3.0 Remediation System Performance

This section describes the key components of the floodplain and terrace groundwater remediation systems and summarizes their performance for the 2009–2010 reporting period.

3.1 Floodplain Remediation System

The floodplain remediation system consists of the three major components shown in Figure 1–1: two extraction wells (wells 1089 and 1104); two drainage trenches (horizontal wells), Trench 1 and Trench 2; and a sump (collection drain) used to collect discharges from seeps 0425 and 0426 on the escarpment. The objective of the floodplain groundwater extraction system is to reduce the mass of COCs in alluvial groundwater near the San Juan River and to lessen exposure and potential risks to aquatic life. All groundwater collected from the floodplain extraction wells and trenches is piped south to the terrace and discharged into the evaporation pond.

3.1.1 Extraction Well Performance

The floodplain extraction well system consists of wells 1089 and 1104 (Figure 1–1). These wells were constructed using slotted culverts placed in trenches excavated to bedrock. Corresponding pumping rates and cumulative volumes of groundwater extracted are plotted in Figures 3–1 and 3–2. From April 2009 through March 2010, approximately 3 million gallons of water were removed from well 1089 at an average pumping rate of 5.9 gpm.[11] These values are comparable to those reported last year (DOE 2009a). Pumping rates at well 1104 were much lower than at well 1089, averaging about 0.6 gpm and yielding a total cumulative extracted volume of nearly 297,000 gallons. During the 7-year period since the start of operations in March 2003 through the end of March 2010, totals of approximately 19.7 and 3.4 million gallons of water have been removed from wells 1089 and 1104, respectively.

3.1.2 Floodplain Drain System Performance

In spring 2006, two drainage trenches—Trench 1 (1110) and Trench 2 (1109)—were installed in the floodplain just below the escarpment to enhance the extraction of groundwater from the alluvial system (Figure 1–1). Pumping began in April 2006. From April 2009 through March 2010, approximately 3.8 million gallons of water were removed from Trench 1 at an average pumping rate of 9.0 gpm (Figure 3–3). Although the average pumping rate is comparable to that reported for the 2008–2009 performance evaluation period (9.2 gpm; DOE 2009a), the cumulative volume was lower than last year's production of 4.9 million gallons.

In 2009–2010, nearly 2.3 million gallons of water were removed from Trench 2 at an average pumping rate of 15.2 gpm (Figure 3–4). Although this rate is similar to that reported last year (16.1 gpm average, DOE 2009a), the annual extracted volume is markedly lower than the approximate 8.5 million gallons pumped in 2008–2009. This reduction in annual extracted volume is attributable to the fact that pumping at Trench 2 was shut down periodically to increase evaporation pond capacity and maintain safe pond water levels (see Section 3.2.3 for further discussion).

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[11] In the text of this report, total volumes are rounded (e.g., to the nearest thousand or larger); corresponding non-rounded values are shown in the figures and are listed in Table 3–2. Also (important to consider in any comparisons), average pumping rates reported here are for pumping conditions only (zero values are excluded).

