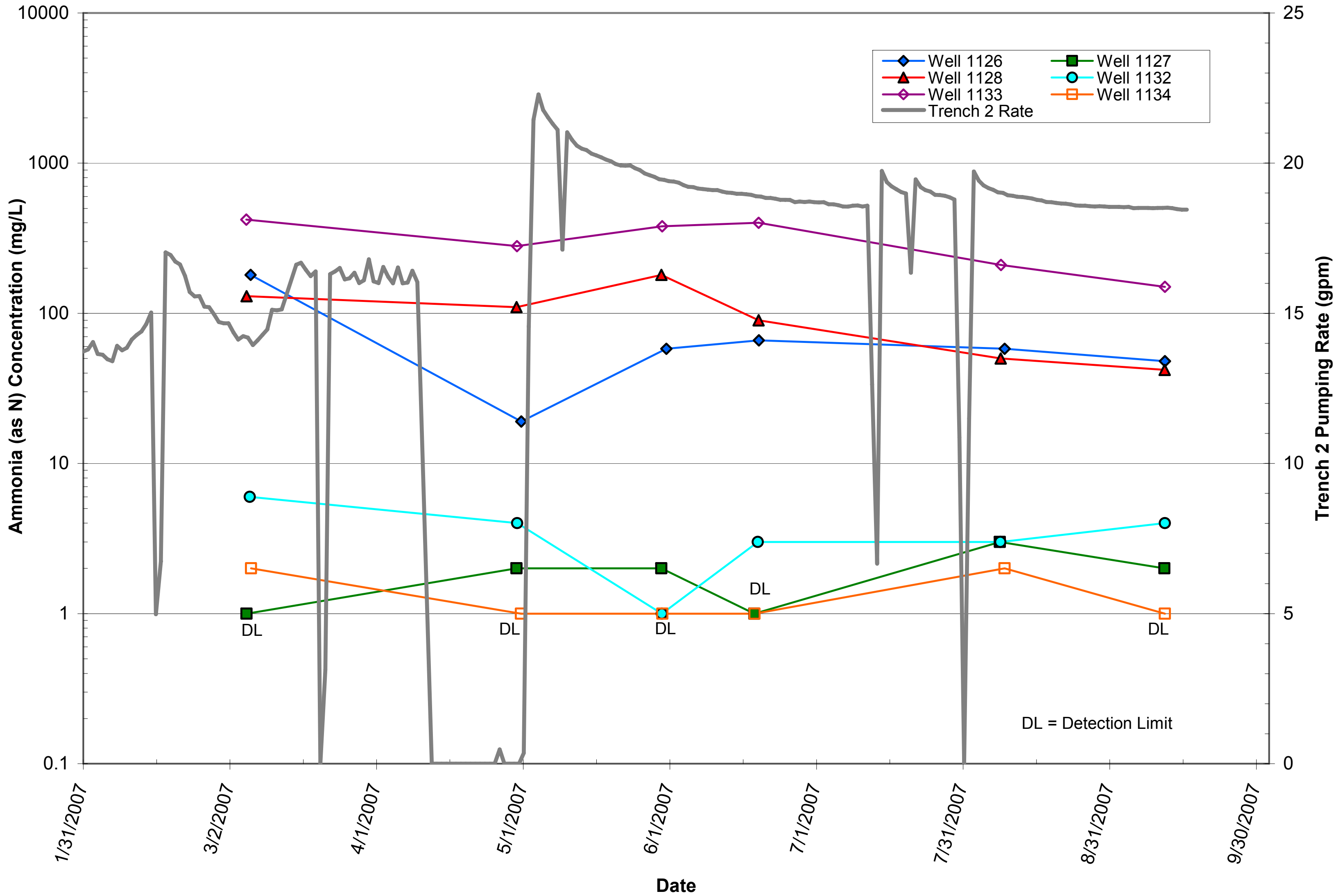

Figure 28. Ammonia (as N) Concentrations at Near-Trench Wells Installed During 2007

Table 5. Initial and Final Chemical Parameters at Near-Trench Wells Installed in Spring 2007

Parameter	Well 1126		Well 1127		Well 1128		Well 1132		Well 1133		Well 1134	
	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date
Salinity												
Initial Specific Conductance (mS/cm)	16.95	3/6/2007	1.225	3/5/2007	10.64	3/5/2007	0.68	3/6/2007	17.35	3/5/2007	0.79	3/6/2007
Final Specific Conductance (mS/cm)	3.44	8/9/2007	0.454	8/8/2007	5.66	8/8/2007	0.39	8/8/2007	11.49	8/8/2007	0.47	8/9/2007
Change (mS/cm)	-13.51		-0.771		-4.98		-0.29		-5.86		-0.32	
Percent Change	-79.7		-62.9		-46.8		-42.6		-33.8		-40.5	
Cations												
Initial Sodium (mg/L)	3000	3/6/2007	108	3/5/2007	2000	3/5/2007	50	3/6/2007	1550	3/5/2007	66	3/6/2007
Final Sodium (mg/L)	360	8/9/2007	54	8/8/2007	840	8/8/2007	46	8/8/2007	1540	8/8/2007	64	8/9/2007
Change (mg/L)	-2640		-54		-1160		-4		-10		-2	
Percent Change	-88.0		-50.0		-58.0		-8.0		-0.6		-3.0	
Initial Magnesium (mg/L)	1350	3/6/2007	70	3/5/2007	1900	3/5/2007	39	3/6/2007	1800	3/5/2007	49	3/6/2007
Final Magnesium (mg/L)	270	8/9/2007	24	8/8/2007	360	8/8/2007	21	8/8/2007	900	8/8/2007	33	8/9/2007
Change (mg/L)	-1080		-46		-1540		-18		-900		-16	
Percent Change	-80.0		-65.7		-81.1		-46.2		-50.0		-32.7	
Anions												
Initial Sulfate (mg/L)	6053	3/6/2007	319	3/5/2007	1350	3/5/2007	168	3/6/2007	9395	3/5/2007	201	3/6/2007
Final Sulfate (mg/L)	1662	8/9/2007	112	8/8/2007	350	8/8/2007	81	8/8/2007	6088	8/8/2007	90	8/9/2007
Change (mg/L)	-4391		-207		-1000		-87		-3307		-111	
Percent Change	-72.5		-64.9		-74.1		-51.8		-35.2		-55.2	
Initial Nitrate (mg/L)	1167	3/6/2007	36	3/5/2007	1733	3/5/2007	0.5*	3/6/2007	2371	3/5/2007	0.5*	3/6/2007
Final Nitrate (mg/L)	172	8/9/2007	4	8/8/2007	752	8/8/2007	1*	8/8/2007	1900	8/8/2007	1*	8/9/2007
Change (mg/L)	-995		-32		-981		NA		-471		NA	
Percent Change	-85.3		-88.9		-56.6		NA		-19.9		NA	
Additional Contaminants												
Initial Uranium (mg/L)	0.51	3/6/2007	0.039	3/5/2007	0.633	3/5/2007	0.022	3/6/2007	1.382	3/5/2007	0.019	3/6/2007
Final Uranium (mg/L)	0.276	8/9/2007	0.018	8/8/2007	0.386	8/8/2007	0.017	8/8/2007	0.598	8/8/2007	0.014	8/9/2007
Change (mg/L)	-0.234		-0.021		-0.247		-0.005		-0.784		-0.005	
Percent Change	-45.9		-53.8		-39.0		-22.7		-56.7		-26.3	
Initial Ammonia (as N) (mg/L)	180	3/6/2007	1	3/5/2007	130	3/5/2007	6	3/6/2007	420	3/5/2007	2	3/6/2007
Final Ammonia (as N) (mg/L)	58	8/9/2007	3	8/8/2007	50	8/8/2007	3	8/8/2007	210	8/8/2007	2	8/9/2007
Change (mg/L)	-122		2		-80		-3		-210		0	
Percent Change	-67.8		200.0		-61.5		-50.0		-50.0		0.0	
Average Percent Change	-74.2		-26.6		-59.6		-36.9		-35.2		-31.5	

* Value at detection limit.; NA = not applicable

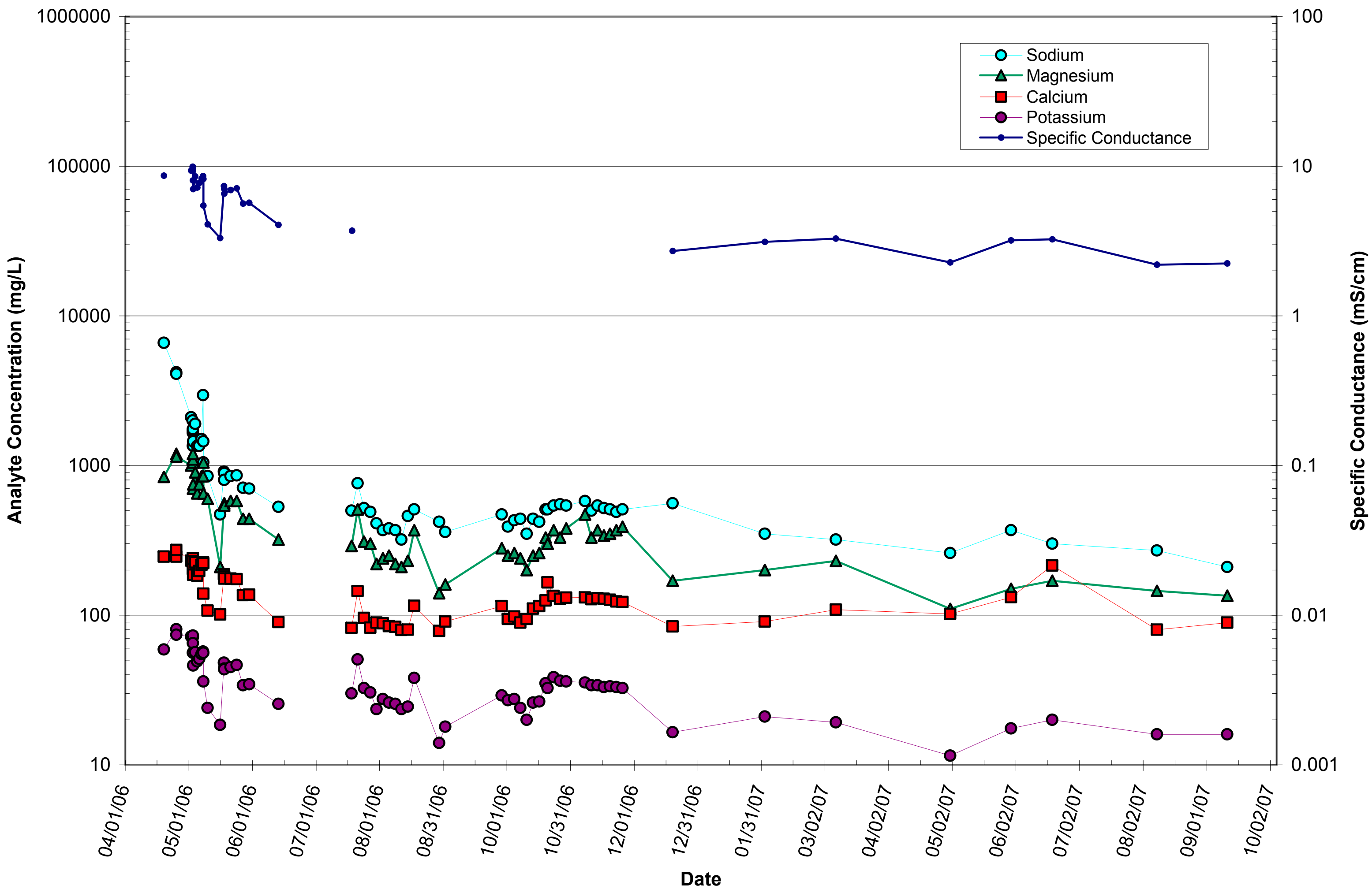

Figure 29. Concentrations of Significant Cations in Trench 2 Discharge

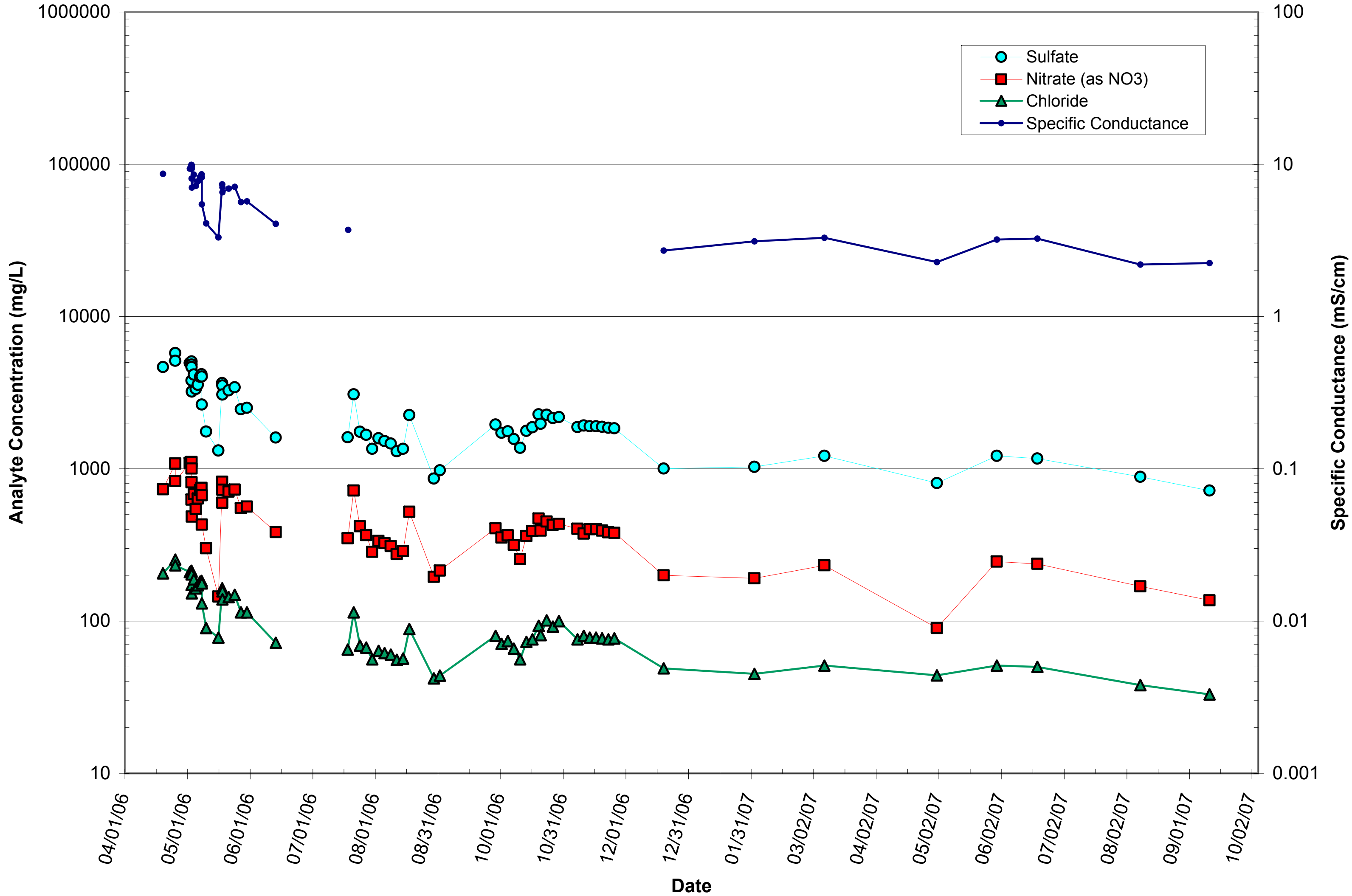

Figure 30. Concentrations of Significant Anions in Trench 2 Discharge

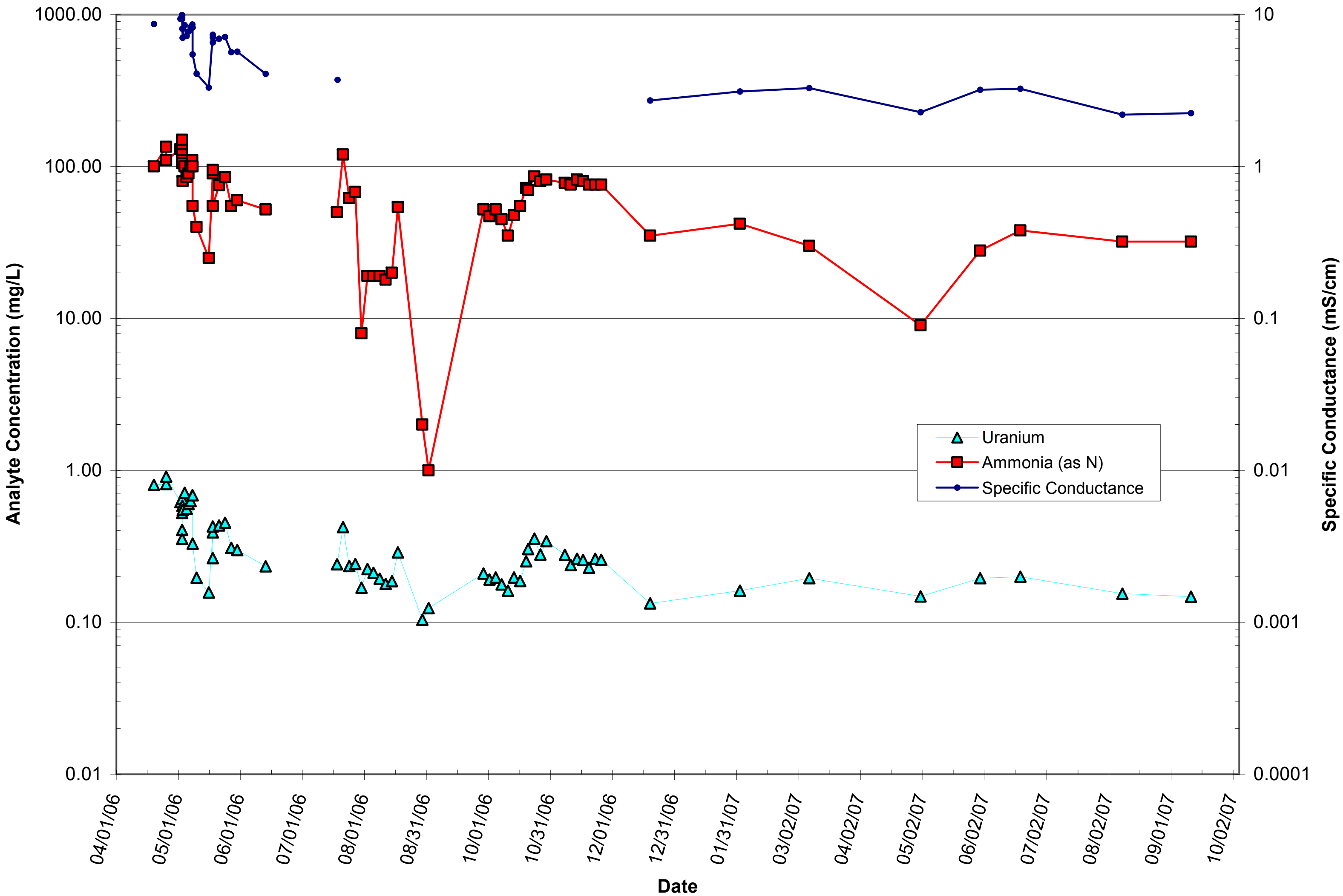

Figure 31. Concentrations of Uranium and Ammonia (as N) in Trench 2 Discharge

A sensor placed in the Trench 2 sump in mid-March 2007 provided virtually continuous measurements of specific conductance in the remediation system's discharge through mid-September 2007 (Figure 32). These data had the same general magnitude of manually measured conductances over the same period (Figure 29), ranging from about 4 mS/cm in spring to about 2 mS/cm in late summer. In comparison, continuous measurements of specific conductance over the same time span at Well 1132, which is located about 25 ft east of the trench, ranged from about 0.4 mS/cm to 0.6 mS/cm (Figure 32), well below conductances measured in the system's discharge. Additional continuously measured specific conductances ranging between 0.4 and 0.5 mS/cm were recorded from June to September 2007 at Well 1117, which is located about 35 ft east of the trench. Such relatively low conductance values suggested that most, if not all, of the groundwater drawn into the trench from its east side during spring and summer 2007 originated as induced inflow of river water.

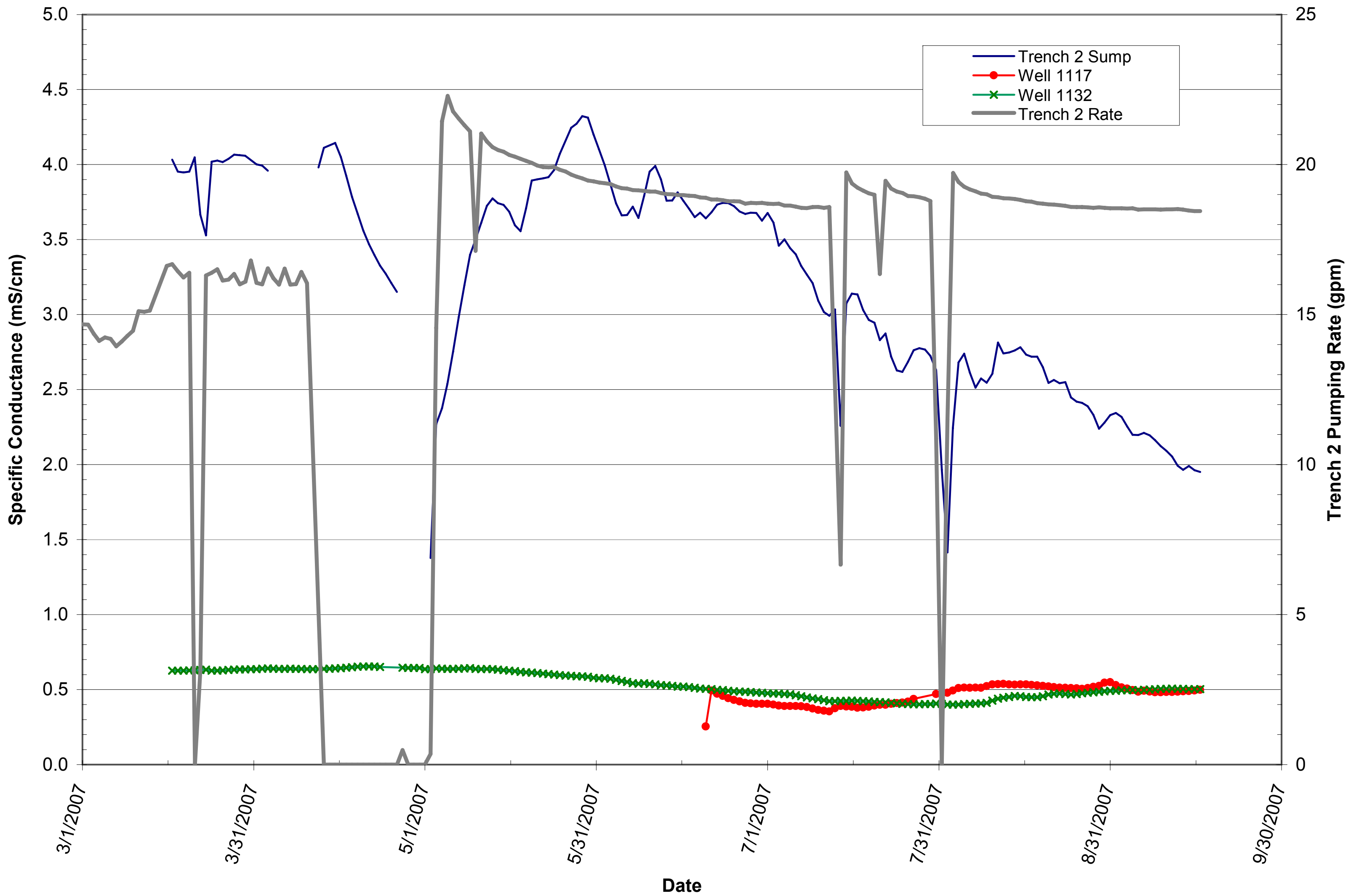

Figure 32. Continuously Collected Specific Conductance Data at the Trench 2 Sump and Wells 1117 and 1132

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7.0 Modeling

A groundwater flow and transport model was developed for the purpose of better understanding the effects of Trench 2 pumping on the alluvial aquifer. The aquifer was assigned a single layer in the model; thus, flow simulation was two-dimensional. Rather than explicitly simulating groundwater flow in the Mancos Shale that lies under and west of the alluvial aquifer, the model was constructed in a manner that simply allowed for subsurface flow inputs representing discharge across the Mancos Shale escarpment. Similarly, no attempt was made to simulate flow beneath the San Juan River; rather the west edge of the river was assigned boundary conditions that permitted flow to occur both to and from the river. The transport portion of the model was used to analyze the spatial and temporal distribution of specific conductance. Though specific ions and contaminants were not examined in the transport modeling, most of the findings regarding specific conductance were considered applicable to individual inorganic constituents as well.

The computer code used to model groundwater flow was MODFLOW (Harbaugh and McDonald 1996), a finite-difference simulator developed and maintained by the USGS. Solute transport was modeled with the simulator MT3DMS (Zheng and Wang 1996), whose groundwater velocity inputs are derived from MODFLOW. The particle tracking module MODPATH (Pollock 1989) was employed to delineate flow paths in the groundwater system. Combined use of these codes was managed within the graphical user interface (GUI) referred to as Groundwater Vistas (ESI 2001).

7.1 Model Construction

The upgradient and downgradient ends of the model were selected to approximately coincide with the north and south ends of the study area depicted in Figure 3. Finite-difference rows were aligned with Trench 2 (i.e., about 12 degrees west of north). As a consequence, model columns were essentially oriented orthogonal to the escarpment and the river. The model comprised 76 rows and 25 columns. Row spacings varied between 1 and 10 ft, with the thinnest rows being assigned to the area encompassed by Trench 2. Column widths were assigned a uniform value of 10 ft. Because the location for Well 1113 fell just beyond the northern edge of the finite-difference grid, water levels at this well were not used as calibration targets in the model.

Because the relatively thin saturated thicknesses in the alluvial aquifer within the study area (5 to 10 ft) have the potential to strongly affect local flow patterns and rates, some consideration was given in the modeling to using spatially variable aquifer bottom elevations for the alluvial aquifer. The purpose of doing so would have been to better represent the larger saturated thicknesses associated with potential paleochannels in the immediate vicinity of Trench 2 (Section 6.2). However, this approach was abandoned because the several bedrock elevations estimated at wells located close to Trench 2 (Figure 12) could not be reliably used to estimate bedrock elevations to the south and north of the trench. Rather, the base of the aquifer in the model was assigned a uniform elevation of 4882.1 ft amsl, which was the average of all estimated top-of-bedrock elevations in the study area (Table 1). It was believed that this approach was adequate for assessing general flow patterns and an overall water budget for the study area despite the possibility that simulated water elevations and flow magnitudes in some parts of the model domain might not accurately represent local conditions.

In much the same manner that insufficient information prevented the use of variable aquifer bottom elevations in the model, spatially variable hydraulic conductivities were not considered. Though an aquifer test had been conducted in the alluvial aquifer at the Shiprock Site (DOE 1999, 2000), it was applicable to an area located north of the Trench 2 study area and could not be reliably used to represent the Trench 2 area. Even if aquifer testing had been conducted in the immediate area surrounding Trench 2, translation of the resulting hydraulic conductivity estimates to areas north and south of the trench would have been conjectural.

In lieu of accounting for variable hydraulic conductivity, several different values of a uniform hydraulic conductivity were considered for the model. Some of the values initially considered were taken from previous modeling investigations (DOE 2000, Knight Piesold 2002), which had used hydraulic conductivities of 100 and 110 ft/day to represent the alluvial aquifer. Ultimately, a range of reasonable estimates of hydraulic conductivity was identified from a series of calibration runs with the model (see Section 7.2). In addition, predictive simulations were made using a single, representative value of hydraulic conductivity that was in the middle of the range of conductivities derived from calibration. As with the assumption of a uniform bedrock elevation, the adoption of a uniform hydraulic conductivity meant that locally computed water elevations and flows might diverge somewhat from actual conditions. Nevertheless, the adopted approach was thought to be useful for helping to interpret the general effects of Trench 2 pumping on flow and transport.

As shown in Figure 33, multiple types of boundary conditions were used in the model. To account for inflows to groundwater from the San Juan River as wells as outflows to this water body, prescribed head boundaries were assigned to model blocks located along the west side of the river. On the basis of river water chemistry data collected in the vicinity of the USGS gaging station on the Shiprock Site (Figure 2), inflow from the river was assigned a specific conductance of 0.4 mS/cm. Diffuse areal recharge to the aquifer from infiltration of precipitation was assumed to be uniform over the model area and was assigned a constant 0.0001 ft/day (0.44 inches per year) in all simulations. This value, which was selected because it was approximately the average of the uniform recharge rates adopted in the models by DOE (2000) and Knight Piesold (2002) as a result of calibration efforts, represented about six percent of the average annual precipitation (7 inches) in the Shiprock area (DOE 2000). The recharge water was assigned a zero specific conductance.

Outflow across the downgradient boundary of the model (i.e., at the study area’s northern end, Figure 33) was simulated using general head boundary (GHB) conditions (Harbaugh and McDonald 1996). The input parameters for this boundary condition were held constant in all simulations, but the use of this type of boundary allowed the flow across the northern edge of the model domain to change in response to varying flow conditions within the study area. Total water discharges from Trench 2 (prescribed flow) due to pumping were divided equally between 20 contiguous model blocks.

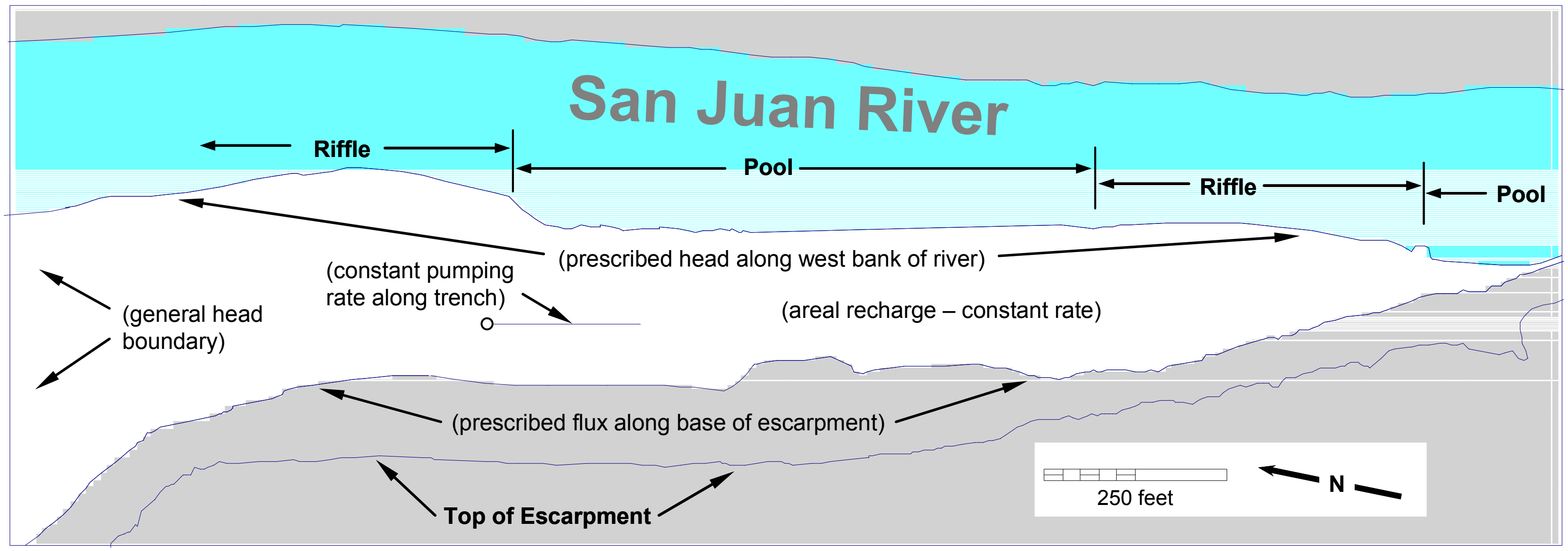

Figure 33. Boundary Conditions (in parentheses) in the Trench 2 Area Model

Prescribed flow boundary conditions were used along the base of the escarpment to represent the inflow of contaminated water across the Mancos Shale Escarpment. A uniform flux value of 0.05 cubic foot per day (ft^3/day) (0.002597 gpm) per foot of the escarpment face was initially assigned to this boundary, which was based on estimates of the flow from the terrace to the alluvial aquifer as derived from DOE's model of the Shiprock Site (DOE 2000). Changes to this inflow component were allowed during calibration runs with the model (Section 7.2), and a uniform value specific conductance assigned to the prescribed inflow across the escarpment was also allowed to vary during model calibration. It was assumed that there was no influx of water from Mancos Shale underlying the alluvium.

7.2 Model Calibration

The model was calibrated in an approximate manner such that it was capable of meeting two objectives: (1) roughly match observed water levels in monitoring wells at different times and (2) generally match observed spatial distributions of specific conductance under background, pre-remediation conditions. Trial-and-error simulations with the flow portion of the model using the previously described initial boundary influx of 0.05 ft^3/day across each foot of the bedrock escarpment face were used to accomplish the first objective, resulting in estimates of representative hydraulic conductivity. The second objective was met using the transport portion of the model.

Rather than running the flow model in a transient mode over multi-month time spans to develop estimates of aquifer hydraulic conductivity, the model was used to simulate six different "quasi steady-state" flow systems, each associated with a specific one- or two-day period during 2007. Inherent in this simulation approach was the assumption that the "time constant" (Domenico and Schwartz 1998) for the local groundwater flow system was relatively short, perhaps as small as a few days. The time periods representing the six quasi steady-state systems were selected to represent various combinations of river flow, variable heads at the river's edge in response to the river flow, saturated aquifer thickness, and pumping rates from Trench 2.

Upon identifying a representative hydraulic conductivity for a given quasi steady-state system, the model was then used to conduct multiple calibration simulations of steady-state transport of specific conductance. It was assumed in the transport modeling that specific conductance behavior was not affected by sorption of dissolved species on aquifer sediments. As a consequence, only four parameters were adjusted during transport calibration efforts. Two of these were the uniformly prescribed influx of water across the escarpment and the single value of specific conductance assigned to that inflowing water and the remaining two were longitudinal and transverse horizontal dispersivity. To assure that previous flow calibration was not significantly changed, care was taken during the transport runs to minimize the perturbations of prescribed influx around the initial value adopted for this flow component. Calibration was considered complete for a given quasi steady-state system once a combination of hydraulic conductivity, prescribed inflow across the escarpment, specific conductance at the escarpment boundary, and aquifer dispersivities produced a steady-state distribution of specific conductance that reasonably matched distributions associated with pre-2006 conditions (Section 6.5.1). This approach ultimately resulted in six different model calibrations.

7.2.1 Quasi Steady-State Systems

Table 6 lists data pertinent to each of the six quasi steady-state models used for flow calibration. Some of the data shown were used as model calibration targets (i.e., average daily water levels at most wells), whereas others were used to develop model inputs (prescribed hydraulic heads along the river, Trench 2 pumping rates). As indicated, three of the simulation periods were based on three different single-day periods, data for each of which were drawn from automatically collected data, not only for water levels in wells but also for the Trench 2 pumping rate. The three additional time periods coincided with three separate two-day sampling events for which both water chemistry and water level data were available. The specific conductance and constituent concentration data from these latter events provided some insight to flow conditions that could not be fully discerned on the basis of water levels alone. In lieu of using automatically collected water level data at each well to develop head calibration targets for the two-day events, a single, manual measurement of water level during one of the two days was used as the target. Though this step failed to account for any temporal variations in hydraulic head that might have occurred during the two days of sampling, it did produce a set of water levels that were all measured in a consistent manner.

The parameters presented in Table 6 as being applicable to groundwater flow on April 30 and May 1 of 2007 were of interest because they represented flow conditions during the last two days of a previously mentioned multi-day period beginning in April of little to no pumping at Trench 2. Thus, this simulation time was potentially representative of a background flow system that existed prior to the installation and operation of Trench 2. Moreover, this time may have been representative of “average” flow conditions when pumping does not occur because the average flow of the river during the two-day period was 2,435 cfs, which was slightly larger than the long-term average flow in the river of about 2,050 cfs.

7.2.2 Prescribed Head Boundary at the River

One of the most challenging aspects of developing calibrated flow models for each of the six time periods shown in Table 6 was the determination of prescribed hydraulic heads along the west edge of the San Juan River. Short of having actual measured water elevations for the river surface, it was assumed that water levels measured at Well 1130 (Figure 9) during each of the simulated times could be used as a prescribed head for the model block in which the well sits. However, corresponding prescribed heads along the river’s edge upstream and downstream of Well 1130 had to be estimated. The most practical method for deriving such heads was to use groundwater levels measured at wells within the study area.

Table 6. Data Applicable to Flow Model Calibration Simulations Under Quasi Steady-State Conditions

Location	Data Type	Date Simulated					
		4/4/2007	4/30 - 5/1/2007	5/14/2007	6/18/ - 6/19/2007	7/11/2007	8/8 - 8/9/2007
Port A	Average Daily Water Level (ft amsl)	4886.10	4889.02*	4888.49	4886.94*	4885.43	4886.22*
Port C	Average Daily Water Level (ft amsl)	4886.73	4888.8*	4888.93	4887.43*	4886.54	NA
Well 1114	Average Daily Water Level (ft amsl)	NA	4888.1*	NA	4887.56*	NA	4886.93*
Well 1115	Average Daily Water Level (ft amsl)	4886.33	4888.66*	4888.52	4887.04*	4885.64	4886.33
Well 1116	Average Daily Water Level (ft amsl)	NA	4888.68*	NA	4887.54*	NA	4886.98*
Well 1117	Average Daily Water Level (ft amsl)	4886.88	4888.78*	4889.18	4887.97*	4886.55	4887.42*
Well 1125	Average Daily Water Level (ft amsl)	4887.15	4888.57*	4889.45	4888.68*	4886.54	4887.26*
Well 1126	Average Daily Water Level (ft amsl)	4886.76	4888.57*	4888.80	4887.31*	4886.01	4886.71*
Well 1127	Average Daily Water Level (ft amsl)	NA	4888.8*	NA	4888.41*	4890.04	4887.95*
Well 1128	Average Daily Water Level (ft amsl)	4886.80	4888.69*	4888.89	4887.48*	4886.48	4886.95*
Well 1129	Average Daily Water Level (ft amsl)	NA	4888.89*	4891.46	4888.53*	4888.52	4888.02*
Well 1130	Average Daily Water Level (ft amsl)[1]	4888.85	4889.14*	4891.91	4889.28*	4888.55	4888.73**
Well 1131	Average Daily Water Level (ft amsl)	4887.29	4888.71*	4889.73	4887.91*	4886.89	4887.75*
Well 1132	Average Daily Water Level (ft amsl)	4886.88	4888.72*	4889.16	4887.6*	4886.37	4886.97*
Well 1133	Average Daily Water Level (ft amsl)	4886.40	4888.68*	4888.62	4887.12*	4885.97	4886.48*
Well 1134	Average Daily Water Level (ft amsl)	4886.70	4888.71*	4888.93	4887.27*	4885.95	4886.77*
River at Upstream End of the Model	Prescribed Hydraulic Head (ft amsl)[2]	4890.38	4890.67	4893.44	4890.81	4890.08	4890.26
River at Downstream End of the Model	Prescribed Hydraulic Head (ft amsl)[3]	4887.63	4887.92	4890.69	4888.06	4887.33	4887.51
Trench 2 Pumping Well	Average Daily Pumping Rate (gpm)	16.21**	0	20.48**	18.93**	18.56**	19.02**
San Juan River Gaging Station	Average Daily River Flow (cfs)	1220**	2435**	8450**	3620**	784**	3930**

[1]Measured water levels at Well 1130 used as a prescribed head at the edge of the river.
[2]Upstream prescribed head = water elevation at Well 1130 + 1.53 ft.
[3]Downstream prescribed head = water elevation at Well 1130 - 1.22 ft.
*Manual measurement
**Average of automated measurements over the two-day sampling event.
NA - Reliable water level not available

As discussed in Section 6.2.1, pre-2006 water level data in Wells 735 and 608, located 1,610 ft apart, showed that south-to-north hydraulic gradients within the study area could vary between 0.00077 and 0.00244. Assuming that the average of these two gradients, a value of 0.0016, was representative of the floodplain aquifer during several different states of river flow, prescribed heads on the west edge of the river were estimated for the quasi steady-state periods listed in Table 6. This was accomplished by using the average gradient to extrapolate measured water elevations at Well 1130 to both the upstream and downstream ends of the model (Table 1), and then interpolating between the three elevations to derive prescribed heads at interlying model blocks along the river's edge. One of the drawbacks of this methodology was that it failed to account for spatial changes in the longitudinal profile of the water surface attributable to sequential pools and riffles. That is, a relatively flat water surface would be expected in river pools and steeper water gradients would be associated with riffles, the combination of which tends to control flow through hyporheic zones (Section 4.1, Figure 5). Nevertheless, assignment of steadily decreasing heads from south to north along the west side of the river provided a preliminary means of assessing water exchanges between the river and the aquifer.

7.2.3 Calibration Findings

The six quasi steady-state calibration efforts revealed that uniform hydraulic conductivities ranging from 50 to 100 ft/day were capable of reproducing measured water elevations in study area wells. Most of the estimated hydraulic conductivities resulting from the calibration runs fell in the higher end of this range. The lowest estimated hydraulic conductivity of 50 ft/day resulted from attempts to match observed water elevations on May 14, 2007, at a time when flow in the San Juan River (8,450 cfs) was moderately high due to spring runoff. The corresponding high groundwater elevations at this time indicated that the top of the saturated zone was located in the fine-grained sediments that tend to occupy the uppermost 4 to 6 ft of alluvium at the floodplain. Consequently, the relatively low hydraulic conductivity used to calibrate the model at the time of large river discharge may have been indicative of some flow through the shallow fine-grained materials.

The six different calibrations of the flow model identified a uniform hydraulic conductivity of 85 ft/day as being generally representative of the materials comprising the alluvial aquifer. Simulations of specific conductance transport revealed that pre-2006 distributions of specific conductance were best duplicated when using the combination of a uniform prescribed influx of 0.07 ft^3/day (3.6 x 10^{-4} gpm) per foot of escarpment length and a uniform specific conductance of 20 mS/cm in the inflowing water. Additional flow simulations using this prescribed inflow showed that, despite the fact that it was larger than the influx value initially used in the modeling, it had little impact on the earlier flow calibrations. In effect, the flow portion of the model was found to be much more sensitive to changes in hydraulic conductivity than to changes in the escarpment inflow.

Aquifer dispersivity appeared to strongly affect the distribution of specific conductance between the escarpment and the river. In particular, multiple simulations with the transport portion of the model indicated that, in addition to the predominantly northward flow paths in the aquifer, anomalously low values of dispersivity were necessary for duplicating the large drop in specific conductance observed between the west and east edges of the model area prior to Trench 2 operations (Figure 16). Under the assumption that a longitudinal dispersivity of about 10 percent of total plume length typically best represents transport within that plume (Gelhar et al. 1985), values of longitudinal dispersivity initially used in the simulations were as large as 200 ft.

However, values of this magnitude tended to produce computed plumes that were more diffuse than had been observed prior to 2006. Ultimately, a longitudinal dispersivity of 10 ft and a transverse horizontal was used to reasonably duplicate background distributions of specific conductance. Transverse horizontal dispersivity was assigned a value of 1 ft, or ten percent of the longitudinal dispersivity.

7.3 Simulations of Average Flow Processes

Using the findings from the quasi steady-state calibration simulations, two flow models were developed to depict "average" flow processes in the Trench 2 study area. One model accounted for steady-state flow under background (non-pumping) conditions and the other represented a steady-state flow configuration resulting from continuous, steady pumping at the trench. Graphical and tabular results from the models are presented in the following sections.

7.3.1 Background Conditions

The flow model of average background conditions was based on the assumption that flow in the San Juan River is maintained at a constant value of 2,050 cfs, the long-term average discharge in the river. On the basis of information provided in Table 6 for the April 30/May 1 period in 2007, prescribed heads at model blocks representing the west edge of the river at Well 1130, the upstream end of the model, and the downstream end of the model were set at 4889.10, 4890.63, and 4887.88 ft amsl, respectively. Hydraulic conductivity was assigned a uniform value of 85 ft/day and the escarpment influx rate was set at 0.07 ft^3/day (3.6 x 10^{-4} gpm) per foot of boundary length. An aquifer porosity of 0.25 was used in the model to calculate groundwater velocities.

The computed steady-state groundwater elevations and corresponding velocity vectors produced by this model (Figure 34) indicated mostly northward flow, parallel to both the river and the escarpment. Numerical particle tracking conducted with the model generated multiple traces for particles released several hundred feet south of Trench 2 that extended the full length of the study area (Figure 35), which comported with flow paths described in the site conceptual model (Section 4.1, Figure 5). Some of these traces originated as seepage from the river adjacent to the river pool identified near the southern end of the study area, and eventually passed about 50 to 60 ft east of the Trench 2 footprint. Additional particles released near the escarpment and in the southern half of the model came within 10 to 20 ft of the trench, indicating delivery of site contaminants to the trench vicinity under background flow conditions.

The traces of particles released close to the river at several locations within the steady-state model (Figure 35) suggested that much of the water entering the aquifer due to river seepage discharges back to the river within relatively short distances downstream of where the inflow occurs. Though it may be difficult to prove using field data, these relatively short flow paths within the model domain were likely numerical artifacts resulting from the use of prescribed head boundary conditions to account for river-aquifer exchanges and were not considered representative of actual flow. Despite this numerical difficulty, some particle traces were similar to the hyporheic zone flow patterns that were thought to exist under non-pumping conditions near two pool-and-riffle sequences on the river within the study area (Figure 5). More accurate simulation of the groundwater flow between successive pools on the river would likely be achieved by better accounting for the respective changes in water surface profile induced by sequential pools and riffles.

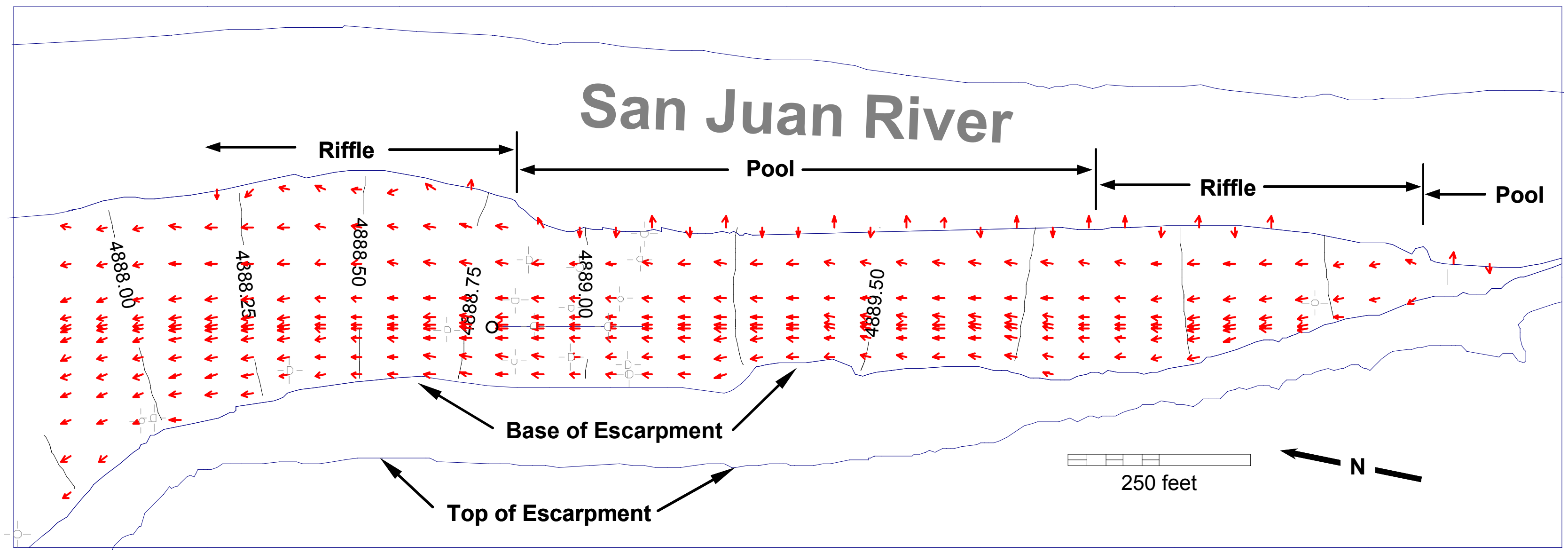

Figure 34. Computed Groundwater Elevations and Velocity Vectors Produced by the Model of Average Background Flow Conditions

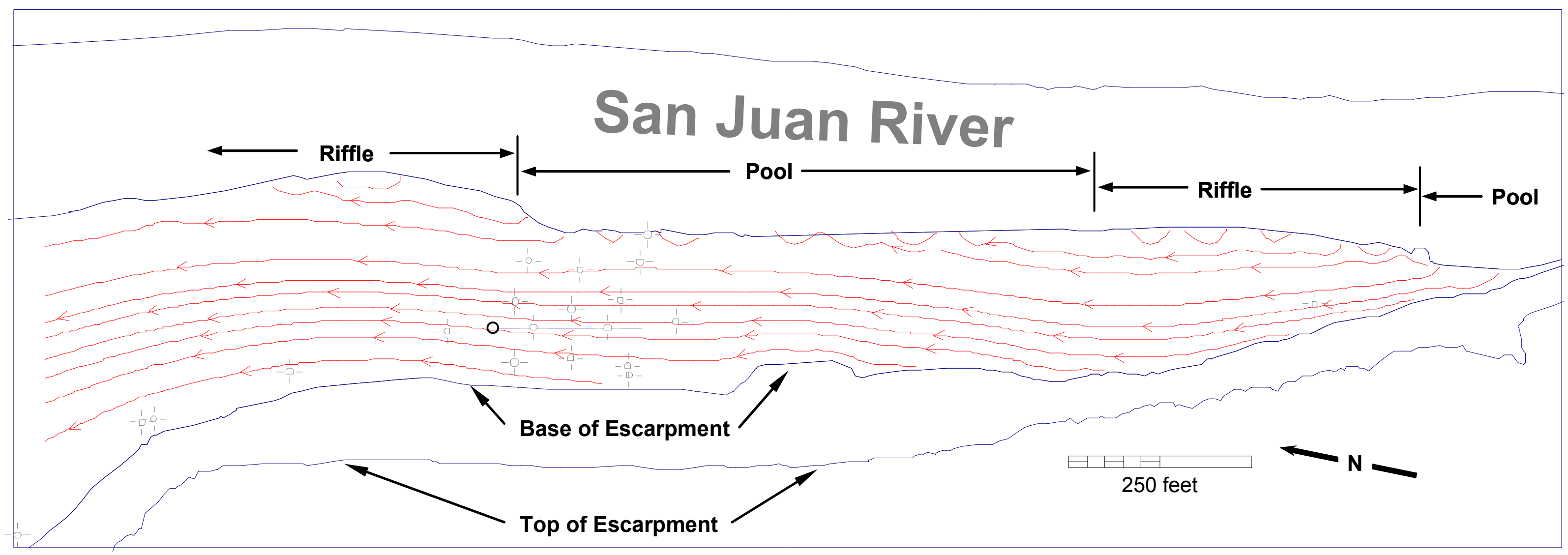

Figure 35. Particle Tracks Produced by the Model of Average Background Flow Conditions

The steady-state water budget produced by the model of average, background flow conditions, as summarized in Table 7, showed that the amount of groundwater migrating through the study area when Trench 2 was not pumping was limited to about 7 gpm. The model also indicated that as much as 85 percent of the total inflow to the study area came from river losses, and the inflow from groundwater discharge along the escarpment was about 11 percent of the total. Recharge from precipitation was limited to about 3 percent of the total inflow to the model area. Of some interest is the fact that the background flow model showed 79 percent of the system inflow leaving the study area by way of discharge to the river, which in turn meant that most of the river water entering the system flowed back to the river rather than migrate northward across the model's northern boundary.