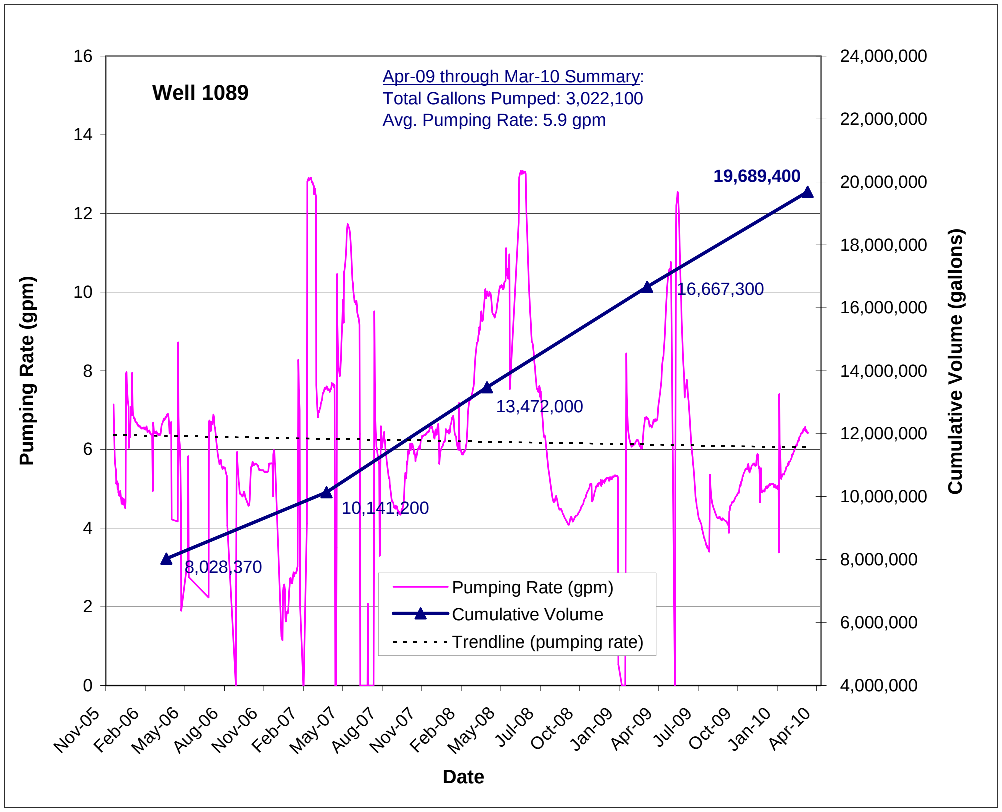

Figure 3–1. Floodplain Well 1089 Pumping Rate and Cumulative Groundwater Volume Extracted

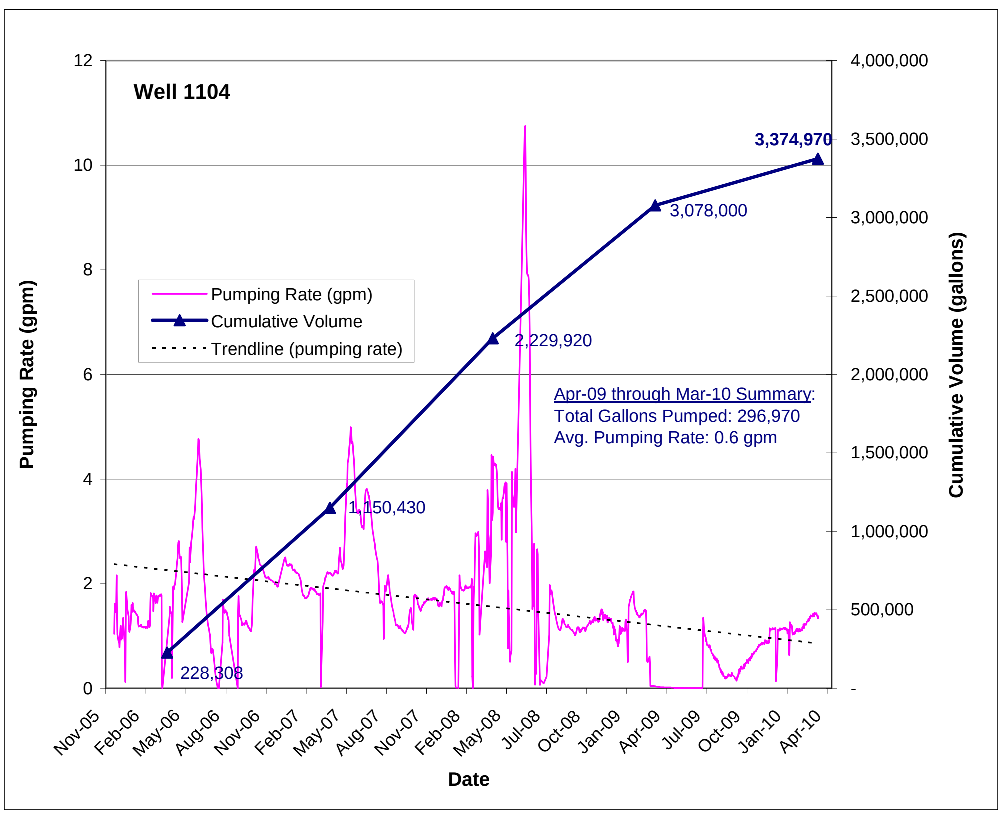

Figure 3–2. Floodplain Well 1104 Pumping Rate and Cumulative Groundwater Volume Extracted