Table 7. Steady-State Water Budgets in the Models of Average Flow Conditions

Flow Component	Background Flow			Pumping Conditions		
	(ft^3/day)	(gpm)	percent	(ft^3/day)	(gpm)	percent
Inflow						
Riverbed Seepage	1104.0	5.73	85.6	4256.9	22.10	95.8
Recharge from Precipitation	43.4	0.23	3.4	43.4	0.23	1.0
Bedrock Discharge	141.4	0.73	11.0	141.4	0.73	3.2
Outflow						
Riverbed Seepage	1017.8	5.3	79.0	567.8	2.95	12.8
North Model Boundary	270.7	1.4	21.0	214.2	1.11	4.8
Trench 2 Pumping Rate	0.0	0.0	0.0	3659.8	19.00	82.4

7.3.2 Steady Pumping Conditions

The model of average flow conditions associated with Trench 2 pumping assumed that the trench was pumped continuously at a rate of 19 gpm, which was a typical rate achieved by the remediation system during spring and early summer 2007. The aquifer and boundary parameters adopted in this model were identical to those used to simulate background flow conditions; thus no attempt was made to account for temporally variable river elevation. As shown in Figure 36, the steady-state water levels and velocity vectors produced by this model took on a radically different look from those associated with background flow. The pumping caused flow to converge on the trench from all directions and the only water in the study area that was not captured by the trench was located several hundred feet north of the trench. The simulation predicted a drop in water level of about 3 ft (Figure 36) between the river and the trench, which correlated well with observed differences in water level between these two locations during pumping (Section 6.2.2).

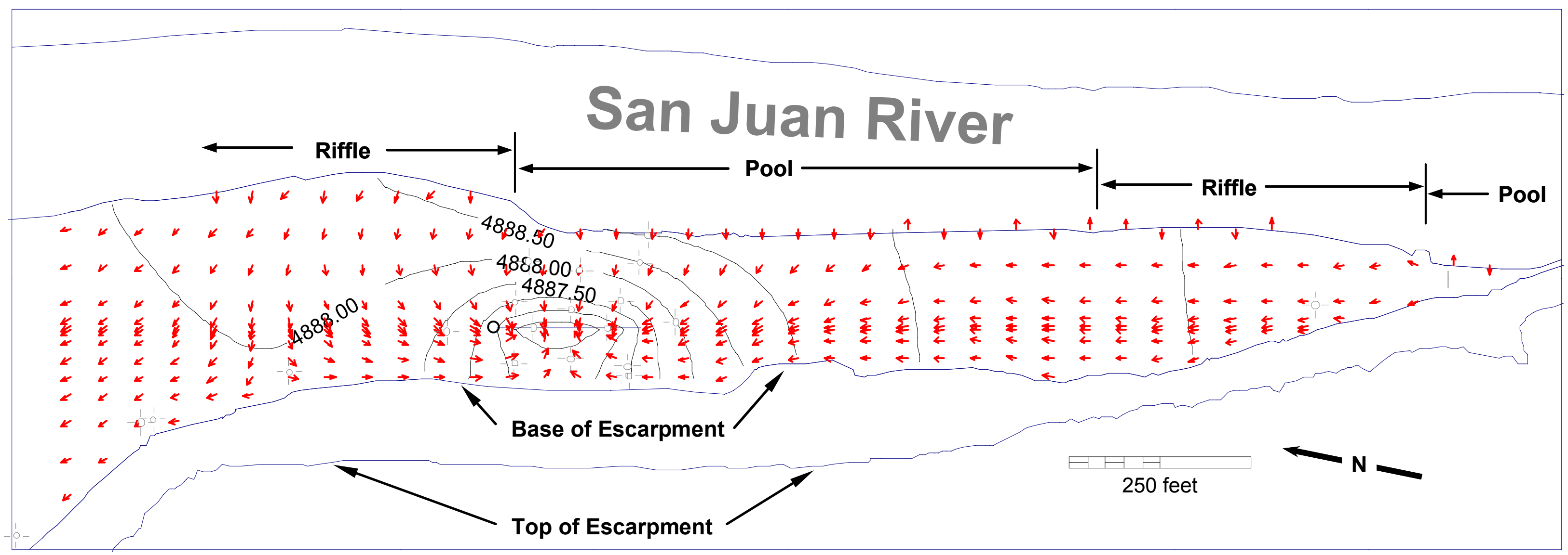

Figure 36. Computed Groundwater Elevations and Velocity Vectors Produced by the Model of Average Pumping Conditions

Particle tracks produced in the flow model of continuous pumping (Figure 37) further illustrated the degree to which remedial pumping could cause flow to converge on the trench. The particle traces suggested that Trench 2 operations could induce inflow from riverbed seepage as far as 400 ft upstream (south) of the trench's southern end. Similarly, the trench appeared capable of capturing groundwater and river water as much as 350 ft north of the trench sump. As shown in Figure 37, a significant portion of the water drawn into the trench entered the horizontal well from the west. Water entering the well from the east appeared to originate as river losses along a 300-foot long section of the river. Travel times associated with the particle traces originating along this river section indicated that it would take about 3 weeks to 2 months for river water to reach the trench. As expected, the travel times associated with particle traces entering the west side of the trench were longer and varied greatly depending on the total length of travel and the rate of decrease in water velocity with distance from the trench.

The flow budget for the model of steady trench pumping, summarized in Table 7, suggested that the quantity of river water entering the flow system during pumping was almost four times the comparable quantity that occurred under background flow conditions. Trench 2 pumping also greatly decreased the amount of groundwater that discharged to the river or flowed out of the study area across the model's north boundary (Table 7). Further inspection of model results revealed that about 70 percent of the pumped water entered the trench from its east side and 30 percent came from the west. This observation helped illustrate the significant impact that the river area nearest the trench could have on the remediation system despite the tendency for water entering the trench on its west side to cover a much larger source area (Figure 37). Accordingly, contaminated water entering the horizontal well was expected to be heavily diluted by the inflow of groundwater originating as riverbed seepage.

7.4 Representative Simulations of Specific Conductance Transport

The model of average background flow conditions (Sections 7.3.1) was used to conduct an associated simulation of representative steady-state specific conductance distribution in the alluvial aquifer before Trench 2 pumping began. Similarly, the model of average flow conditions in response to pumping (Section 7.3.2) was used to project how specific conductance distributions generally changed over time in the aquifer since continuous pumping from Trench 2 began in the first week of May 2006. Transport parameters used in both simulations (Table 8) were based on findings from the calibration effort (Section 7.2.3).

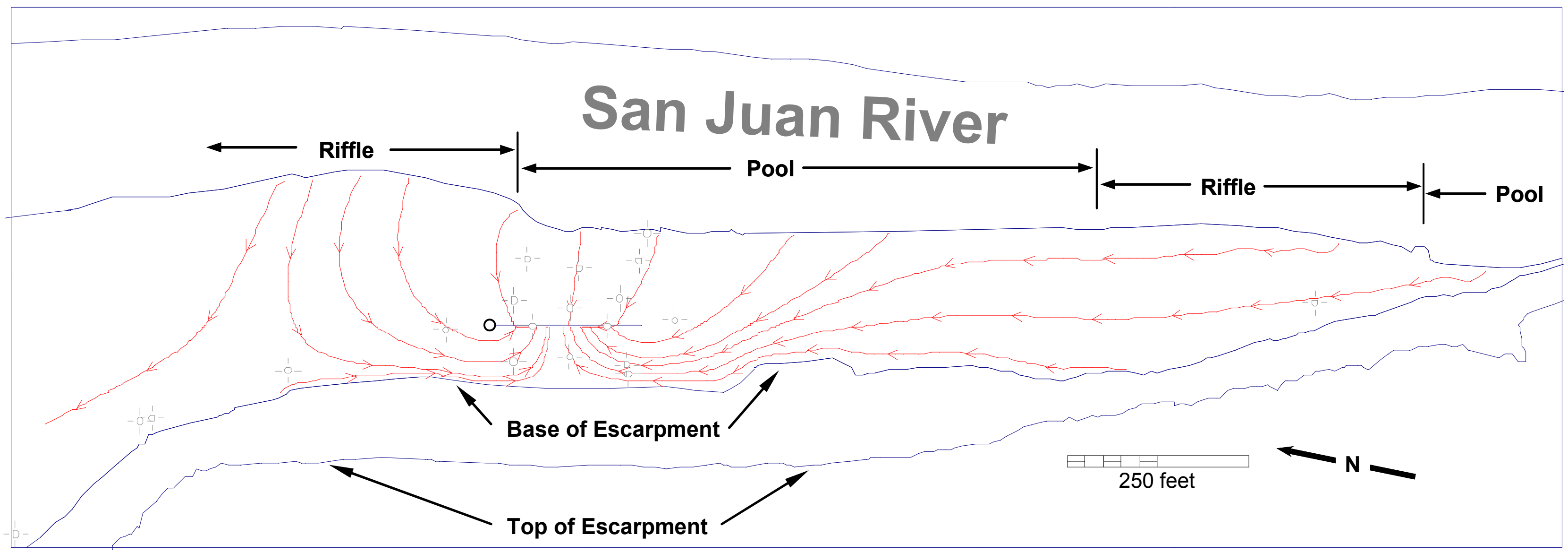

Figure 37. Computed Groundwater Elevations and Velocity Vectors Produced by the Model of Average Pumping Conditions

Table 8. Parameters Use to Conduct Transport Simulations for Specific Conductance

Parameter	(Units)	Value
Effective Porosity	dimensionless	0.25
Longitudinal Dispersivity	(ft)	10
Transverse Horizontal Dispersivity	(ft)	1
Specific Conductance of River Water	(mS/cm)	0.4
Specific Conductance of Water Discharging from Bedrock at the Escarpment	(mS/cm)	20

7.4.1 Specific Conductance Distribution Prior to Trench 2 Operation

Steady-state specific conductances generated by the model of average background conditions (Figure 38) generally correlated well with measured values of this water chemistry parameter prior to 2006 (Figure 16). For example, computed specific conductance between Trench 2 and the escarpment ranged from 14 to 20 mS/cm, and specific conductance at the trench itself was about 13 mS/cm. In addition, the model produced a continuous band of non-contaminated water (specific conductance ≅ 0.4 to 1.2 mS/cm) adjacent to the river throughout the study area's length. However, the model performed less admirably in matching observed specific conductances at Well 735, near the southern end of the study area. Though the computed steady-state specific conductance in the local area (5-6 mS/cm) fell in the low end of the range of measured values at Well 735 prior to 2006 (2-24 mS/cm [Table 3]), measured specific conductances at the well during 2006 and 2007 were significantly larger, varying between 13 and 16 mS/cm (Figure 17). As discussed in Section 6.5.1, this difference could have been attributed to temporally varying amounts of river water in the area mixing with contaminated water flowing locally across the escarpment. Short of having more thorough hydraulic and water chemistry information for the area surrounding Well 735 during 2006 and 2007, it was impossible to tell which boundary condition (local losses of river water or specific conductance influx across the escarpment) could have been defensibly adjusted in the model to achieve a better match to Well 735 water chemistry.

7.4.2 Effects of Trench 2 Pumping on Specific Conductance

The simulation of transient transport of specific conductance accounted for the time between May 4, 2006, when generally continuous pumping began, and the first week in September 2007, some 16 months later. It was assumed in this model run that the trench was pumped at a steady-rate of 14.2 gpm, which was the average groundwater extraction rate (including non-pumping days) measured at the Trench 2 sump over this time period. The steady-state specific conductances generated by the transport model of average background conditions (Section 7.4.1) were used as initial conditions in the transient simulation.

7.4.2.1 Areal Distribution

Map views of resulting computed specific conductances were prepared for simulation times of 1 month, 3 months, 6 months, 1 year, and 15 months after the start of pumping (Figures 39 through 43, respectively). These times corresponded to the first weeks of June, August and November of 2006, and May and September of 2007.

As shown in Figure 39, continuous pumping through the first week of June 2006 was expected to have reduced almost all specific conductances on the east side of the trench from pre-pumping values as large 13 mS/cm to as little as 4 mS/cm. In addition, computed conductances immediately north of the trench (at Well 1126) and south of the trench (at Well 1127) had decreased significantly at this time. Though the area directly west of the trench also experienced some change, the drop in computed specific conductance here was much less dramatic than that occurring east of the trench. Similarly, any computed changes in specific conductance outside the immediate vicinity of the trench appeared to be minor to insignificant (Figure 39).

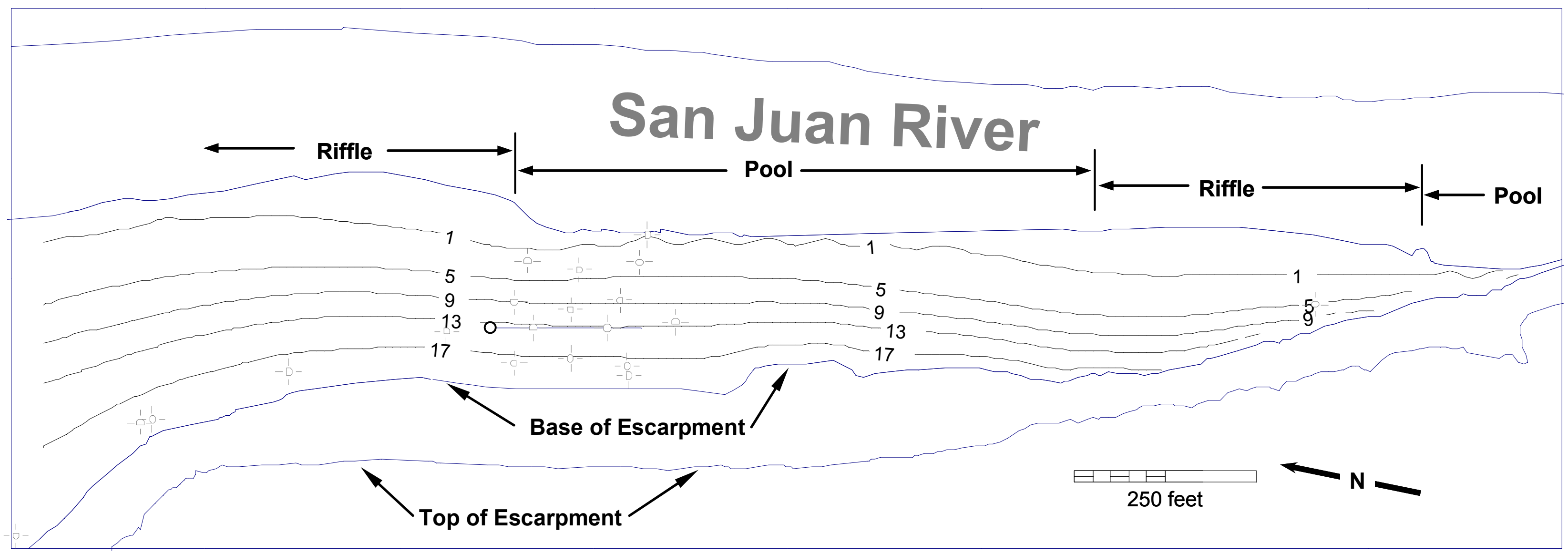

Figure 38. Computed Specific Conductances (mS/cm) by the Model of Average Background Conditions

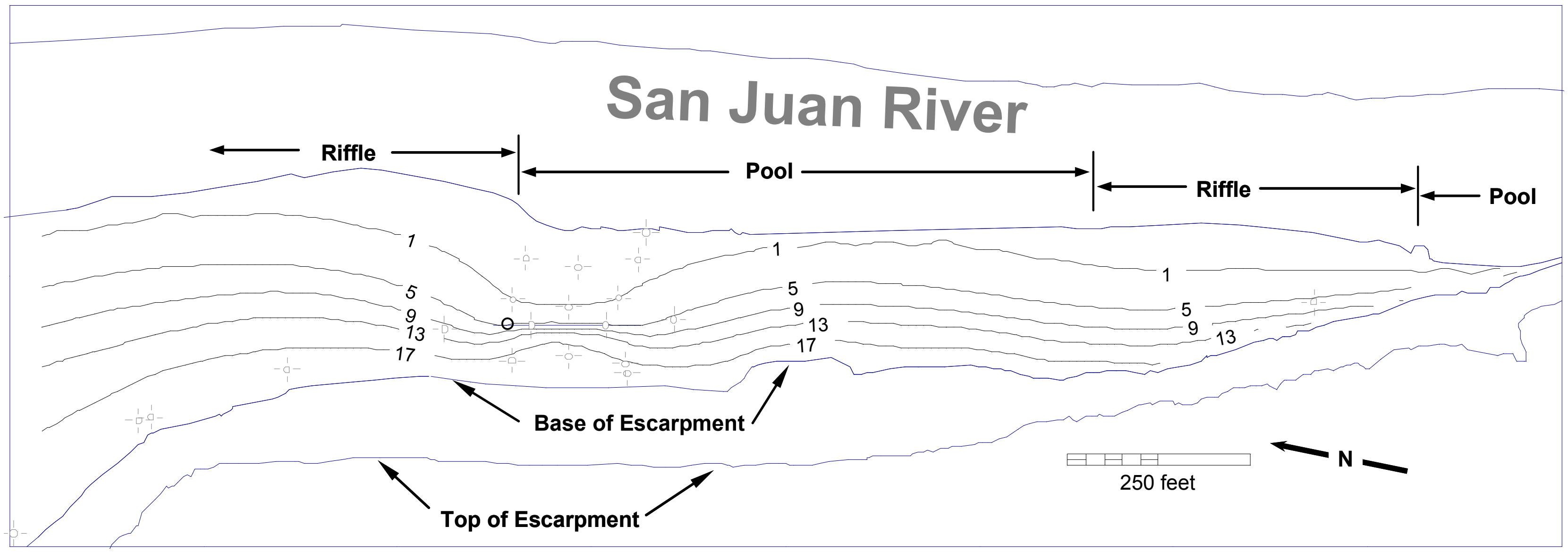

Figure 39. Computed Specific Conductances (mS/cm) in the First Week of June 2006 (After 1 Month of Pumping)

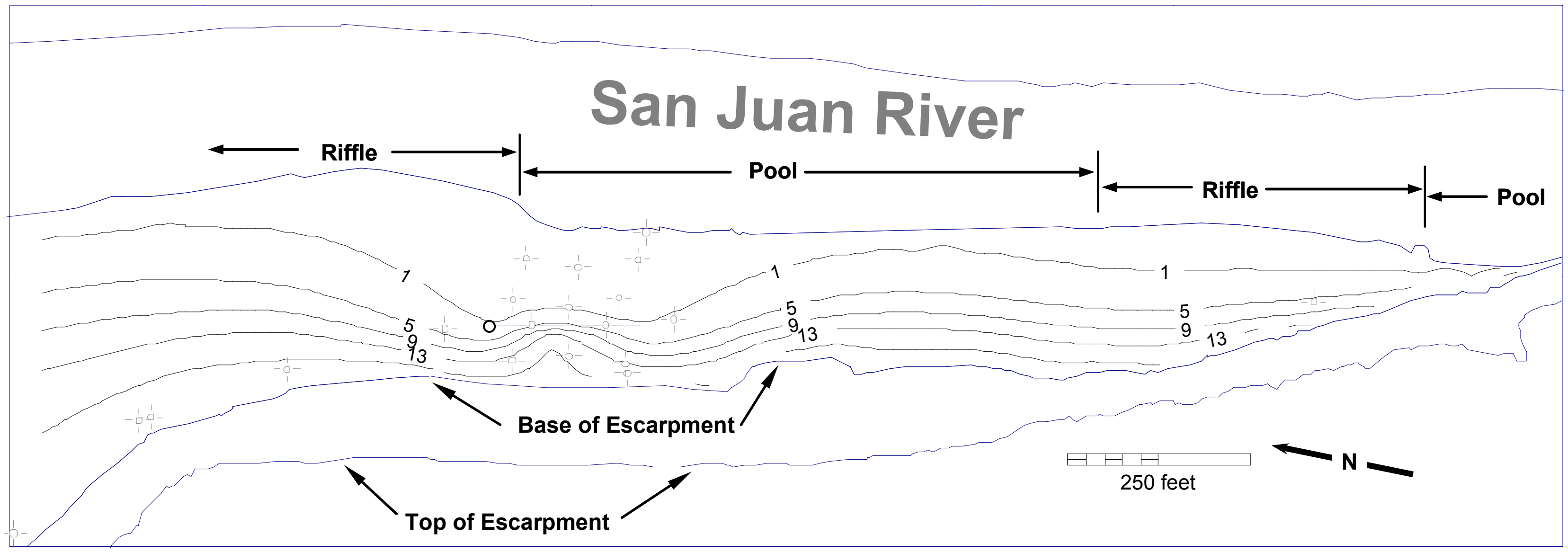

Figure 40. Computed Specific Conductances (mS/cm) in the First Week of August 2006 (After 3 Months of Pumping)

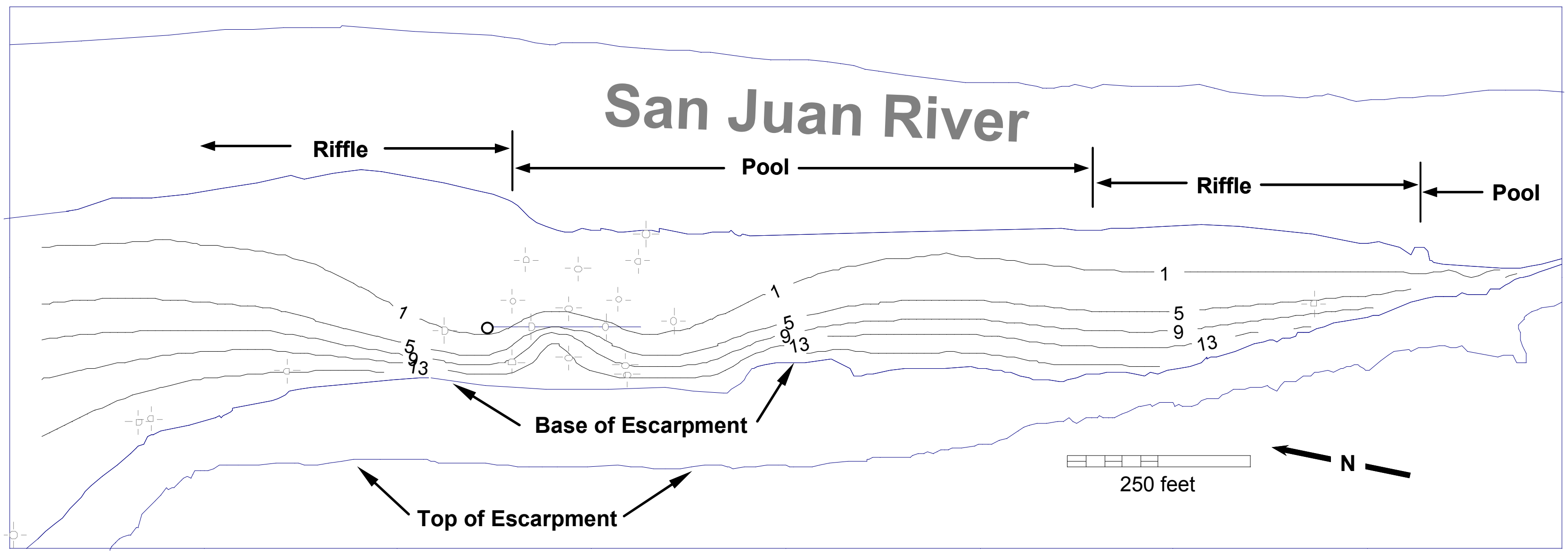

Figure 41. Computed Specific Conductances (mS/cm) in the First Week of November 2007 (After 6 Months of Pumping)

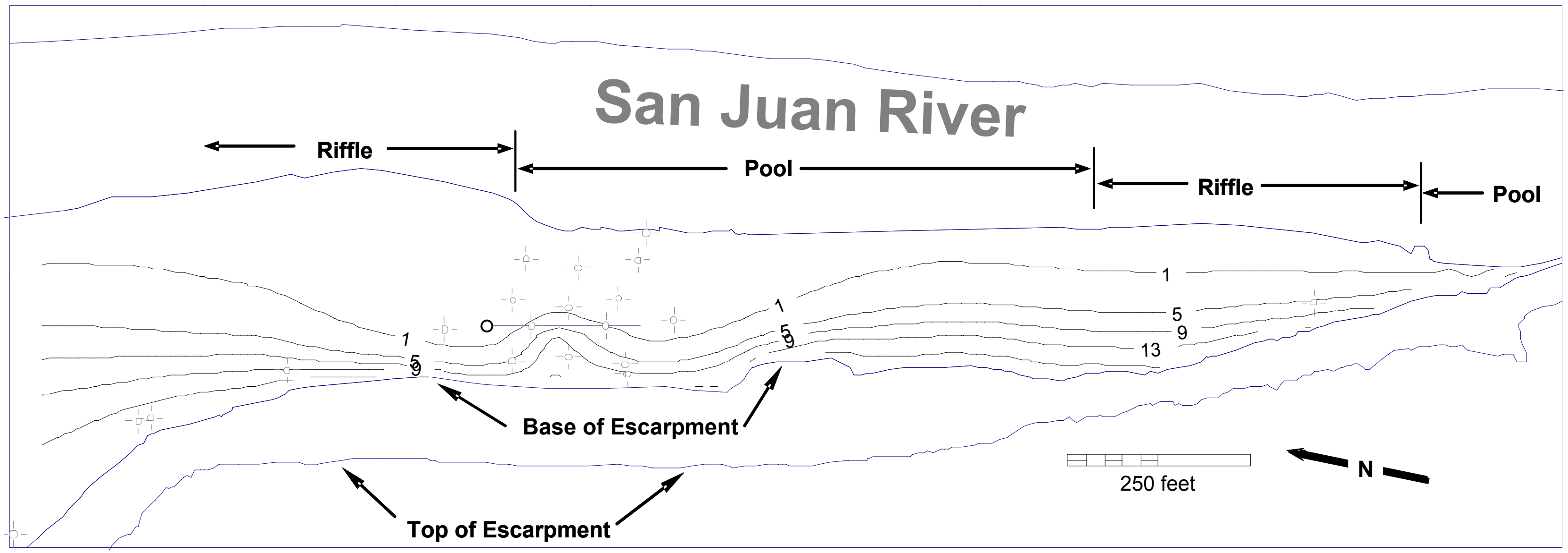

Figure 42. Computed Specific Conductances (mS/cm) in the First Week of May 2007 (After 1 Year of Pumping)

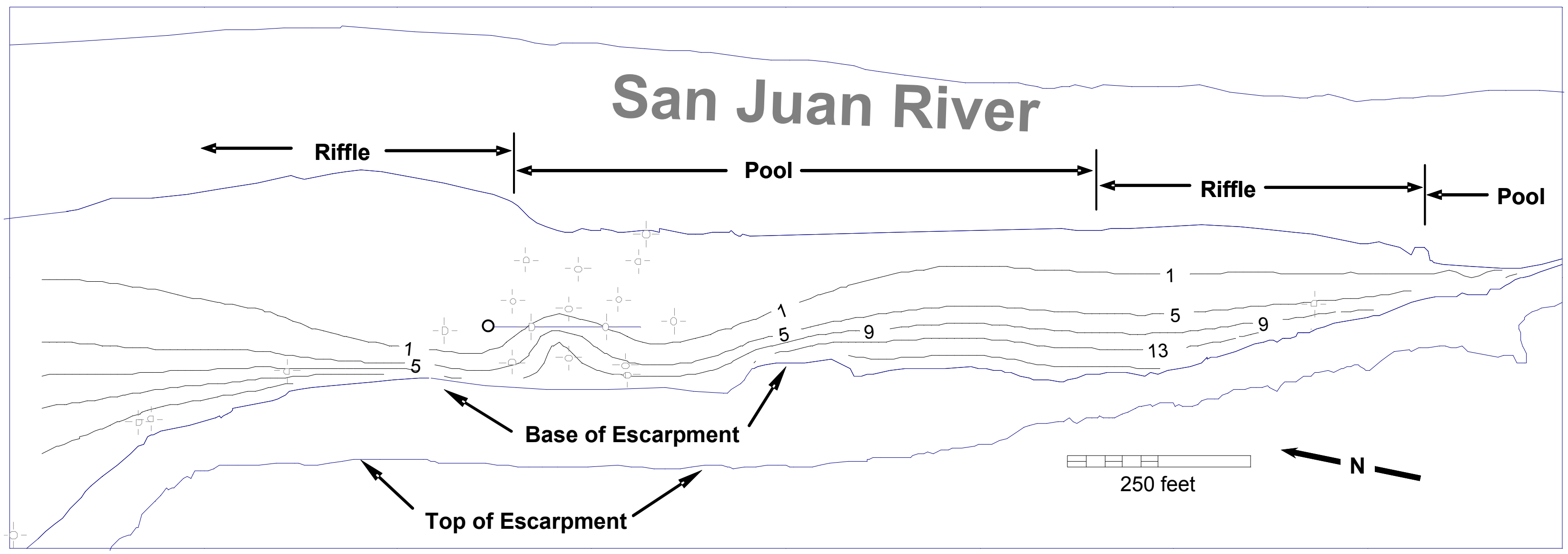

Figure 43. Computed Specific Conductances (mS/cm) in the First Week of September 2007 (After 16 Months of Pumping)

Model-generated changes in specific conductance after three months of pumping (in August 2006) were quite dramatic (Figure 40). Groundwater directly south of the trench, at Well 1127, appeared to be dominated by non-contaminated water that came from an area next to the river, and significant reductions in specific conductance were also occurring north of the trench in the vicinity of Well 1126. In addition, some reductions in background levels of specific conductance were observed close to the escarpment and as much as 150 ft upgradient (south) of the trench. As shown in Figure 41, these changes become even more evident after six months of continuous pumping, at a time representing early November 2006.

Model results after one-year of pumping (Figure 42, representing the first week of May 2007) were significant because they suggested that specific conductance in nearly all groundwater occurring between the trench and the escarpment directly to the west, as well as 100 ft to the north and south of this area, had been reduced well below the values of 15 to 20 mS/cm that dominated this area adjacent to the escarpment prior to the start of pumping (Figure 38). Very similar results after a total of sixteen months of pumping (Figure 43, representing early September 2007) suggested that dissolved constituent transport had reached a virtual steady state in areas within 100 ft of the trench.

The most noticeable feature of each of the transport snapshots generated by simulations of Trench 2 pumping since early May 2006 was the creation of a clear demarcation line between low specific conductance on the east side of the trench and noticeably larger specific conductances directly west of the trench. Such results, which generally comported with actual sampling results at near-trench wells since remediation began (Figures 17 and 23, Tables 4 and 5), were attributed to replacement of contaminated water on the east side of the trench by river water. The model projections in Figures 39-43 helped to show how this replacement occurred and further demonstrated that installation of a groundwater extraction system close to the escarpment provides an effective mechanism for removing contamination between the system and the river.

7.4.2.2 Temporal Behavior of Specific Conductance at Selected Wells

As a measure of the transport model's capacity to predict changes in constituent concentration in response to Trench 2 pumping, model-computed specific conductances were compared to corresponding values measured at several sampling locations in the study area during 2006 and 2007. One of these comparisons was made between monitored specific conductance values in discharge water at the Trench 2 sump and the average conductance computed for the 20 model cells containing the trench. Graphical results from this evaluation, presented in Figure 44, showed that the model overpredicted specific conductance at the sump during the first few months of pumping (May 4 through mid-July 2006) and underpredicted specific conductance between December 2006 and August 2007. Nonetheless, the model appeared to capture the general nature of dissolved constituent decreases at the sump due to the increasing dilution of contaminant influx with increasing time.

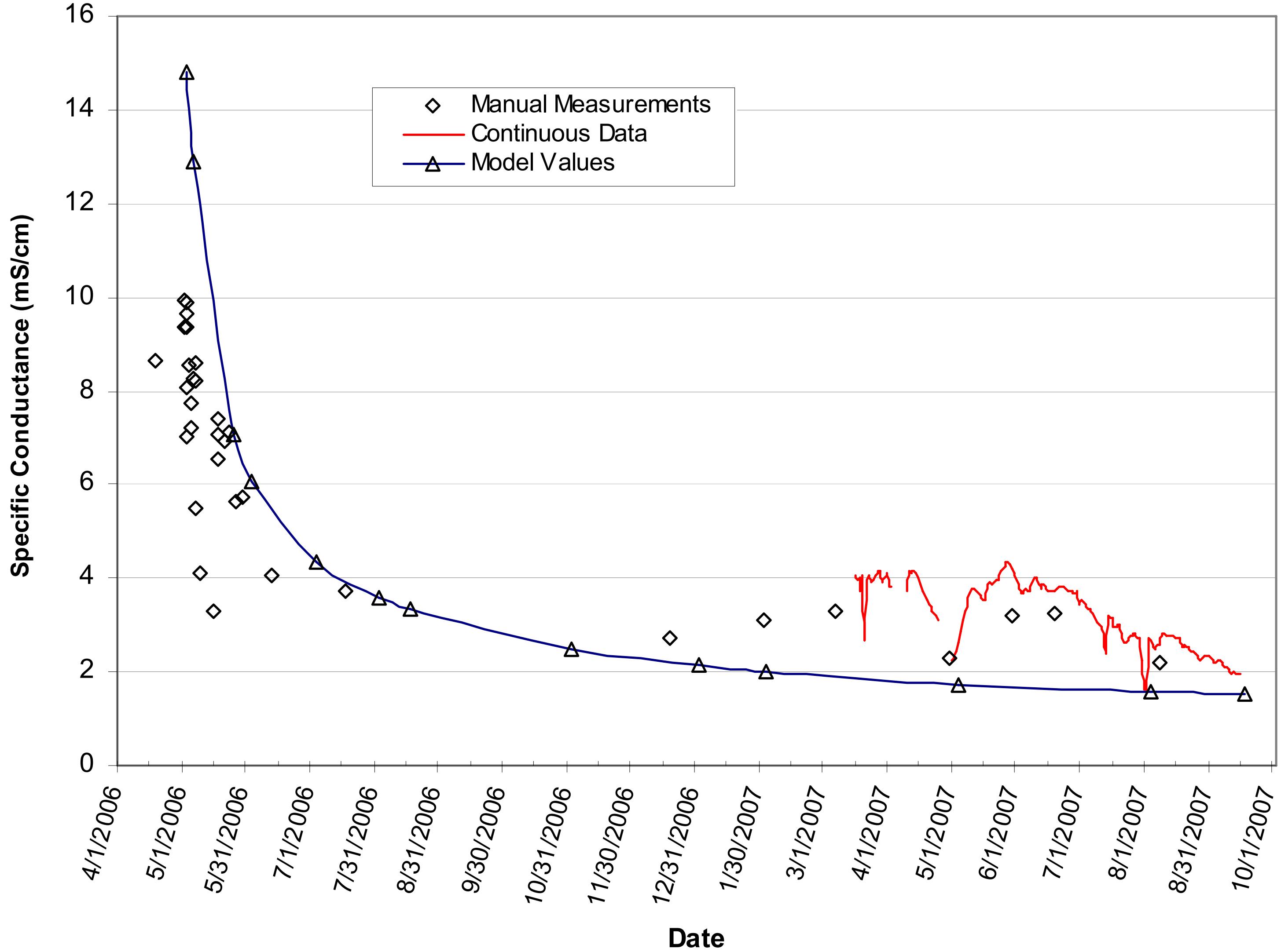

Figure 44. Comparison of Computed and Measured Specific Conductances in Trench 2 Discharge

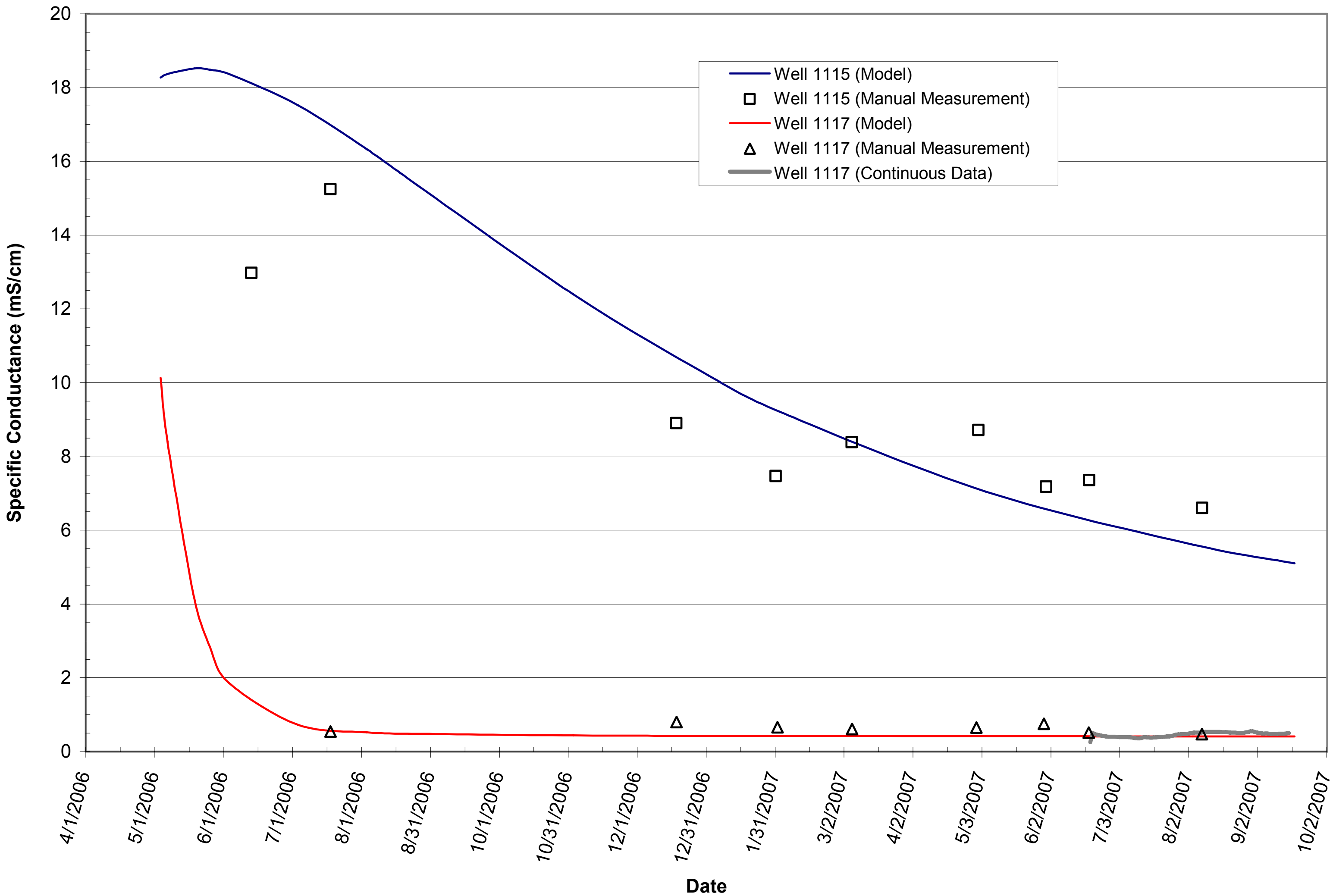

Figure 45. Comparison of Computed and Measured Specific Conductances at Wells 1115 and 1117

Additional evaluations of the model's predictive capability were made by comparing computed and measured specific conductances at specific monitor wells. These comparisons provided mixed results. For example, in a manner similar to that observed at the Trench 2 sump, the model noticeably overpredicted conductance at Well 1115 (directly west of Trench 2) during 2006 and underpredicted in 2007 (Figure 45). In contrast, the model performed well in matching the relatively steady conductance values measured at Well 1117, which lies directly east of the trench, after June 2006 (Figure 45). This latter result bore little reflection on the model's capacity to predict early rates of decrease in specific conductance because the model projected that groundwater in areas directly east of the trench would be dominated by low-conductance water within a month of the start of pumping (Figure 39).

The model consistently overpredicted specific conductance at Well 1114 (Figure 46), which is located close to the escarpment and about 350 ft downgradient (north) of the trench, just within the trench's projected capture zone (Figure 37). This result partly reflected the fact that simulated specific conductances under background conditions (Figure 38) in this part of the study area (18-19 mS/cm) were larger than actual values at Well 1114 in mid June 2006 (15.3 mS/cm). Though the exact reason for this difference is unknown, one possible cause may be that the influx of contaminated water across the escarpment varies spatially and is not uniform as had been assumed in the modeling. In contrast to the persistent overprediction of conductance values at Well 1114, the model did readily capture the low specific conductances observed at Well 1132 (on the east side of the trench) between spring and summer 2007 (Figure 46) due to rapid, pumping-induced influx of river water.

As discussed in Section 6.5.2, similar chemical responses to Trench 2 pumping were expected at Well 526 and Well 527 because they are located at opposite ends of the trench (Figure 9) and about the same distance from the escarpment (65 to 85 ft) Indeed the transient model of specific conductance transport showed both wells were expected to be dominated by river water within six months of the start of pumping (Figure 41), which meant that specific conductances at both sites would have been less than 2 mS/cm by the beginning of 2007. Comparison of measured and model-computed conductances at Well 1127 (Figure 47) conformed with this projection, as observed specific conductance here varied between 1.5 and 0.5 mS/cm between May and September 2007. In contrast, specific conductance at Well 1126 was as large as 17 mS/cm in March 2007 and fluctuated between about 3 and 6 mS/cm during following late spring and summer months. Thus, though the model predicted that it would take longer for river water to dominate the area surrounding Well 1126 (Figure 47), it significantly underpredicted specific conductance at this location.

It is difficult at this time to determine the exact reason for the significant discrepancies between model-computed and measured specific conductance at Well 1126. However, one plausible cause is the discharge of contaminated water from fractures in Mancos Shale underlying Well 1126, rather than discharge across the escarpment as has been assumed in the model. If additional investigation were to reveal such a phenomenon, it would provide evidence that the capacity of groundwater extraction remedies to clean up the alluvial aquifer can be dependent on spatially variable discharge of groundwater from the Mancos Shale.

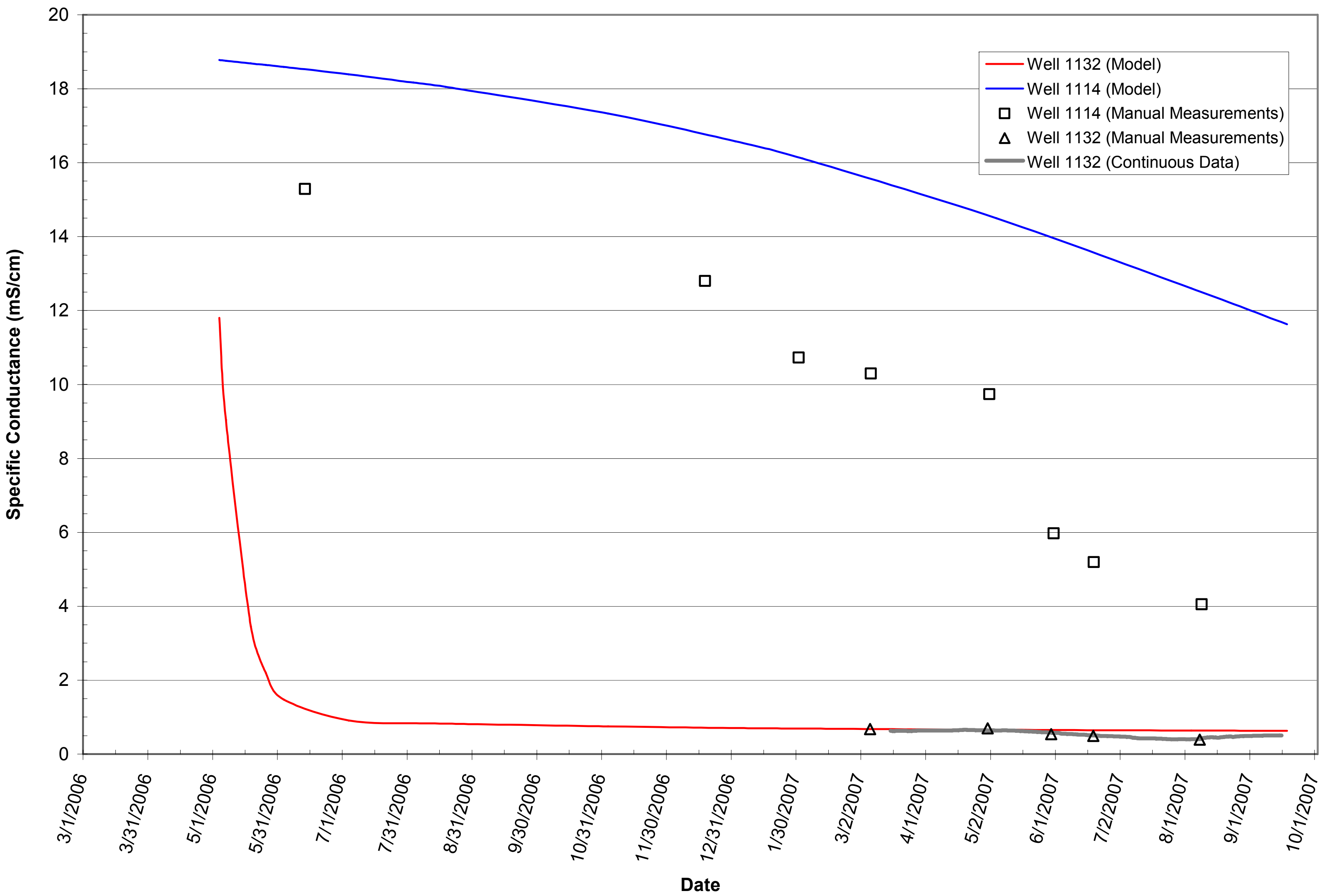

Figure 46. Comparison of Computed and Measured Specific Conductances at Wells 1114 and 1132