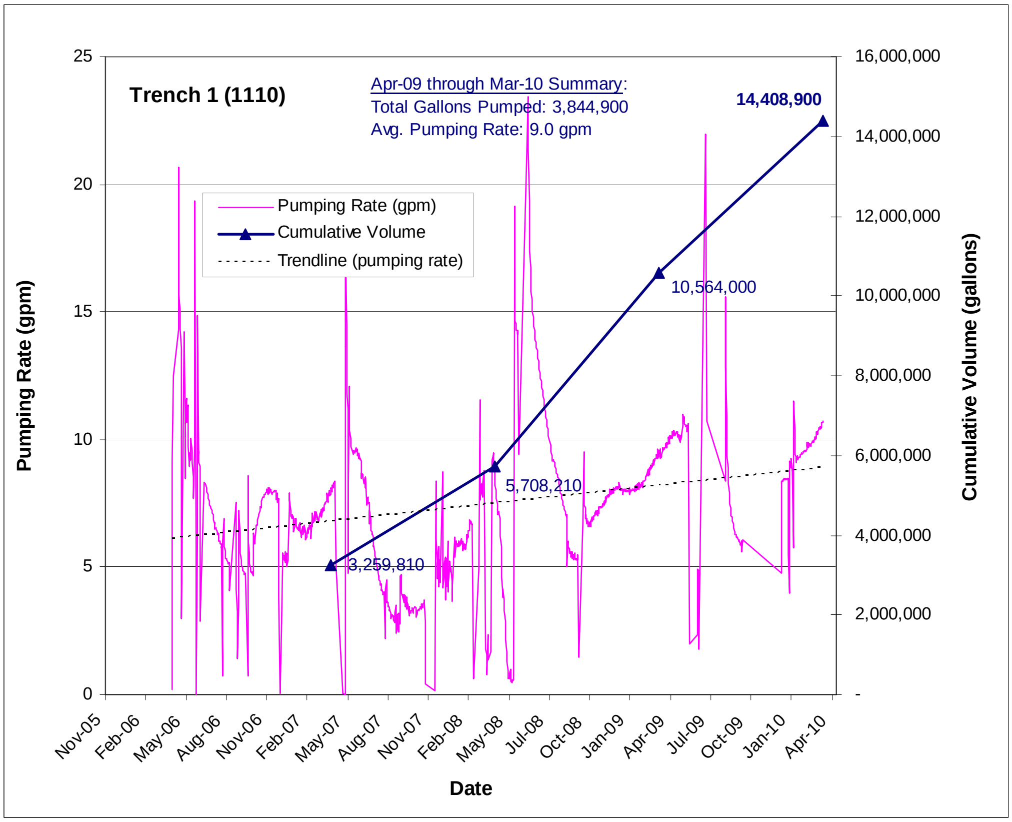

Figure 3–3. Floodplain Trench 1 Pumping Rate and Cumulative Groundwater Volume Extracted