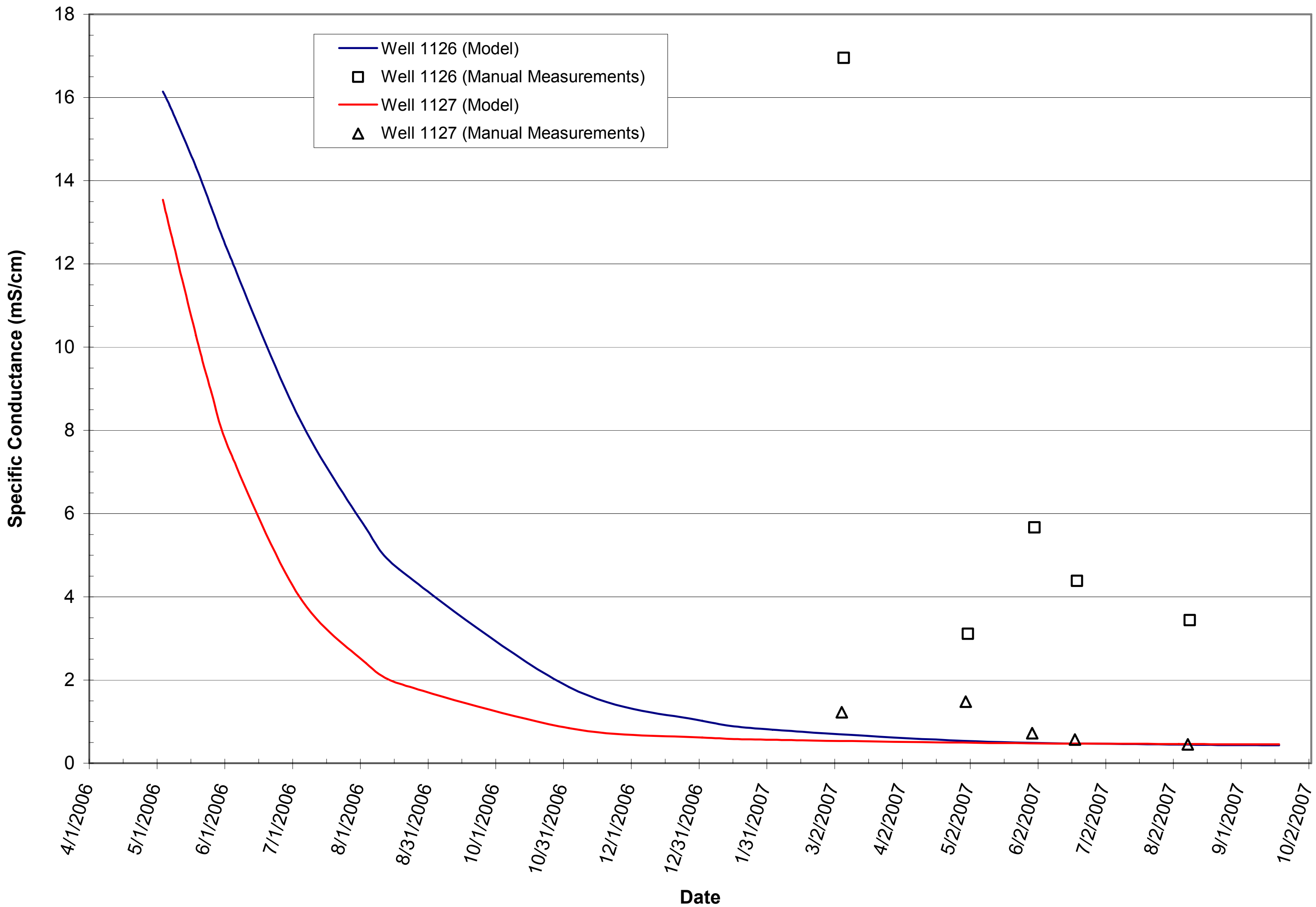

Figure 47. Comparison of Computed and Measured Specific Conductances at Wells 1126 and 1127

7.5 Potential Model Improvements

The results of the transport simulations suggested that predictions of specific conductance behavior could be greatly improved if the model was enhanced in several ways. Potential model enhancements and the activities that would be involved include:

1. Account for variability of groundwater discharge from bedrock – This step would largely require the identification of areas along the escarpment or in bedrock below the alluvium where discharge of contaminated water from fractures tends to be concentrated. It might also involve identification of temporal variations of the discharge that might be caused, for example, by periodic fluctuations in groundwater levels on the terrace to the west of the floodplain in response to recharge from rainfall events. Considerable effort, such as the drilling of multiple wells close to the escarpment throughout the study area, would likely be needed to accomplish these tasks.
2. Simulate the effects of variable river flow conditions on groundwater flow – Attempts to account for changes in the longitudinal profile of surface water elevations in the San Juan River associated with the two pool-and-riffle areas in the study area (Figure 5) would help the identification of areas within the floodplain alluvial aquifer that mostly receive flow from the river as well as those that mostly discharge to the river, thereby assisting the delineation of hyporheic zones. However, confirmation of flow directions in the respective areas would likely require networks of wells whose water levels would better define local flow patterns, and may involve chemical tracer studies. In addition, it is likely that transient simulations with the model that take into account changes in heads along the river in response to varying river flows, such as those illustrated for Well 1130 in Figure 15, would improve the model's ability to match observed behavior of specific conductance in the aquifer. Such transient runs would also assist in developing a better calibrated model than has been achieved in this investigation. A significant amount of effort would be required to set up temporally varying boundary conditions along the river and at the model's northern border, as individual stress periods in the flow portion of the model may need to be as small as just a few days to adequately account for changes in river flow.
3. Conduct simulations of the transport of individual cations, anions, or the contaminants uranium and ammonia – In much the same manner that modeling of specific conductance behavior has shed light on flow and transport processes in the floodplain alluvium, it is expected that additional simulations examining the transport of individual dissolved species would assist in improving the model. Assuming this additional modeling would be carried out using only the same data sources and approach employed in the specific conductance modeling, the effort required to conduct the individual species simulations would be relatively small.

8.0 Summary and Conclusions

Water level and chemical data from multiple wells installed in the alluvial aquifer were used in this study to evaluate the performance of the Trench 2 remediation system at the Shiprock, New Mexico, Legacy Management Site. Numerical modeling of both groundwater flow and the disposition of specific conductance in alluvial aquifer groundwater under both background flow conditions and as affected by Trench 2 pumping provided additional insight into the most significant processes affecting the remediation system's performance. Conclusions drawn from this study include:

- The Trench 2 remediation system removes significant quantities of dissolved mass from the alluvial aquifer. Much of the extracted mass consists of contaminants.
- Pumping from Trench 2 causes decreases in specific conductance and the concentrations of several aqueous chemical species, including contaminants, at wells surrounding the trench. These responses to pumping correlate with gradual decreases in dissolved species concentrations observed over time in the discharge from the trench, which consists of a mixture of contaminated groundwater and gradually increasing amounts of groundwater originating as seepage losses from the river.
- The remediation system successfully intercepts contamination discharging across the Mancos Shale escarpment and creates a zone of non-contaminated water between the trench and the river.
- Data collected at local wells, well points and shallow trenches support the conceptual model of background flow conditions previously developed for the Shiprock Site in several DOE publications (DOE 1999, 2000, 2004). In this model, predominantly north-northwestward groundwater flow in the alluvial aquifer is primarily driven by seepage losses from the nearby San Juan River. Influxes of contaminated groundwater from Mancos Shale bedrock, mostly across the Mancos Shale escarpment that borders the area, comprise the major source of contamination in the aquifer.
- Within a prescribed study area that encompasses Trench 2, seepage losses from the San Juan River and the locations at which groundwater discharges to the river appear to be defined by sequential pools and riffles on the river. Two local hyporheic zones within the alluvial aquifer appear to result from the inflow of river water from river pools and subsequent discharge of that water near the downstream ends of succeeding riffles.
- Pumping from the Trench 2 system induces additional inflow to the study area from river seepage and prevents much of the groundwater that would normally discharge back to river from doing so.
- Groundwater elevations in the alluvial aquifer increase with increases in San Juan River flow, and vice versa. A scatter plot of measured water levels in a well on the river's west bank and average daily flows in the river shows that the relationship between them is complex; water levels associated with a specific river flow might vary by as much as 1.5 to 2 ft depending on the time of data collection.
- The Trench 2 remediation system is highly efficient, as measured water levels in water wells located very close to the trench sump tend to be only slightly larger than water levels in the sump itself. Impediments to groundwater entering the openings in the horizontal well pipe in the trench appear to be minor.

- Multiple steady-state calibration runs with the flow portion of the site model designed to match observed water levels in wells at selected times indicate that a hydraulic conductivity of 85 ft/day is representative of the floodplain alluvium. A combination of the flow calibration runs and transport simulations focused on producing specific conductance distributions under background, non-pumping conditions indicates that a flux of 0.07 ft^3/day (3.6 x 10^{-4} gpm) per foot of escarpment length is representative of groundwater into the alluvial aquifer across the Mancos Shale escarpment.
- Simulation of "average" flow conditions when Trench 2 is pumped suggests that the pumping can induce seepage from the San Juan River as much as 400 ft upstream of the trench and capture groundwater as much as 350 ft downgradient of the trench.
- Modeling shows that Trench 2 pumping can increase the quantity of groundwater flowing through the study area by almost 400 percent, with most of the flow originating as pumping-induced seepage losses from the river. The majority of the induced seepage comes from a reach of river directly west of the trench that is only slightly longer than the trench itself. Estimated travel times from the river to the trench directly in this area range from about 3 weeks to 2 months.
- Use of the site model to predict specific conductances in Trench 2 discharge and at selected wells during 16 months of trench pumping produces mixed results. Though the model generally matches observed temporal trends for specific conductance, it overpredicts conductance in many instances and underpredicts in others. Possible explanations for significant differences between measured and modeled conductance include spatially variable discharge of contaminated water across the Mancos Shale escarpment and discharge of contaminated water from fractures in the Mancos Shale underlying the alluvial aquifer, neither of which are accounted for in the model.
- The monitoring system for Trench 2 and surrounding areas facilitated a detailed assessment of flow and transport processes in the study area such that the effectiveness of the remediation system could be adequately documented and maintained. Continuously collected data from SOARS monitoring locations in the form of groundwater levels, Trench 2 discharge, and specific conductance at selected locations was crucial to carrying out the assessment.
- Several steps could be taken to improve the modeling conducted for this study. Potential model enhancements include the simulation of spatially and temporally variable inflow across the Mancos Shale escarpment, accounting for variable river flows and their effects on water elevations in river pools and riffles, and simulation of individual inorganic solutes. Though such model additions would increase the understanding of flow and transport processes in the alluvial aquifer, they are unlikely to contribute significantly to the effectiveness of the Trench 2 remediation system or the ability to monitor the system's performance.

9.0 Recommendations

It is recommended that a monitoring system similar to the one used in this study be installed at and in the area surrounding Trench 1, which is located about 2,000 ft north-northwest of Trench 2. To the extent possible, this system should be connected to SOARS so that as much continuously collected data as possible is available for analysis. In the interest of developing better understanding of the flow interactions between the San Juan River and groundwater in the alluvial aquifer, it is suggested that surface water level data be collected from a stilling well in the river. Similarly, periodic measurements of surface water levels at several locations along the river are recommended. Upon completing one to two years of data collection, the performance of the Trench 1 remediation system could be evaluated using many of the techniques employed in this investigation.

Further modeling of the alluvial aquifer in the Trench 2 study area is not recommended at this time. The extensive network of observation wells in the vicinity of the trench, most of which are being remotely and continuously monitored under SOARS, provides the data necessary to assure that the system operates properly. Thus the practical benefits of additional modeling would be limited.

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10.0 References

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Appendix A

Measured Water Levels in Trench 2 Area Wells

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Table A−1. Average Daily Water Levels (ft amsl[1]) at Continuously Monitored Wells in the Trench 2 Area

Date	Trench 2 Sump	Port A	Port C	Well 1115	Well 1117	Well 1125	Well 1126	Well 1127	Well 1128	Well 1129	Well 1130	Well 1131	Well 1132	Well 1133	Well 1134
03/28/07	4885.95	4886.29	4886.84	4886.49	4887.00	4887.30	4886.91	4890.52	4886.91	4889.05	4888.99	4887.43	4887.01	4886.54	4886.85
03/29/07	4885.89	4886.24	4886.81	4886.46	4886.98	4887.27	4886.88	4890.50	4886.89	4889.04	4888.99	4887.41	4886.98	4886.51	4886.81
03/30/07	4885.87	4886.22	4886.80	4886.44	4886.96	4887.26	4886.87	4890.49	4886.87	4889.02	4888.96	4887.39	4886.96	4886.49	4886.79
03/31/07	4885.85	4886.19	4886.80	4886.41	4886.95	4887.24	4886.84	4890.48	4886.87	4889.01	4888.94	4887.38	4886.95	4886.48	4886.78
04/01/07	4885.85	4886.18	4886.78	4886.40	4886.93	4887.22	4886.83	4890.45	4886.85	4888.98	4888.91	4887.36	4886.92	4886.46	4886.75
04/02/07	4885.80	4886.15	4886.77	4886.38	4886.92	4887.20	4886.81	4890.43	4886.83	4888.97	4888.91	4887.34	4886.91	4886.45	4886.73
04/03/07	4885.78	4886.12	4886.74	4886.35	4886.89	4887.17	4886.77	4890.40	4886.80	4888.94	4888.86	4887.31	4886.89	4886.42	4886.74
04/04/07	4885.75	4886.10	4886.73	4886.33	4886.88	4887.15	4886.76	4890.39	4886.80	4888.92	4888.85	4887.29	4886.88	4886.40	4886.70
04/05/07	4885.70	4886.06	4886.72	4886.31	4886.86	4887.13	4886.74	4890.37	4886.78	4888.90	4888.82	4887.27	4886.86	4886.39	4886.67
04/06/07	4885.70	4886.05	4886.71	4886.29	4886.85	4887.11	4886.72	4890.36	4886.77	4888.89	4888.81	4887.26	4886.85	4886.37	4886.67
04/07/07	4885.67	4886.03	4886.70	4886.27	4886.84	4887.10	4886.70	4890.35	4886.76	4888.89	4888.84	4887.25	4886.83	4886.36	4886.66
04/08/07	4885.62	4886.00	4886.69	4886.25	4886.84	4887.09	4886.68	4890.36	4886.75	4888.90	4888.86	4887.25	4886.82	4886.34	4886.62
04/09/07	4885.68	4886.04	4886.72	4886.26	4886.87	4887.12	4886.70	4890.39	4886.77	4888.93	4888.91	4887.28	4886.85	4886.36	4886.63
04/10/07	4885.67	4886.04	4886.73	4886.27	4886.89	4887.14	4886.72	4890.42	4886.79	4888.96	4888.93	4887.30	4886.87	4886.38	4886.65
04/11/07	4885.93	4886.26	4886.80	4886.33	4886.91	4887.15	4886.74	4890.43	4886.81	4888.97	4888.93	4887.31	4886.91	4886.43	4886.69
04/12/07	4887.23	4887.36	4887.44	4887.04	4887.24	4887.45	4887.19	4890.63	4887.20	4889.14	4888.99	4887.57	4887.39	4887.11	4887.30
04/13/07	4887.63	4887.77	4887.83	4887.45	4887.54	4887.75	4887.51	4890.84	4887.56	4889.35	4889.11	4887.86	4887.77	4887.56	4887.68
04/14/07	4887.90	4888.04	4888.09	4887.70	4887.75	4887.96	4887.74	4890.99	4887.85	4889.51	4889.20	4888.06	4888.00	4887.84	4887.91
04/15/07	4888.10	4888.24	4888.29	4887.91	4887.91	4888.11	4887.92	4891.12	4888.06	4889.62	4889.22	4888.21	4888.17	4888.05	4888.08
04/16/07	4888.22	4888.36	4888.41	4888.03	4888.00	4888.21	4888.03	4891.20	4888.18	4889.69	4889.25	4888.31	4888.28	4888.17	4888.19
04/17/07	4888.31	4888.44	4888.49	4888.12	4888.06	4888.27	4888.11	4891.25	4888.26	4889.74	4889.29	4888.37	4888.35	4888.26	4888.27
04/18/07	4888.39	4888.52	4888.58	4888.21	4888.14	4888.34	4888.18	4891.32	4888.35	4889.80	4889.34	4888.44	4888.42	4888.34	4888.34
04/19/07	4888.44	4888.57	4888.63	4888.26	4888.18	4888.39	4888.24	4891.36	4888.41	4889.83	4889.34	4888.48	4888.48	4888.40	4888.40
04/20/07	4888.48	4888.61	4888.67	4888.30	4888.21	4888.42	4888.27	4891.38	4888.46	4889.85	4889.35	4888.51	4888.51	4888.43	4888.43
04/21/07	4888.51	4888.64	4888.70	4888.34	4888.24	4888.45	4888.30	4891.41	4888.46	4889.89	4889.39	4888.54	4888.54	4888.47	4888.46
04/22/07	4888.55	4888.68	4888.73	4888.37	4888.28	4888.48	4888.34	4891.44	4888.49	4889.91	4889.42	4888.58	4888.57	4888.50	4888.50
04/23/07	4888.57	4888.70	4888.76	4888.40	4888.29	4888.50	4888.35	4891.45	4888.51	4889.92	4889.39	4888.59	4888.59	4888.52	4888.52
04/24/07	4888.59	4888.72	4888.77	4888.41	4888.31	4888.52	4888.37	4891.46	4888.52	4889.94	4889.42	4888.61	4888.61	4888.54	4888.53
04/25/07	4888.61	4888.73	4888.79	4888.43	4888.33	4888.54	4888.39	4891.49	4888.54	4889.98	4889.52	4888.63	4888.63	4888.56	4888.55
04/26/07	NA	NA	4888.82	NA	4888.37	4888.57	NA	4891.54	4888.58	4890.02	4889.55	4888.67	4888.66	4888.57	4888.58
04/27/07	NA	NA	4888.81	NA	4888.34	4888.54	NA	4891.50	4888.56	4889.97	4889.42	4888.63	4888.64	4888.56	4888.56
04/28/07	NA	NA	4888.78	NA	4888.30	4888.50	NA	4891.45	4888.54	4889.92	4889.38	4888.59	4888.60	4888.53	4888.53
04/29/07	NA	NA	4888.78	NA	4888.30	4888.49	NA	4891.45	4888.54	4889.92	4889.42	4888.59	4888.60	4888.53	4888.52
04/30/07	NA	NA	4888.85	NA	4888.38	4888.56	NA	4891.56	4888.62	4890.04	4889.65	4888.69	4888.67	4888.58	4888.58
05/01/07	NA	NA	4888.93	NA	4888.51	4888.68	NA	4891.73	4888.71	4890.26	4890.20	4888.88	4888.77	4888.65	4888.67
05/02/07	4888.15	4888.39	4888.70	4883.65	4888.61	4888.84	4888.40	4891.96	4888.61	4890.60	4890.81	4889.08	4888.75	4888.43	4888.57
05/03/07	4887.42	4887.72	4888.17	4887.83	4888.43	4888.73	4888.08	4891.96	4888.21	4890.68	4891.12	4889.01	4888.44	4887.88	4888.20
05/04/07	4887.44	4887.75	4888.21	4887.91	4888.55	4888.87	4888.15	4892.13	4888.25	4890.88	4891.45	4889.16	4888.52	4887.91	4888.28
05/05/07	4887.62	4887.92	4888.37	4887.99	4888.71	4889.04	4888.31	4892.32	4888.34	4891.06	4891.57	4889.33	4888.68	4888.06	4888.45
05/06/07	4887.76	4888.05	4888.48	4888.08	4888.81	4889.14	4888.42	4892.41	4888.44	4891.13	4891.55	4889.41	4888.78	4888.18	4888.56
05/07/07	4887.86	4888.13	4888.57	4888.17	4888.86	4889.18	4888.51	4892.45	4888.52	4891.15	4891.52	4889.45	4888.85	4888.26	4888.62
05/08/07	4887.93	4888.20	4888.64	4888.25	4888.90	4889.21	4888.58	4892.49	4888.60	4891.17	4891.49	4889.48	4888.90	4888.33	4888.68

Table A−1 (continued). Average Daily Water Levels (ft amsl[1]) at Continuously Monitored Wells in the Trench 2 Area

Date	Trench 2 Sump	Port A	Port C	Well 1115	Well 1117	Well 1125	Well 1126	Well 1127	Well 1128	Well 1129	Well 1130	Well 1131	Well 1132	Well 1133	Well 1134
05/09/07	4888.21	4888.44	4888.81	4888.42	4888.98	4889.26	4888.66	4892.53	4888.74	4891.19	4891.46	4889.53	4889.00	4888.50	4888.80
05/10/07	4888.02	4888.28	4888.72	4888.33	4888.95	4889.24	4888.62	4892.52	4888.69	4891.17	4891.45	4889.50	4888.95	4888.42	4888.73
05/11/07	4888.01	4888.26	4888.70	4888.32	4888.93	4889.22	4888.61	4892.51	4888.67	4891.16	4891.44	4889.48	4888.93	4888.40	4888.71
05/12/07	4888.05	4888.30	4888.74	4888.35	4888.97	4889.26	4888.64	4892.55	4888.71	4891.22	4891.57	4889.53	4888.97	4888.44	4888.75
05/13/07	4888.15	4888.39	4888.83	4888.43	4889.08	4889.36	4888.72	4892.66	4888.79	4891.35	4891.77	4889.64	4889.07	4888.52	4888.84
05/14/07	4888.25	4888.49	4888.93	4888.52	4889.18	4889.45	4888.80	4892.77	4888.89	4891.46	4891.91	4889.73	4889.16	4888.62	4888.93
05/15/07	4888.35	4888.58	4889.02	4888.60	4889.28	4889.54	4888.87	4892.87	4888.97	4891.57	4892.06	4889.83	4889.25	4888.71	4889.02
05/16/07	4888.47	4888.70	4889.14	4888.70	4889.42	4889.68	4888.97	4893.02	4889.09	4891.76	4892.31	4889.98	4889.39	4888.82	4889.15
05/17/07	4888.61	4888.83	4889.27	4888.83	4889.54	4889.79	4889.08	4893.13	4889.21	4891.84	4892.32	4890.09	4889.51	4888.96	4889.27
05/18/07	4888.55	4888.77	4889.20	4888.79	4889.38	4889.64	4889.05	4892.92	4889.17	4891.51	4891.61	4889.88	4889.40	4888.90	4889.18
05/19/07	4888.31	4888.53	4888.96	4888.58	4889.12	4889.38	4888.85	4892.64	4888.94	4891.23	4891.35	4889.62	4889.14	4888.67	4888.94
05/20/07	4888.26	4888.48	4888.91	4888.53	4889.08	4889.36	4888.81	4892.63	4888.88	4891.25	4891.46	4889.60	4889.10	4888.62	4888.90
05/21/07	4888.27	4888.49	4888.92	4888.55	4889.09	4889.36	4888.82	4892.65	4888.90	4891.26	4891.47	4889.61	4889.11	4888.63	4888.90
05/22/07	4888.19	4888.40	4888.83	4888.46	4888.99	4889.27	4888.75	4892.53	4888.81	4891.10	4891.15	4889.50	4889.02	4888.55	4888.82
05/23/07	4888.12	4888.32	4888.75	4888.40	4888.88	4889.20	4888.69	4892.41	4888.72	4890.98	4890.95	4889.41	4888.93	4888.47	4888.75
05/24/07	4888.00	4888.21	4888.63	4888.30	4888.72	4889.04	4888.60	4892.23	4888.61	4890.76	4890.60	4889.23	4888.79	4888.36	4888.62
05/25/07	4887.83	4888.08	4888.44	4888.19	4888.51	4888.81	4888.49	4891.99	4888.43	4890.51	4890.33	4888.99	4888.58	4888.17	4888.41
05/26/07	4887.60	4887.81	4888.24	4888.02	4888.29	4888.59	4888.23	4891.78	4888.23	4890.29	4890.15	4888.78	4888.37	4887.97	4888.21
05/27/07	4887.41	4887.63	4888.06	4887.86	4888.11	4888.41	4888.09	4891.61	4888.05	4890.12	4890.01	4888.60	4888.19	4887.80	4888.03
05/28/07	4887.24	4887.46	4887.91	4887.76	4887.97	4888.26	4887.98	4891.47	4887.93	4889.98	4889.92	4888.45	4888.04	4887.65	4887.87
05/29/07	4887.08	4887.31	4887.77	4887.64	4887.85	4888.13	4887.83	4891.37	4887.82	4889.91	4889.96	4888.34	4887.91	4887.51	4887.73
05/30/07	4887.00	4887.23	4887.70	4887.51	4887.83	4888.10	4887.73	4891.36	4887.73	4889.93	4890.07	4888.32	4887.86	4887.44	4887.67
05/31/07	4886.97	4887.20	4887.68	4887.46	4887.82	4888.08	4887.70	4891.36	4887.73	4889.91	4890.06	4888.31	4887.84	4887.41	4887.65
06/01/07	4886.93	4887.16	4887.64	4887.38	4887.80	4888.06	4887.63	4891.34	4887.71	4889.90	4890.07	4888.29	4887.82	4887.38	4887.61
06/02/07	4886.91	4887.14	4887.63	4887.35	4887.80	4888.06	4887.58	4891.35	4887.66	4889.93	4890.16	4888.30	4887.81	4887.36	4887.60
06/03/07	4886.95	4887.18	4887.66	4887.36	4887.84	4888.10	4887.59	4891.40	4887.68	4889.99	4890.26	4888.35	4887.84	4887.38	4887.63
06/04/07	4887.00	4887.23	4887.71	4887.40	4887.89	4888.15	4887.62	4891.45	4887.72	4890.04	4890.30	4888.40	4887.89	4887.43	4887.68
06/05/07	4887.05	4887.27	4887.75	4887.44	4887.92	4888.17	4887.66	4891.47	4887.75	4890.05	4890.27	4888.41	4887.92	4887.47	4887.70
06/06/07	4887.06	4887.28	4887.76	4887.45	4887.93	4888.16	4887.70	4891.48	4887.78	4890.05	4890.28	4888.41	4887.93	4887.48	4887.71
06/07/07	4887.07	4887.30	4887.78	4887.44	4887.95	4888.21	4887.66	4891.50	4887.77	4890.08	4890.27	4888.45	4887.95	4887.49	4887.74
06/08/07	4887.00	4887.22	4887.70	4887.39	4887.83	4888.08	4887.61	4891.37	4887.71	4889.90	4889.95	4888.30	4887.85	4887.43	4887.64
06/09/07	4886.85	4887.08	4887.57	4887.27	4887.68	4887.92	4887.50	4891.21	4887.61	4889.72	4889.73	4888.14	4887.71	4887.31	4887.50
06/10/07	4886.73	4886.96	4887.47	4887.17	4887.58	4887.82	4887.41	4891.11	4887.52	4889.63	4889.72	4888.05	4887.60	4887.20	4887.40
06/11/07	4886.68	4886.91	4887.44	4887.11	4887.57	4887.81	4887.36	4891.11	4887.48	4889.67	4889.85	4888.04	4887.57	4887.15	4887.36
06/12/07	4886.72	4886.94	4887.47	4887.13	4887.62	4887.88	4887.38	4891.18	4887.49	4889.75	4889.95	4888.12	4887.62	4887.17	4887.41
06/13/07	4886.75	4886.97	4887.50	4887.16	4887.64	4887.88	4887.40	4891.19	4887.51	4889.76	4889.95	4888.12	4887.64	4887.20	4887.43
06/14/07	4886.71	4886.94	4887.49	4887.13	4887.60	4887.82	4887.37	4891.14	4887.50	4889.69	4889.84	4888.06	4887.60	4887.18	4887.38
06/15/07	4886.65	4886.88	4887.45	4887.07	4887.55	4887.77	4887.31	4891.09	4887.46	4889.65	4889.86	4888.01	4887.55	4887.12	4887.32
06/16/07	4886.63	4886.85	4887.44	4887.04	4887.55	4887.76	4887.28	4891.11	4887.44	4889.68	4889.95	4888.02	4887.54	4887.10	4887.31
06/17/07	4886.66	4886.89	4887.50	4887.06	4887.59	4887.79	4887.29	4891.16	4887.47	4889.73	4890.00	4888.06	4887.57	4887.13	4887.33
06/18/07	4886.64	4886.87	4887.48	4887.04	4887.55	4887.75	4887.26	4891.11	4887.45	4889.67	4889.91	4888.01	4887.54	4887.11	4887.30
06/19/07	4886.63	4886.85	4887.45	4887.02	4887.61	4887.75	4887.24	4891.06	4887.15	4889.87	4890.03	4888.01	4887.53	4887.09	4887.30
06/20/07	4886.60	4886.82	4887.43	4887.00	4887.60	4887.70	4887.22	4891.00	4887.00	4889.72	4890.00	4887.95	4887.49	4887.07	4887.26
06/21/07	4886.54	4886.77	4887.36	4886.95	4887.42	4887.64	4887.18	4891.00	4887.00	4889.46	4889.83	4887.89	4887.44	4887.03	4887.21

Table A−1 (continued). Average Daily Water Levels (ft amsl[1]) at Continuously Monitored Wells in the Trench 2 Area

Date	Trench 2 Sump	Port A	Port C	Well 1115	Well 1117	Well 1125	Well 1126	Well 1127	Well 1128	Well 1129	Well 1130	Well 1131	Well 1132	Well 1133	Well 1134
06/22/07	4886.48	4886.70	4887.29	4886.90	4887.20	4887.57	4887.12	4890.96	4887.11	4889.57	4889.75	4887.82	4887.38	4886.97	4887.15
06/23/07	4886.42	4886.64	4887.25	4886.85	4887.36	4887.52	4887.08	4890.90	4887.25	4889.39	4889.49	4887.77	4887.33	4886.92	4887.10
06/24/07	4886.34	4886.57	4887.20	4886.78	4887.31	4887.46	4887.02	4890.85	4887.20	4889.34	4889.45	4887.71	4887.27	4886.86	4887.03
06/25/07	4886.26	4886.49	4887.12	4886.71	4887.25	4887.40	4886.95	4890.79	4887.15	4889.29	4889.42	4887.65	4887.20	4886.79	4886.96
06/26/07	4886.21	4886.45	4887.10	4886.67	4887.23	4887.37	4886.92	4890.77	4887.12	4889.26	4889.39	4887.63	4887.17	4886.76	4886.93
06/27/07	4886.15	4886.39	4887.07	4886.62	4887.18	4887.32	4886.87	4890.72	4887.08	4889.20	4889.32	4887.57	4887.12	4886.70	4886.87
06/28/07	4886.08	4886.32	4887.04	4886.56	4887.13	4887.26	4886.81	4890.67	4887.04	4889.15	4889.26	4887.52	4887.06	4886.65	4886.81
06/29/07	4886.00	4886.25	4887.00	4886.50	4887.08	4887.20	4886.76	4890.61	4886.99	4889.08	4889.15	4887.46	4887.01	4886.60	4886.75
06/30/07	4885.90	4886.17	4886.97	4886.43	4887.01	4887.13	4886.70	4890.53	4886.94	4888.99	4889.04	4887.39	4886.94	4886.54	4886.68
07/01/07	4885.79	4886.07	4886.92	4886.35	4886.96	4887.06	4886.64	4890.47	4886.89	4888.94	4888.98	4887.33	4886.87	4886.47	4886.60
07/02/07	4885.66	4885.98	4886.88	4886.26	4886.90	4886.99	4886.58	4890.41	4886.83	4888.88	4888.93	4887.26	4886.80	4886.40	4886.51
07/03/07	4885.54	4885.89	4886.85	4886.18	4886.86	4886.92	4886.54	4890.35	4886.80	4888.83	4888.88	4887.21	4886.74	4886.34	4886.42
07/04/07	4885.41	4885.81	4886.78	4886.10	4886.80	4886.85	4886.47	4890.30	4886.76	4888.77	4888.82	4887.15	4886.67	4886.28	4886.34
07/05/07	4885.27	4885.74	4886.71	4886.01	4886.75	4886.79	4886.36	4890.24	4886.69	4888.72	4888.77	4887.10	4886.61	4886.22	4886.26
07/06/07	4885.14	4885.69	4886.67	4885.93	4886.71	4886.74	4886.30	4890.21	4886.66	4888.69	4888.75	4887.06	4886.56	4886.17	4886.19
07/07/07	4885.04	4885.66	4886.66	4885.86	4886.68	4886.70	4886.27	4890.18	4886.66	4888.67	4888.76	4887.03	4886.52	4886.13	4886.14
07/08/07	4884.97	4885.62	4886.65	4885.81	4886.67	4886.67	4886.21	4890.17	4886.63	4888.66	4888.74	4887.01	4886.50	4886.10	4886.10
07/09/07	4884.90	4885.57	4886.63	4885.76	4886.64	4886.64	4886.12	4890.14	4886.58	4888.63	4888.69	4886.98	4886.46	4886.06	4886.06
07/10/07	4884.81	4885.51	4886.59	4885.71	4886.59	4886.59	4886.07	4890.09	4886.54	4888.57	4888.60	4886.94	4886.42	4886.02	4886.01
07/11/07	4884.72	4885.43	4886.54	4885.64	4886.55	4886.54	4886.01	4890.04	4886.48	4888.52	4888.55	4886.89	4886.37	4885.97	4885.95
07/12/07	4885.03	4885.62	4886.55	4885.66	4886.55	4886.55	4886.00	4890.02	4886.45	4888.53	4888.59	4886.90	4886.38	4885.97	4885.99
07/13/07	4886.21	4886.52	4886.87	4886.31	4886.78	4886.81	4886.35	4890.13	4886.67	4888.61	4888.55	4887.09	4886.75	4886.45	4886.54
07/14/07	4885.17	4885.77	4886.70	4886.01	4886.84	4886.77	4886.25	4889.11	4886.61	4888.21	4888.41	4887.07	4886.61	4886.22	4886.27
07/15/07	4884.79	4885.57	4886.60	4885.77	4886.96	4886.65	4886.07	4887.38	4886.50	4887.48	4888.11	4886.97	4886.47	4886.06	4886.07
07/16/07	4884.60	4885.44	4886.52	4885.64	4886.91	4886.57	4885.96	4887.34	4886.44	4887.44	4888.08	4886.91	4886.39	4885.96	4885.96
07/17/07	4884.45	4885.35	4886.47	4885.54	4886.87	4886.52	4885.88	4887.30	4886.40	4887.41	4888.04	4886.87	4886.33	4885.89	4885.89
07/18/07	4884.33	4885.28	4886.39	4885.46	4886.82	4886.47	4885.82	4887.26	4886.35	4887.36	4887.99	4886.82	4886.28	4885.83	4885.83
07/19/07	4884.29	4885.20	4886.35	4885.41	4886.79	4886.43	4885.77	4887.23	4886.31	4887.34	4887.97	4886.79	4886.24	4885.78	4885.79
07/20/07	4884.60	4885.27	4886.33	4885.41	4886.76	4886.41	4885.75	4887.21	4886.28	4887.32	4887.96	4886.77	4886.22	4885.76	4885.79
07/21/07	4884.98	4885.21	4886.34	4885.42	4886.77	4886.43	4885.75	4887.22	4886.28	4887.35	4888.01	4886.79	4886.23	4885.78	4885.79
07/22/07	4884.87	4885.13	4886.31	4885.33	4886.77	4886.42	4885.70	4887.25	4886.25	4887.40	4888.16	4886.80	4886.20	4885.72	4885.74
07/23/07	4884.95	4885.18	4886.36	4885.34	4886.85	4886.49	4885.73	4887.35	4886.30	4887.51	4888.32	4886.88	4886.26	4885.75	4885.79
07/24/07	4885.07	4885.26	4886.43	4885.41	4886.92	4886.55	4885.79	4887.41	4886.36	4887.57	4888.37	4886.94	4886.33	4885.81	4885.87
07/25/07	4885.17	4885.32	4886.47	4885.47	4886.95	4886.59	4885.84	4887.44	4886.40	4887.59	4888.34	4886.97	4886.37	4885.86	4885.91
07/26/07	4885.24	4885.37	4886.49	4885.51	4886.97	4886.61	4885.87	4887.45	4886.42	4887.59	4888.32	4886.99	4886.40	4885.89	4885.95
07/27/07	4885.28	4885.38	4886.49	4885.54	4886.94	4886.60	4885.89	4887.40	4886.42	4887.53	4888.18	4886.96	4886.39	4885.90	4885.95
07/28/07	4885.25	4885.37	4886.49	4885.53	4886.93	4886.59	4885.88	4887.39	4886.40	4887.52	4888.21	4886.96	4886.37	4885.89	4885.94
07/29/07	4885.26	4885.38	4886.50	4885.54	4886.93	4886.60	4885.89	4887.39	4886.41	4887.52	4888.20	4886.96	4886.38	4885.90	4885.95
07/30/07	4885.79	4885.72	4886.56	4885.64	4887.00	4886.65	4885.95	4887.46	4886.44	4887.61	4888.34	4887.02	4886.45	4885.96	4886.05
07/31/07	4887.13	4886.80	4887.00	4886.42	4887.20	4886.90	4886.41	4887.57	4886.72	4887.68	4888.30	4887.19	4886.86	4886.55	4886.66
08/01/07	4887.05	4886.74	4887.13	4886.66	4887.37	4887.11	4886.68	4887.69	4886.96	4887.79	4888.36	4887.37	4887.08	4886.79	4886.87
08/02/07	4886.35	4886.06	4886.82	4886.27	4887.23	4887.00	4886.48	4887.62	4886.76	4887.73	4888.30	4887.27	4886.83	4886.41	4886.54
08/03/07	4886.15	4885.89	4886.74	4886.11	4887.17	4886.92	4886.38	4887.58	4886.67	4887.70	4888.31	4887.21	4886.71	4886.27	4886.41
08/04/07	4886.07	4885.83	4886.74	4886.04	4887.18	4886.91	4886.33	4887.61	4886.64	4887.76	4888.51	4887.22	4886.69	4886.22	4886.36

Table A−1 (continued). Average Daily Water Levels (ft amsl[1]) at Continuously Monitored Wells in the Trench 2 Area

Date	Trench 2 Sump	Port A	Port C	Well 1115	Well 1117	Well 1125	Well 1126	Well 1127	Well 1128	Well 1129	Well 1130	Well 1131	Well 1132	Well 1133	Well 1134
08/05/07	4886.16	4885.90	4886.79	4886.08	4887.26	4887.00	4886.38	4887.71	4886.69	4887.87	4888.64	4887.30	4886.76	4886.27	4886.43
08/06/07	4886.29	4886.00	4886.84	4886.17	4887.33	4887.10	4886.46	4887.79	4886.74	4887.96	4888.80	4887.39	4886.84	4886.33	4886.53
08/07/07	4886.43	4886.12	4886.89	4886.26	4887.39	4887.17	4886.54	4887.84	4886.80	4888.00	4888.78	4887.46	4886.91	4886.40	4886.63
08/08/07	4886.53	4886.21	4886.94	4886.34	4887.44	4887.23	4886.60	4887.90	4886.85	4888.06	4888.84	4887.51	4886.98	4886.47	4886.70
08/09/07	4886.57	4886.25	4886.95	4886.38	4887.42	4887.21	4886.62	4887.85	4886.87	4887.97	4888.58	4887.47	4886.98	4886.50	4886.71
08/10/07	4886.45	4886.13	4886.91	4886.31	4887.31	4887.07	4886.54	4887.72	4886.79	4887.82	4888.40	4887.34	4886.88	4886.43	4886.60
08/11/07	4886.33	4886.03	4886.87	4886.22	4887.25	4887.00	4886.46	4887.65	4886.73	4887.76	4888.32	4887.27	4886.80	4886.36	4886.51
08/12/07	4886.20	4885.93	4886.82	4886.13	4887.18	4886.91	4886.38	4887.57	4886.67	4887.67	4888.22	4887.19	4886.72	4886.29	4886.41
08/13/07	4886.07	4885.83	4886.74	4886.03	4887.11	4886.83	4886.30	4887.50	4886.61	4887.61	4888.15	4887.13	4886.64	4886.22	4886.32
08/14/07	4885.94	4885.75	4886.65	4885.94	4887.06	4886.76	4886.22	4887.44	4886.57	4887.55	4888.08	4887.07	4886.58	4886.16	4886.23
08/15/07	4885.82	4885.68	4886.62	4885.86	4887.01	4886.70	4886.15	4887.40	4886.52	4887.52	4888.09	4887.02	4886.52	4886.10	4886.16
08/16/07	4885.72	4885.62	4886.60	4885.79	4886.98	4886.66	4886.08	4887.37	4886.48	4887.48	4888.03	4886.99	4886.48	4886.06	4886.10
08/17/07	4885.64	4885.56	4886.57	4885.73	4886.95	4886.63	4886.03	4887.35	4886.45	4887.46	4888.03	4886.96	4886.44	4886.02	4886.05
08/18/07	4885.55	4885.50	4886.51	4885.67	4886.91	4886.58	4885.98	4887.31	4886.42	4887.43	4888.01	4886.92	4886.40	4885.97	4886.00
08/19/07	4885.48	4885.46	4886.47	4885.62	4886.89	4886.55	4885.94	4887.29	4886.39	4887.41	4887.97	4886.90	4886.37	4885.94	4885.96
08/20/07	4885.41	4885.41	4886.44	4885.57	4886.85	4886.51	4885.89	4887.24	4886.36	4887.36	4887.92	4886.86	4886.33	4885.90	4885.91
08/21/07	4885.35	4885.37	4886.43	4885.54	4886.84	4886.49	4885.86	4887.23	4886.34	4887.35	4887.91	4886.84	4886.31	4885.87	4885.88
08/22/07	4885.28	4885.31	4886.39	4885.49	4886.80	4886.44	4885.81	4887.19	4886.30	4887.30	4887.84	4886.80	4886.27	4885.83	4885.84
08/23/07	4885.18	4885.24	4886.33	4885.43	4886.74	4886.39	4885.75	4887.13	4886.26	4887.24	4887.74	4886.74	4886.22	4885.78	4885.77
08/24/07	4885.08	4885.18	4886.28	4885.37	4886.69	4886.33	4885.69	4887.08	4886.21	4887.18	4887.70	4886.69	4886.16	4885.73	4885.72
08/25/07	4884.98	4885.12	4886.25	4885.31	4886.66	4886.29	4885.64	4887.04	4886.17	4887.15	4887.67	4886.66	4886.13	4885.68	4885.67
08/26/07	4884.85	4885.04	4886.20	4885.23	4886.61	4886.24	4885.58	4886.99	4886.12	4887.11	4887.64	4886.60	4886.07	4885.63	4885.61
08/27/07	4884.74	4885.00	4886.17	4885.18	4886.60	4886.22	4885.55	4886.99	4886.10	4887.11	4887.67	4886.59	4886.06	4885.59	4885.58
08/28/07	4884.75	4885.01	4886.21	4885.17	4886.69	4886.31	4885.55	4887.12	4886.11	4887.31	4888.14	4886.72	4886.12	4885.59	4885.62
08/29/07	4884.92	4885.09	4886.26	4885.24	4886.75	4886.39	4885.63	4887.19	4886.18	4887.34	4887.99	4886.78	4886.18	4885.65	4885.70
08/30/07	4884.99	4885.12	4886.26	4885.27	4886.74	4886.38	4885.65	4887.16	4886.18	4887.30	4887.94	4886.76	4886.18	4885.67	4885.71
08/31/07	4885.00	4885.13	4886.26	4885.28	4886.72	4886.36	4885.66	4887.14	4886.18	4887.27	4887.87	4886.74	4886.17	4885.67	4885.71
09/01/07	4884.95	4885.09	4886.23	4885.26	4886.69	4886.32	4885.63	4887.10	4886.15	4887.22	4887.82	4886.69	4886.14	4885.64	4885.67
09/02/07	4884.89	4885.06	4886.21	4885.22	4886.67	4886.30	4885.60	4887.09	4886.13	4887.21	4887.83	4886.68	4886.11	4885.62	4885.64
09/03/07	4884.88	4885.06	4886.22	4885.21	4886.69	4886.32	4885.59	4887.12	4886.13	4887.27	4887.98	4886.71	4886.12	4885.61	4885.65
09/04/07	4884.99	4885.13	4886.28	4885.26	4886.76	4886.39	4885.65	4887.19	4886.19	4887.33	4887.98	4886.77	4886.19	4885.66	4885.71
09/05/07	4885.03	4885.15	4886.29	4885.30	4886.74	4886.38	4885.68	4887.16	4886.20	4887.28	4887.87	4886.75	4886.19	4885.68	4885.73
09/06/07	4885.00	4885.13	4886.26	4885.29	4886.71	4886.36	4885.66	4887.12	4886.18	4887.25	4887.84	4886.72	4886.17	4885.67	4885.71
09/07/07	4884.96	4885.11	4886.25	4885.27	4886.70	4886.34	4885.64	4887.11	4886.16	4887.23	4887.82	4886.71	4886.15	4885.65	4885.69
09/08/07	4884.93	4885.09	4886.24	4885.25	4886.68	4886.32	4885.63	4887.09	4886.15	4887.21	4887.80	4886.69	4886.13	4885.64	4885.67
09/09/07	4884.88	4885.06	4886.19	4885.22	4886.66	4886.29	4885.60	4887.07	4886.12	4887.18	4887.76	4886.66	4886.11	4885.61	4885.63
09/10/07	4884.84	4885.04	4886.15	4885.19	4886.63	4886.27	4885.57	4887.04	4886.09	4887.15	4887.74	4886.63	4886.07	4885.58	4885.61
09/11/07	4884.81	4885.02	4886.15	4885.18	4886.62	4886.25	4885.56	4887.03	4886.08	4887.15	4887.76	4886.62	4886.06	4885.57	4885.59
09/12/07	4884.79	4885.00	4886.14	4885.16	4886.61	4886.24	4885.54	4887.02	4886.07	4887.13	4887.75	4886.61	4886.05	4885.56	4885.58
09/13/07	4884.76	4884.99	4886.14	4885.15	4886.61	4886.23	4885.53	4887.02	4886.07	4887.13	4887.75	4886.60	4886.05	4885.55	4885.57
09/14/07	4884.72	4884.97	4886.13	4885.13	4886.59	4886.22	4885.51	4887.01	4886.06	4887.12	4887.76	4886.59	4886.04	4885.54	4885.55

[1] ft amsl = feet above mean sea level
NA = not available

Table A−2. Manual Measurements of Water Levels at Wells in the Trench 2 Area

Location	Date and Time	Top of Casing (TOC) Elevation	Depth to Water	Water Surface Elevation
		(ft amsl)[1]	(ft below TOC)	(ft amsl)[1]
Trench 2 Sump	12/19/06 10:04	4895.33	8.73	4886.60
Trench 2 Sump	2/1/07 15:04	4895.33	10.01	4885.32
Trench 2 Sump	5/1/07 10:43	4895.33	6.53	4888.80
Trench 2 Sump	5/30/07 16:02	4895.33	8.35	4886.98
Trench 2 Sump	6/19/07 11:08	4895.33	8.69	4886.64
Trench 2 Port A	12/19/06 11:51	4895.33	7.32	4888.01
Trench 2 Port A	2/1/07 14:30	4893.35	7.7	4885.65
Trench 2 Port A	3/6/07 15:00	4893.35	7.72	4885.63
Trench 2 Port A	5/1/07 10:15	4893.35	4.33	4889.02
Trench 2 Port A	5/30/07 15:21	4893.35	6.02	4887.33
Trench 2 Port A	6/19/07 10:52	4893.35	6.41	4886.94
Trench 2 Port A	8/8/07 14:40	4893.35	7.13	4886.22
Trench 2 Port A	9/11/07 8:40	4893.35	8.38	4884.97
Trench 2 Port C	12/19/06 11:31	4895.43	8.87	4886.56
Trench 2 Port C	2/1/07 13:15	4895.43	9.02	4886.41
Trench 2 Port C	3/6/07 14:35	4895.43	9.07	4886.36
Trench 2 Port C	4/30/07 14:25	4895.43	6.53	4888.90
Trench 2 Port C	5/30/07 14:02	4895.43	7.75	4887.68
Trench 2 Port C	6/19/07 10:20	4895.43	8	4887.43
Trench 2 Port C	9/11/07 9:05	4895.43	9.41	4886.02
Well 1113	3/7/07 8:50	4892	5.26	4886.74
Well 1114	12/18/06 16:26	4892.86	5.79	4887.07
Well 1114	1/31/07 16:50	4892.86	5.81	4887.05
Well 1114	3/6/07 17:20	4892.86	5.82	4887.04
Well 1114	5/1/07 12:25	4892.86	4.75	4888.11
Well 1114	5/31/07 11:37	4892.86	4.66	4888.2
Well 1114	6/19/07 13:55	4892.86	5.3	4887.56
Well 1114	8/9/07 9:45	4892.86	5.93	4886.93
Well 1114	9/10/07 18:00	4892.86	6.64	4886.22
Well 1115	3/6/07 8:30	4895.59	9.79	4885.8
Well 1115	5/1/07 11:10	4895.59	6.93	4888.66
Well 1115	5/31/07 10:15	4895.59	8.12	4887.47
Well 1115	6/19/07 13:15	4895.59	8.55	4887.04
Well 1115	8/8/07 15:31	4895.59	9.26	4886.33
Well 1115	9/10/07 17:30	4895.59	10.4	4885.19
Well 1116	3/5/07 16:28	4898.84	12.33	4886.51
Well 1116	4/30/07 11:05	4898.84	10.16	4888.68
Well 1116	5/30/07 10:12	4898.84	10.97	4887.87
Well 1116	6/19/07 11:40	4898.84	11.3	4887.54
Well 1116	8/8/07 13:42	4898.84	11.86	4886.98
Well 1117	12/18/06 17:14	4896.7	10.47	4886.23
Well 1117	2/1/07 12:00	4896.7	10.62	4886.08
Well 1117	3/6/07 12:00	4896.7	9.9	4886.8
Well 1117	4/30/07 13:59	4896.7	7.9	4888.8
Well 1117	5/30/07 11:53	4896.7	8.49	4888.21

Table A−2 (continued). Manual Measurements of Water Levels at Wells in the Trench 2 Area

Location	Date and Time	Top of Casing (TOC) Elevation	Depth to Water	Water Surface Elevation
		(ft amsl)[1]	(ft below TOC)	(ft amsl)[1]
Well 1117	6/19/07 9:40	4896.7	8.73	4887.97
Well 1117	8/8/07 10:34	4896.7	9.28	4887.42
Well 1117	9/10/07 16:50	4896.7	10.16	4886.54
Well 1125	3/6/07 9:35	4895.88	9.27	4886.61
Well 1125	4/30/07 16:36	4895.88	7.31	4888.57
Well 1125	5/30/07 13:16	4895.88	7.81	4888.07
Well 1125	6/18/07 16:25	4895.88	7.2	4888.68
Well 1125	8/8/07 11:14	4895.88	8.62	4887.26
Well 1125	9/11/07 10:30	4895.88	9.73	4886.15
Well 1126	3/6/07 13:40	4895.39	9.13	4886.26
Well 1126	5/1/07 11:55	4895.39	6.82	4888.57
Well 1126	5/31/07 11:01	4895.39	7.66	4887.73
Well 1126	6/19/07 13:30	4895.39	8.08	4887.31
Well 1126	8/9/07 9:15	4895.39	8.68	4886.71
Well 1126	9/11/07 12:00	4895.39	9.86	4885.53
Well 1127	3/5/07 17:59	4896.95	9.73	4887.22
Well 1127	4/30/07 12:35	4896.95	8.05	4888.9
Well 1127	5/30/07 10:33	4896.95	8.26	4888.69
Well 1127	6/18/07 15:15	4896.95	8.54	4888.41
Well 1127	8/8/07 9:50	4896.95	9	4887.95
Well 1127	9/11/07 9:40	4896.95	9.96	4886.99
Well 1128	3/5/07 17:35	4897.63	11.15	4886.48
Well 1128	4/30/07 11:40	4897.63	8.94	4888.69
Well 1128	5/30/07 11:16	4897.63	9.81	4887.82
Well 1128	6/19/07 12:45	4897.63	10.15	4887.48
Well 1128	8/8/07 13:20	4897.63	10.68	4886.95
Well 1128	9/11/07 10:45	4897.63	11.48	4886.15
Well 1129	3/6/07 10:23	4895.53	8.24	4887.29
Well 1129	4/30/07 13:35	4895.53	6.64	4888.89
Well 1129	5/30/07 12:19	4895.53	6.74	4888.79
Well 1129	6/18/07 15:50	4895.53	7	4888.53
Well 1129	8/8/07 10:16	4895.53	7.47	4888.06
Well 1129	9/11/07 9:50	4895.53	8.48	4887.05
Well 1130	3/6/07 10:43	4895.36	7.54	4887.82
Well 1130	4/30/07 13:05	4895.36	6.22	4889.14
Well 1130	5/30/07 12:34	4895.36	5.85	4889.51
Well 1130	6/18/07 15:35	4895.36	6.08	4889.28
Well 1130	9/11/07 11:45	4895.36	7.71	4887.65
Well 1131	3/6/07 9:57	4894.78	7.97	4886.81
Well 1131	4/30/07 16:14	4894.78	6.07	4888.71
Well 1131	5/30/07 12:54	4894.78	6.51	4888.27
Well 1131	6/18/07 16:10	4894.78	6.87	4887.91
Well 1131	8/8/07 10:55	4894.78	7.28	4887.5
Well 1131	9/11/07 10:10	4894.78	8.27	4886.51
Well 1132	3/6/07 9:09	4894.50	8.18	4886.32
Well 1132	4/30/07 15:55	4894.50	5.78	4888.72

Table A−2 (continued). Manual Measurements of Water Levels at Wells in the Trench 2 Area

Location	Date and Time	Top of Casing (TOC) Elevation	Depth to Water	Water Surface Elevation
		(ft amsl)[1]	(ft below TOC)	(ft amsl)[1]
Well 1132	5/30/07 13:45	4894.50	6.63	4887.87
Well 1132	6/19/07 9:25	4894.50	6.9	4887.6
Well 1132	8/8/07 11:55	4894.50	7.53	4886.97
Well 1132	9/11/07 11:15	4894.50	8.53	4885.97
Well 1133	3/5/07 16:04	4896.48	10.47	4886.01
Well 1133	4/30/07 15:05	4896.48	7.8	4888.68
Well 1133	5/30/07 14:48	4896.48	8.96	4887.52
Well 1133	6/19/07 13:00	4896.48	9.36	4887.12
Well 1133	8/8/07 14:10	4896.48	10	4886.48
Well 1133	9/11/07 11:00	4896.48	10.91	4885.57
Well 1134	3/6/07 15:20	4895.88	9.75	4886.13
Well 1134	5/1/07 9:53	4895.88	7.17	4888.71
Well 1134	5/30/07 15:43	4895.88	8.21	4887.67
Well 1134	6/18/07 16:40	4895.88	8.61	4887.27
Well 1134	8/9/07 8:41	4895.88	9.11	4886.77
Well 1134	9/11/07 11:30	4895.88	10.33	4885.55

[1] ft amsl = feet above mean sea level

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Appendix B

Average Daily Pumping Rates from Trench 2 and Average Daily River Flows

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Table B−1. Mean Daily Pumping Rates (gpm)[1] from Trench 2

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2006	2006	2006	2006	2006	2006	2006	2006	2006
1	0.00	0.00	13.91	10.69	15.70	21.60	17.35	16.58	17.47
2	0.00	0.00	13.76	11.80	16.69	22.45	17.28	16.59	17.39
3	0.00	0.03	21.01	11.88	18.77	23.03	17.16	16.58	17.45
4	0.00	8.74	22.66	8.48	18.41	22.85	17.07	16.54	17.51
5	0.00	8.66	22.62	11.07	17.09	23.14	16.92	16.51	16.84
6	0.00	8.63	22.53	12.66	15.73	19.63	16.82	16.54	10.92
7	0.00	8.61	20.83	10.66	15.92	20.23	17.32	16.54	0.00
8	0.00	7.43	16.98	12.71	16.96	19.32	18.35	16.51	19.12
9	0.00	13.75	19.48	14.15	16.83	19.45	18.96	16.45	9.07
10	0.00	21.33	19.51	19.82	15.97	10.40	17.45	16.44	5.24
11	0.00	21.58	19.67	20.00	16.16	19.74	16.90	16.58	11.44
12	0.02	20.62	19.85	19.83	16.67	19.91	17.00	16.48	11.47
13	7.21	20.61	20.00	14.51	15.09	19.67	17.05	16.53	8.23
14	6.73	18.98	21.80	14.78	15.08	19.42	17.48	16.49	13.09
15	0.00	18.03	22.66	15.52	14.78	18.72	17.31	16.44	16.93
16	0.00	9.60	21.01	14.97	14.24	18.21	16.84	16.53	15.07
17	0.00	8.51	19.88	10.87	14.51	17.95	16.86	16.45	14.06
18	0.00	9.49	20.07	11.44	12.06	18.04	16.84	16.49	14.34
19	0.00	16.09	20.34	16.21	0.00	18.17	16.87	16.48	14.05
20	0.00	11.79	20.51	20.28	0.00	18.06	16.92	16.88	14.21
21	0.00	11.12	18.25	15.98	0.00	17.74	16.88	17.50	14.36
22	0.00	12.08	16.12	14.71	0.00	17.58	16.97	17.50	14.61
23	0.00	16.11	12.00	14.00	0.00	19.09	16.92	17.48	13.91
24	0.00	20.22	12.93	14.01	0.00	19.66	16.90	17.46	14.08
25	0.00	18.80	13.10	13.76	0.00	19.21	16.82	17.42	14.44
26	10.37	13.60	11.39	13.72	0.00	18.82	17.02	17.44	14.10
27	6.58	12.82	12.53	13.19	0.00	18.33	17.12	17.47	14.15
28	0.00	12.90	11.95	13.16	NA	17.73	16.71	17.39	16.27
29	0.00	12.49	8.51	13.98	NA	17.53	16.65	17.39	16.58
30	0.00	12.67	10.91	13.21	NA	17.35	16.57	17.65	15.48
31		12.43		13.69	NA		16.57		15.56

[1]gpm = gallons per minute
NA = not available

Table B-1 (continued). Mean Daily Pumping Rates from Trench 2

Date	Jan 2007	Feb 2007	Mar 2007	Apr 2007	May 2007	Jun 2007	Jul 2007	Aug 2007	Sep 2007
1	15.54	13.80	14.67	16.06	0.00	19.40	18.70	0.00	18.54
2	3.02	14.04	14.67	16.01	0.35	19.38	18.69	11.50	18.54
3	0.00	13.64	14.36	16.54	14.56	19.35	18.70	19.72	18.53
4	0.00	13.62	14.13	16.21	21.44	19.27	18.63	19.42	18.54
5	0.00	13.47	14.24	16.00	22.29	19.21	18.63	19.26	18.50
6	0.00	13.40	14.19	16.53	21.77	19.20	18.60	19.17	18.51
7	0.00	13.92	13.94	16.00	21.53	19.15	18.56	19.11	18.51
8	0.00	13.77	14.10	16.02	21.31	19.14	18.55	19.03	18.51
9	0.00	13.85	14.29	16.42	21.11	19.12	18.58	19.01	18.50
10	0.00	14.12	14.46	16.04	17.12	19.10	18.59	18.93	18.51
11	0.00	14.27	15.11	NA	21.03	19.10	18.56	18.91	18.51
12	0.00	14.40	15.09	NA	20.77	19.05	18.58	18.88	18.52
13	0.00	14.63	15.13	0.00	20.58	19.02	12.63	18.87	18.50
14	0.00	15.02	NA	0.00	20.48	19.01	6.66	18.85	18.47
15	0.00	4.98	NA	0.00	20.43	18.98	19.74	18.82	18.45
16	0.00	6.74	16.62	0.00	20.32	18.98	19.37	18.78	
17	0.00	17.03	16.68	0.00	20.26	18.96	19.23	18.76	
18	0.00	16.94	16.44	0.00	20.19	18.95	19.13	18.71	
19	0.00	16.73	16.24	0.00	20.12	18.90	19.04	18.70	
20	0.00	16.63	16.39	0.00	20.06	18.89	18.99	18.67	
21	0.00	16.24	0.00	0.00	19.97	18.84	16.35	18.66	
22	0.00	15.71	3.13	0.00	19.92	18.84	19.46	18.65	
23	0.00	15.56	16.30	0.00	19.91	18.81	19.20	18.62	
24	0.00	15.58	16.39	0.00	19.92	18.78	19.10	18.59	
25	0.00	15.22	16.51	0.00	19.83	18.78	19.05	18.58	
26	5.94	15.20	16.13	0.00	19.77	18.77	18.95	18.58	
27	13.81	14.97	16.16	0.48	19.66	18.70	18.94	18.57	
28	14.11	14.71	16.35	0.00	19.60	18.72	18.91	18.56	
29	13.59		16.01	0.00	19.54	18.71	18.86	18.57	
30	13.98		16.10	0.00	19.47	18.72	18.79	18.56	
31	13.73		16.80		19.44		10.87	18.54	

[1]gpm = gallons per minute
NA = not available

Table B−2. Mean Daily Flows (cfs)[1] on the San Juan River at Shiprock

Date	Apr 2006	May 2006	Jun 2006	Jul 2006	Aug 2006	Sep 2006	Oct 2006	Nov 2006	Dec 2006
1	509	1,040	4,900	650	3,220	584	781	1,000	965
2	546	1,030	5,900	660	3,540	523	724	990	942
3	501	1,300	6,480	650	1,990	649	674	960	988
4	467	1,320	6,510	645	1,070	833	659	955	972
5	444	1,550	6,620	660	1,070	870	732	916	782
6	468	1,490	6,590	677	1,200	589	1,280	901	654
7	528	1,050	6,780	810	2,370	531	6,930	984	694
8	517	977	6,500	1,100	1,550	1,120	8,310	1,060	674
9	476	1,030	5,700	2,100	1,430	1,840	7,280	1,100	637
10	537	1,040	5,200	1,740	1,480	1,270	7,470	1,120	641
11	643	867	4,900	1,620	1,380	928	4,610	1,090	648
12	626	781	4,640	1,520	1,010	742	3,120	1,110	646
13	546	820	3,810	1,290	893	628	2,480	1,070	638
14	619	1,170	3,210	1,100	706	598	2,240	1,050	631
15	868	1,550	2,520	958	746	1,050	6,890	1,000	766
16	1,020	2,470	1,720	837	1,130	1,230	4,850	1,020	881
17	920	2,660	1,300	806	1,330	1,030	3,790	1,020	874
18	932	2,980	1,110	761	990	925	2,430	1,030	854
19	1,020	2,880	1,060	671	645	795	1,940	1,020	899
20	870	2,900	1,010	646	647	778	1,720	1,020	905
21	796	2,440	1,020	674	674	1,650	1,620	1,030	857
22	818	2,680	910	700	935	1,490	1,460	986	856
23	934	3,040	820	713	797	1,010	1,370	992	893
24	975	3,560	740	678	631	892	1,360	978	868
25	1,080	3,860	710	644	694	782	1,360	986	874
26	906	4,020	650	644	1,020	718	1,390	975	868
27	846	4,640	700	765	861	724	1,320	963	861
28	1,020	4,560	790	697	959	720	1,280	994	899
29	1,200	3,990	760	681	796	761	1,250	984	955
30	1,170	3,300	700	1,660	688	853	1,210	1,000	970
31		3,800		2,230	635		1,110		922

[1]cfs = cubic feet per second

Table B–2 (continued). Mean Daily Flows (cfs)[1] on the San Juan River at Shiprock

Date	Jan 2007	Feb 2007	Mar 2007	Apr 2007	May 2007	Jun 2007	Jul 2007	Aug 2007	Sep 2007
1	908	864	864	1,360	3,290	3,660	1,250	1,580	738
2	890	825	840	1,330	5,330	4,000	1,200	1,350	767
3	859	790	854	1,260	6,790	4,360	1,140	1,430	1,010
4	853	806	806	1,210	8,000	4,460	1,040	2,690	1,050
5	819	837	829	1,140	7,940	4,350	978	3,170	834
6	832	864	835	1,110	7,680	4,380	948	3,810	812
7	846	886	883	1,190	7,440	4,260	983	3,860	804
8	852	923	1,010	1,290	7,150	3,300	953	4,580	790
9	853	955	1,210	1,350	6,970	2,750	897	3,090	763
10	801	988	1,240	1,380	6,930	2,890	798	1,850	748
11	837	1,060	1,220	1,470	6,970	3,330	746	1,320	740
12	855	1,430	1,120	1,380	7,500	3,560	861	1,140	711
13	884	2,090	1,130	1,380	8,130	3,570	838	1,050	712
14	868	1,730	1,180	1,340	8,400	3,300	870	956	737
15	852	1,360	1,270	1,220	8,660	3,430	869	1,010	715
16	870	1,140	1,390	1,150	9,090	3,770	825	912	
17	825	1,010	1,470	1,150	9,010	3,890	781	903	
18	833	1,040	1,540	1,180	6,550	3,650	718	924	
19	845	1,050	1,660	1,160	6,080	3,610	688	875	
20	772	1,040	1,690	1,180	6,700	3,310	678	835	
21	667	1,030	1,690	1,200	6,830	3,070	749	789	
22	662	1,010	1,830	1,210	5,610	2,930	1,020	733	
23	658	989	1,730	1,150	4,750	2,660	1,330	643	
24	794	973	1,680	1,160	3,770	2,580	1,370	613	
25	928	912	1,610	1,380	3,240	2,560	1,300	573	
26	847	901	1,540	1,470	3,020	---	1,330	563	
27	847	858	1,410	1,160	2,830	2,300	978	570	
28	842	849	1,400	1,070	2,760	2,170	1,220	1,310	
29	846		1,470	1,160	3,100	1,690	1,320	896	
30	845		1,430	1,610	3,530	1,300	1,770	861	
31	868		1,410		3,520		1,940	792	

[1]cfs = cubic feet per second

Appendix C

Concentrations of Cations and Anions at Wells Installed Prior to 2007

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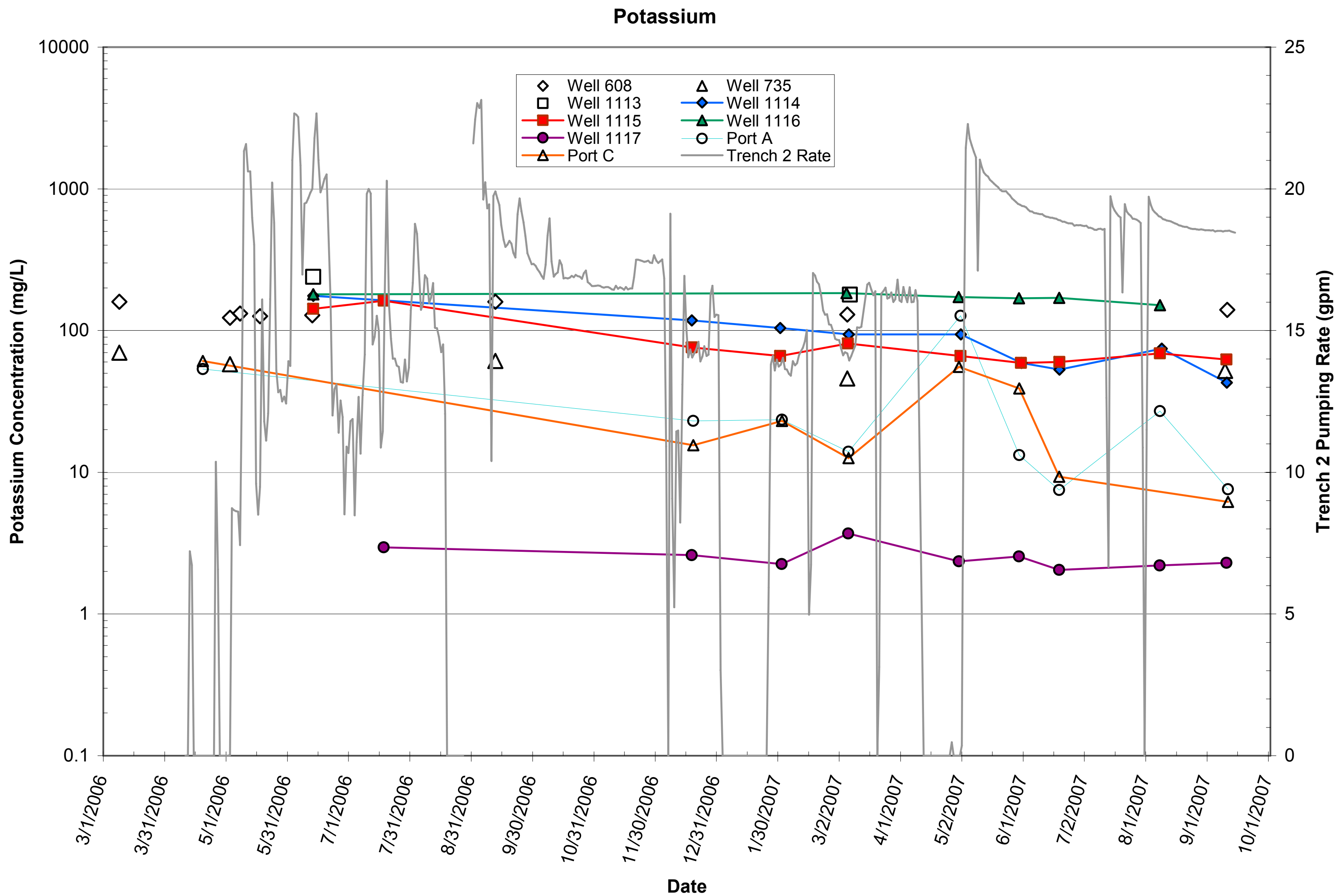
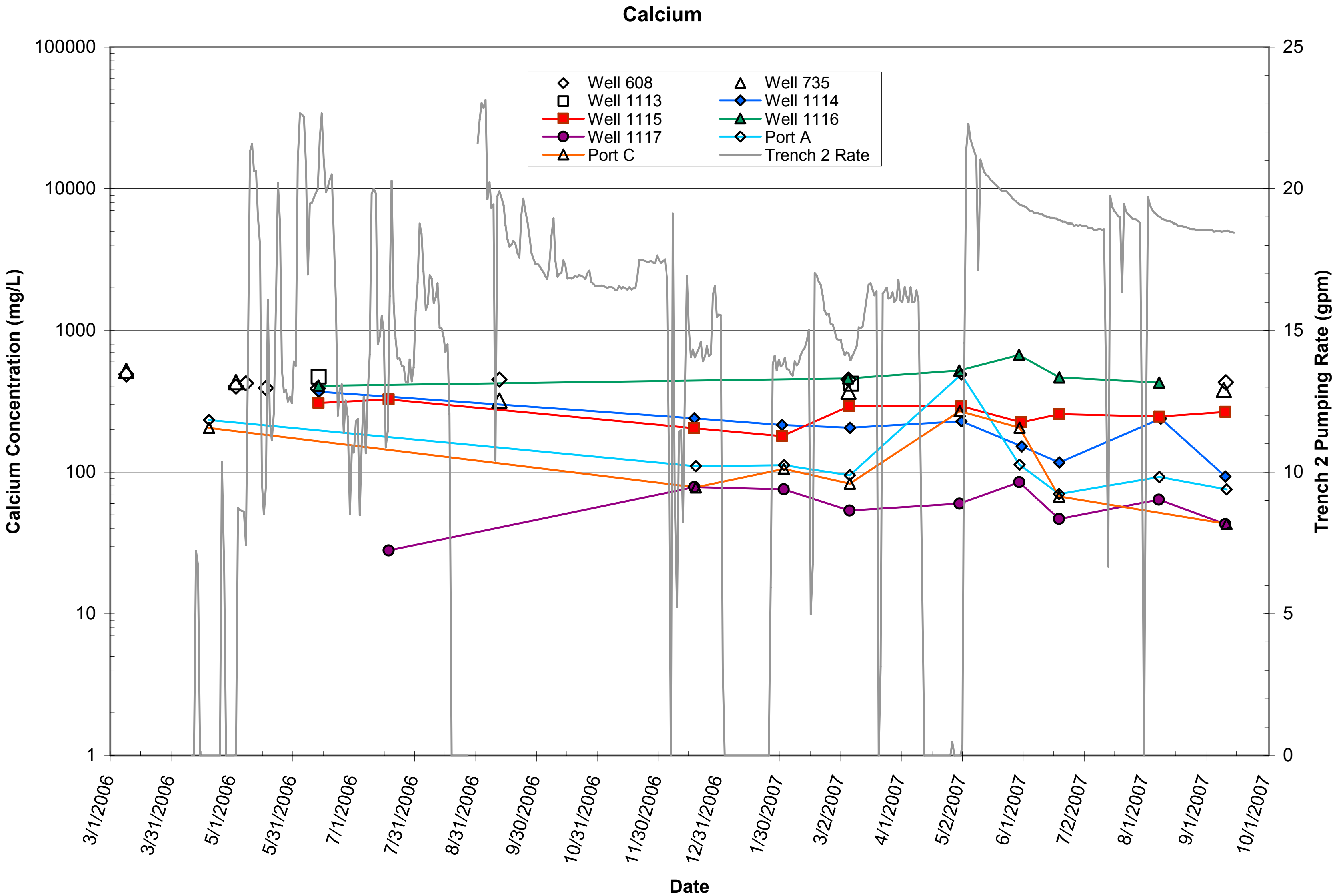
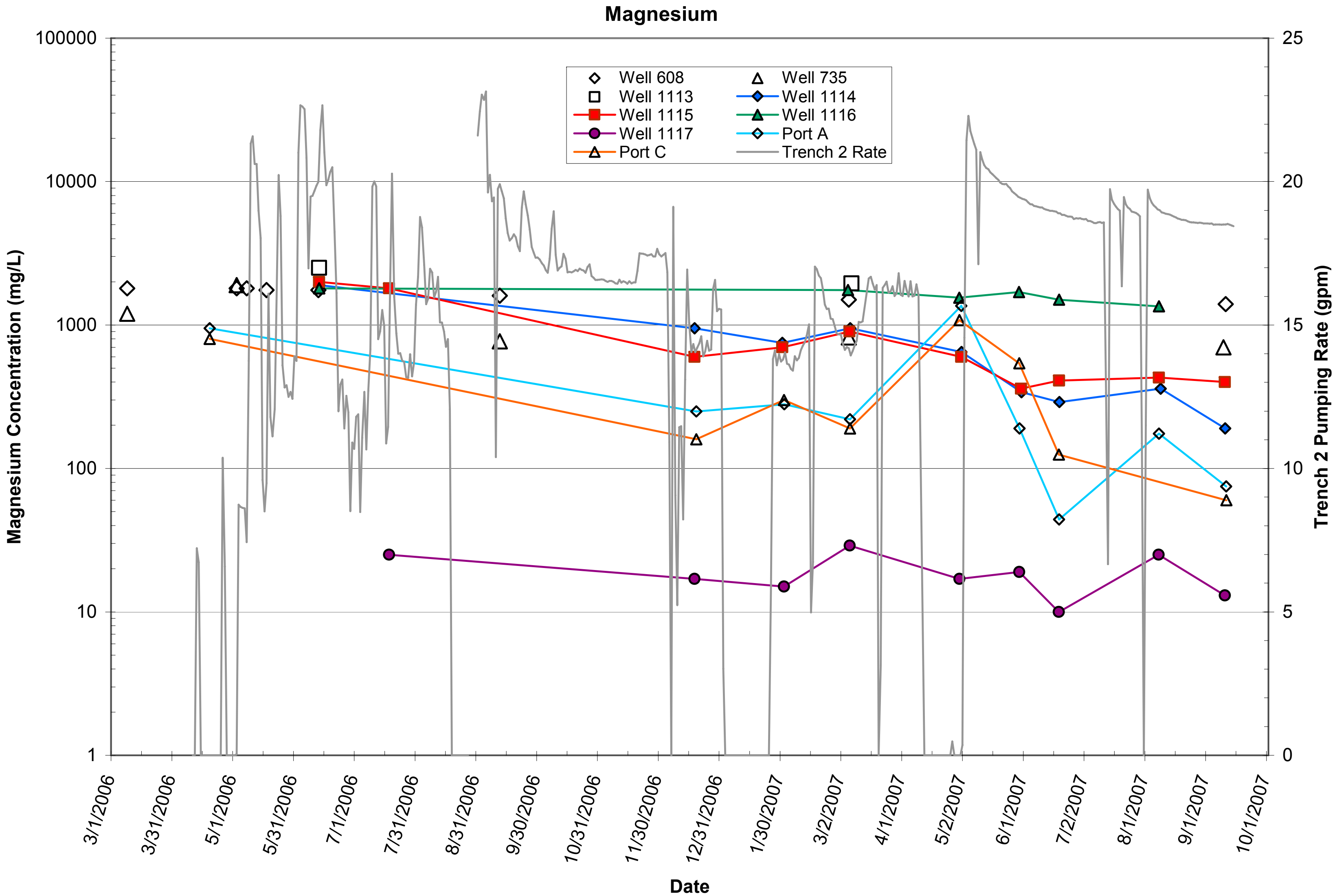
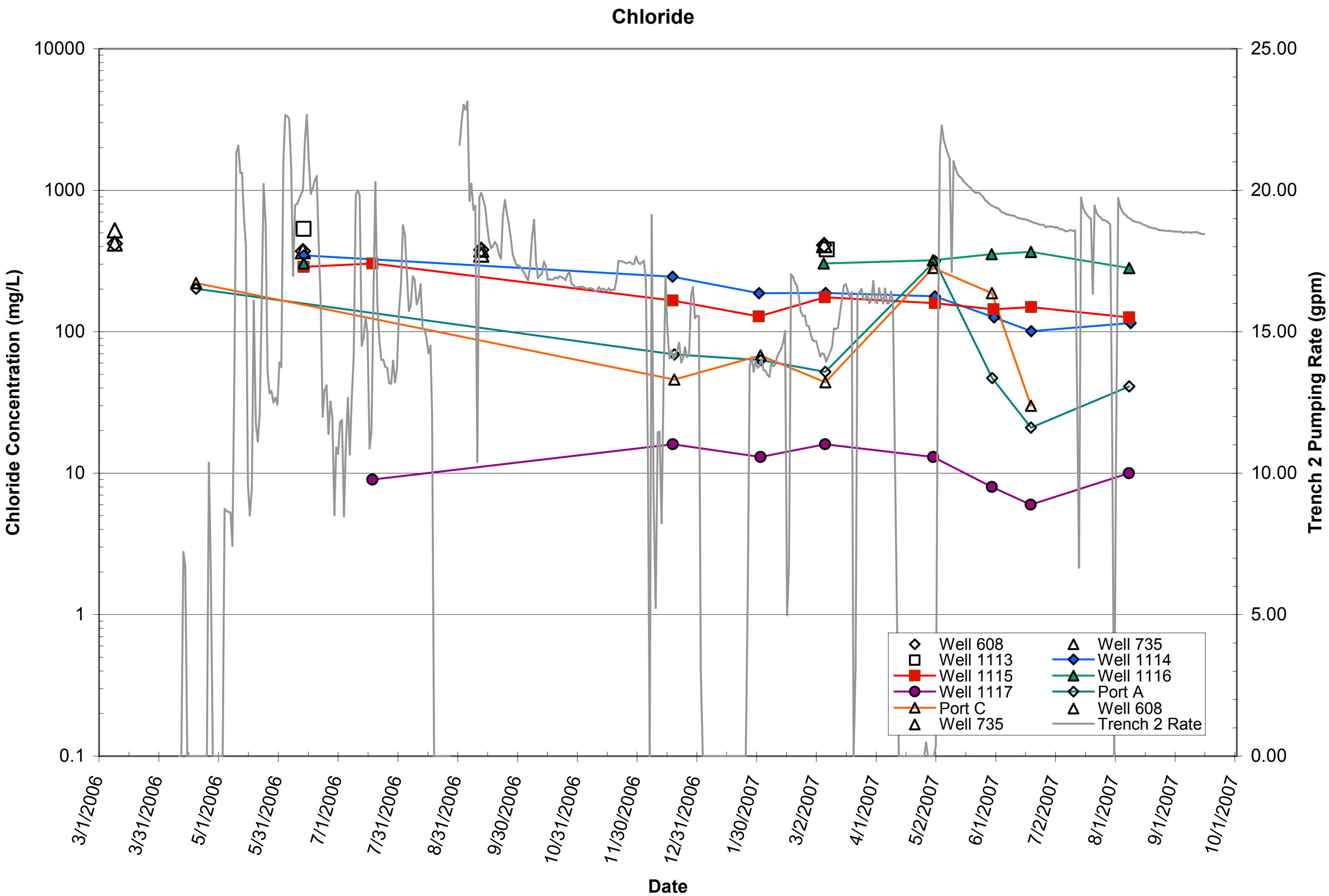

Potassium
Potassium Concentration (mg/L)
Trench 2 Pumping Rate (gpm)
Date
Well 608
Well 1113
Well 1115
Well 1117
Port C
Well 735
Well 1114
Well 1116
Port A
Trench 2 Rate
10000
1000
100
10
1
0.1
25
20
15
10
5
0
3/1/2006
3/31/2006
5/1/2006
5/31/2006
7/1/2006
7/31/2006
8/31/2006
9/30/2006
10/31/2006
11/30/2006
12/31/2006
1/30/2007
3/2/2007
4/1/2007
5/2/2007
6/1/2007
7/2/2007
8/1/2007
9/1/2007
10/1/2007


Calcium
Calcium Concentration (mg/L)
100000
10000
1000
100
10
1
Trench 2 Pumping Rate (gpm)
25
20
15
10
5
0
Well 608
Well 1113
Well 1115
Well 1117
Port C
Well 735
Well 1114
Well 1116
Port A
Trench 2 Rate
3/1/2006
3/31/2006
5/1/2006
5/31/2006
7/1/2006
7/31/2006
8/31/2006
9/30/2006
10/31/2006
11/30/2006
12/31/2006
1/30/2007
3/2/2007
4/1/2007
5/2/2007
6/1/2007
7/2/2007
8/1/2007
9/1/2007
10/1/2007
Date


Magnesium
Magnesium Concentration (mg/L)
Trench 2 Pumping Rate (gpm)
Date
Well 608
Well 735
Well 1113
Well 1114
Well 1115
Well 1116
Well 1117
Port A
Port C
Trench 2 Rate
100000
10000
1000
100
10
1
25
20
15
10
5
0
3/1/2006
3/31/2006
5/1/2006
5/31/2006
7/1/2006
7/31/2006
8/31/2006
9/30/2006
10/31/2006
11/30/2006
12/31/2006
1/30/2007
3/2/2007
4/1/2007
5/2/2007
6/1/2007
7/2/2007
8/1/2007
9/1/2007
10/1/2007


Chloride
Chloride Concentration (mg/L)
Trench 2 Pumping Rate (gpm)
Date
10000
1000
100
10
1
0.1
25.00
20.00
15.00
10.00
5.00
0.00
3/1/2006
3/31/2006
5/1/2006
5/31/2006
7/1/2006
7/31/2006
8/31/2006
9/30/2006
10/31/2006
11/30/2006
12/31/2006
1/30/2007
3/2/2007
4/1/2007
5/2/2007
6/1/2007
7/2/2007
8/1/2007
9/1/2007
10/1/2007
Well 608
Well 1113
Well 1115
Well 1117
Port C
Well 735
Well 735
Well 1114
Well 1116
Port A
Well 608
Trench 2 Rate

Appendix D

Concentrations of Cations and Anions at Wells Installed During 2007

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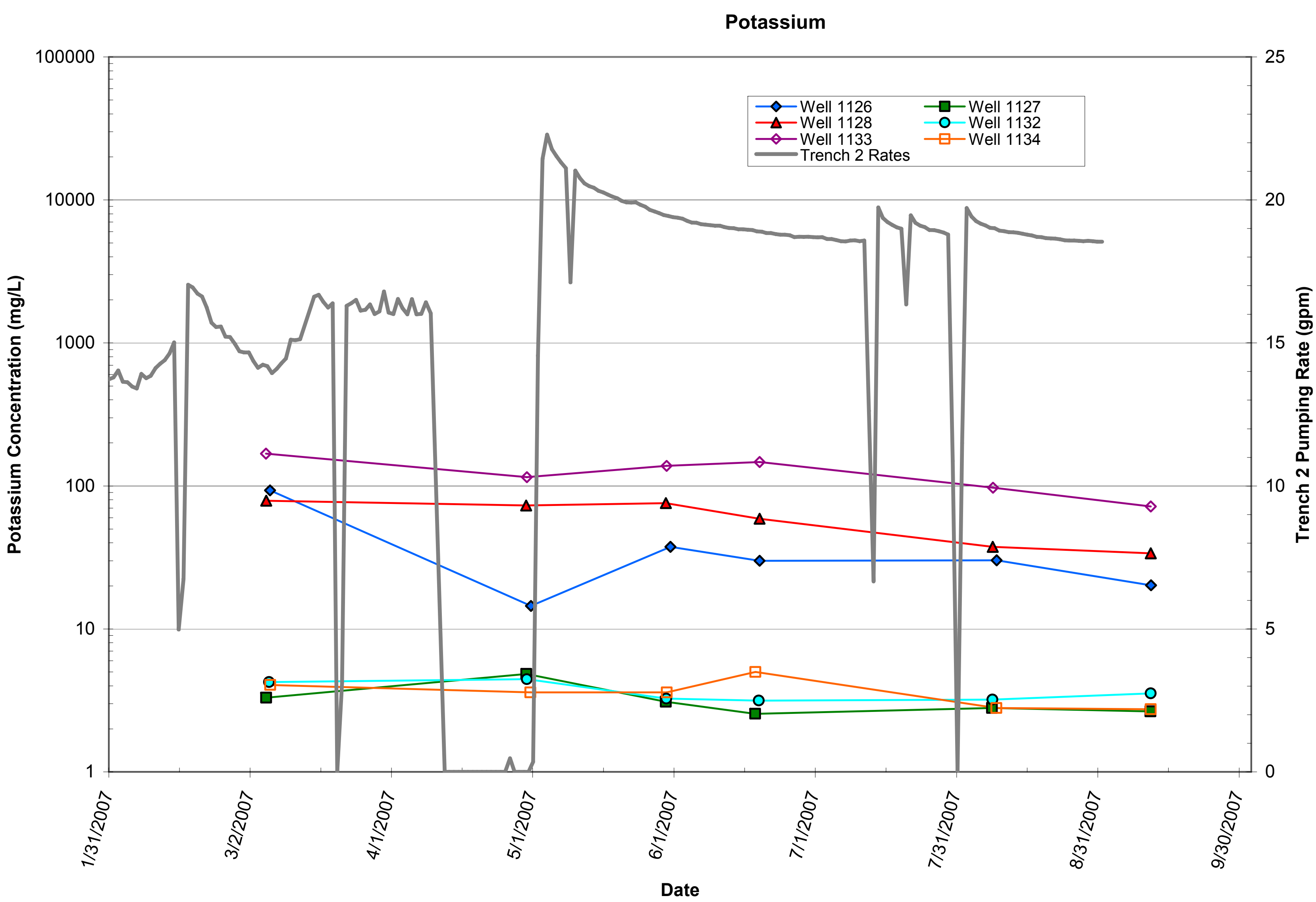
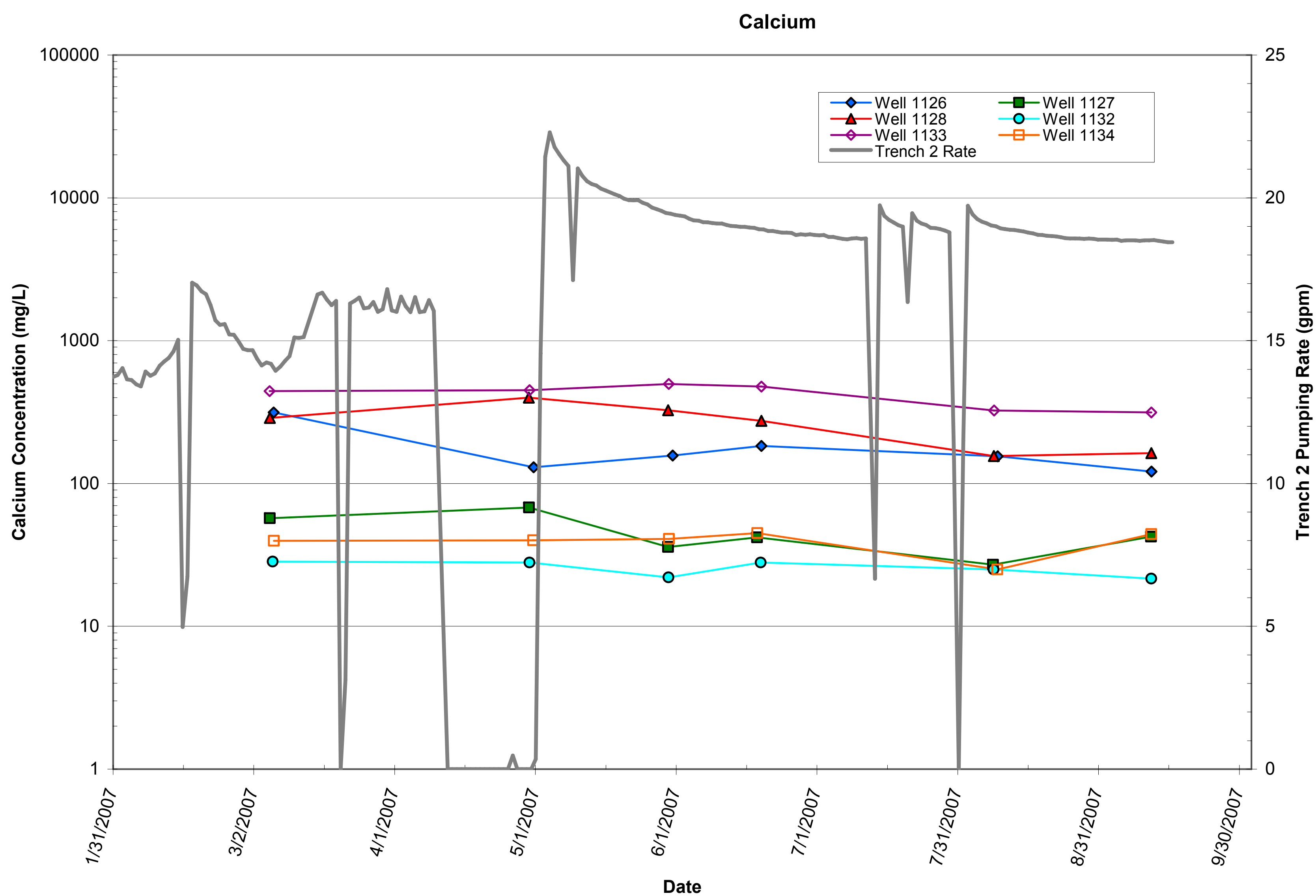
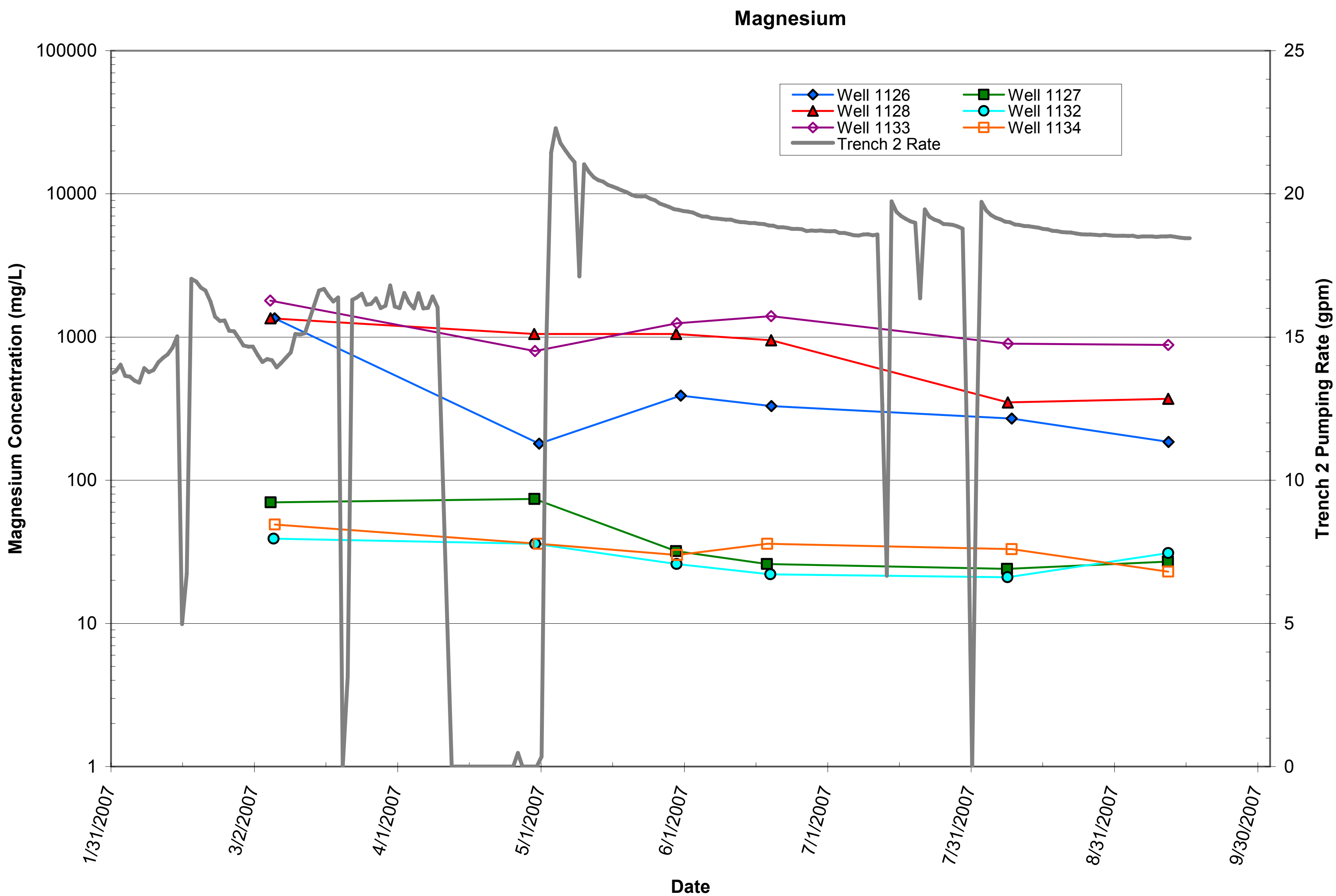
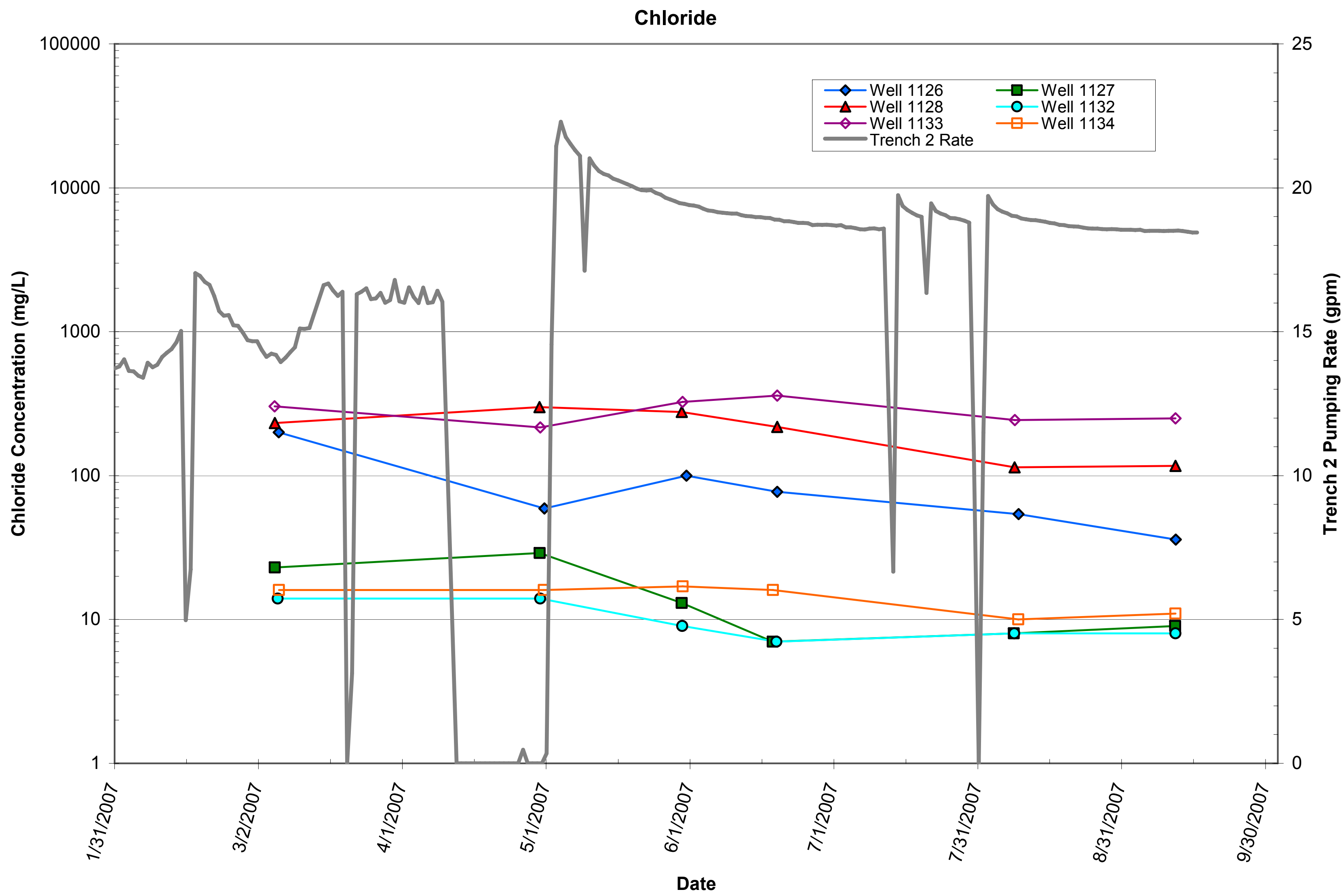

Potassium
Potassium Concentration (mg/L)
100000
10000
1000
100
10
1
Trench 2 Pumping Rate (gpm)
25
20
15
10
5
0
Well 1126
Well 1127
Well 1128
Well 1132
Well 1133
Well 1134
Trench 2 Rates
1/31/2007
3/2/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
7/31/2007
8/31/2007
9/30/2007
Date


Calcium
Calcium Concentration (mg/L)
Trench 2 Pumping Rate (gpm)
Date
100000
10000
1000
100
10
1
25
20
15
10
5
0
1/31/2007
3/2/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
7/31/2007
8/31/2007
9/30/2007
Well 1126
Well 1127
Well 1128
Well 1132
Well 1133
Well 1134
Trench 2 Rate


Magnesium
Magnesium Concentration (mg/L)
Trench 2 Pumping Rate (gpm)
Date
100000
10000
1000
100
10
1
25
20
15
10
5
0
1/31/2007
3/2/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
7/31/2007
8/31/2007
9/30/2007
Well 1126
Well 1127
Well 1128
Well 1132
Well 1133
Well 1134
Trench 2 Rate


Chloride
Chloride Concentration (mg/L)
100000
10000
1000
100
10
1
Trench 2 Pumping Rate (gpm)
25
20
15
10
5
0
Well 1126
Well 1127
Well 1128
Well 1132
Well 1133
Well 1134
Trench 2 Rate
1/31/2007
3/2/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
7/31/2007
8/31/2007
9/30/2007
Date