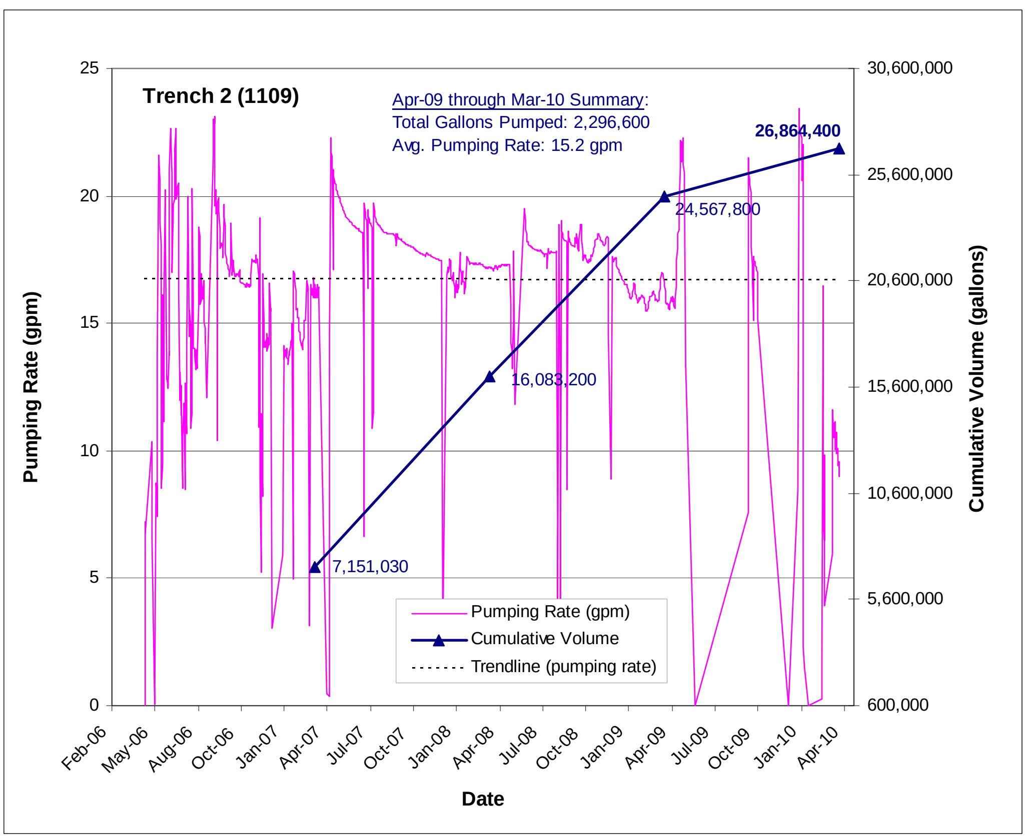

Figure 3–4. Floodplain Trench 2 Pumping Rate and Cumulative Groundwater Volume Extracted

3.1.3 Floodplain Seep Sump Performance

In August 2006, seeps 0425 and 0426 were incorporated into the remediation system. Groundwater discharge from these two seeps is piped into a collection drain (1118 in Figure 1–1) and then pumped to the evaporation pond. From April 2009 through March 2010, the average discharge rate from the seep collection drain was 0.35 gpm (essentially equal to the 0.34 gpm rate reported for 2008–2009). Approximately 182,000 gallons were pumped from the seeps during this period, yielding a total cumulative volume of about 1.2 million gallons. Figure 3–5 plots the historical rates of groundwater discharge from the escarpment seeps, showing the gradual decline in flows over the last several years. Also, with few exceptions, flows have generally been below the previously established goal of 0.9 gpm since spring 2008 (see DOE 2005, DOE 2010a).

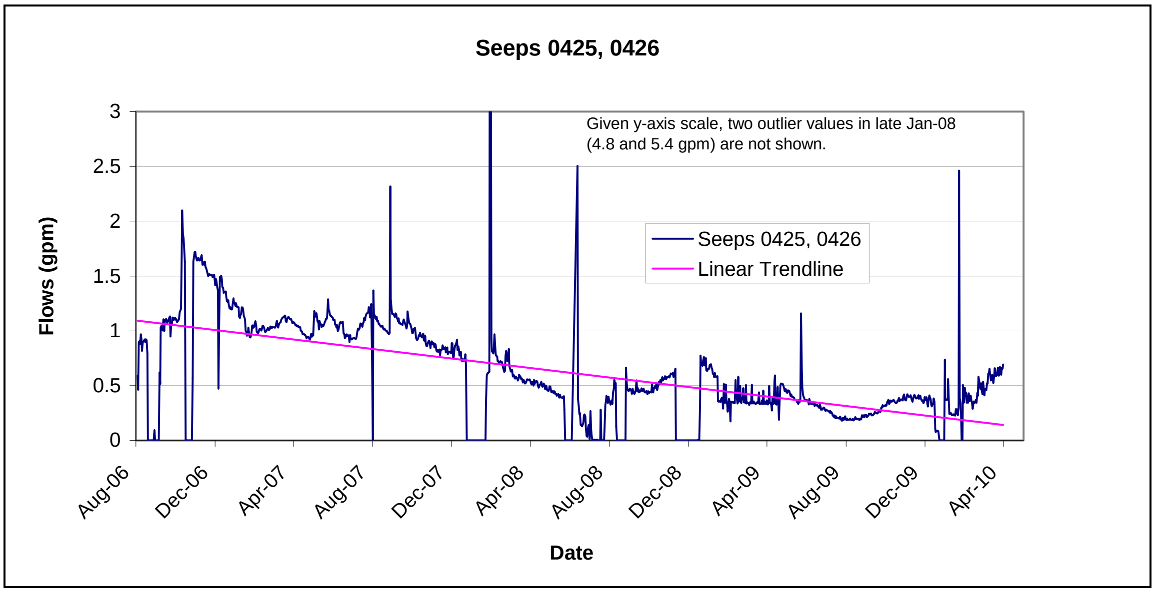

Figure 3–5. Historical Seep Flows (Seeps 0425 and 0426)

3.2 Terrace Remediation System

The objective of the terrace remediation system is to remove groundwater from the southern portion of the terrace area so that potential exposure pathways at seeps and at Bob Lee Wash and Many Devils Wash are eventually eliminated, and the flow of groundwater from the terrace to the floodplain is reduced. The terrace remediation system consists of four major components shown in Figure 1–1: the extraction wells, the evaporation pond, the terrace drains (Bob Lee Wash and Many Devils Wash), and the terrace outfall drainage channel diversion. DOE also continues to evaluate the feasibility of phytoremediation on the terrace, using deep-rooted plants to enhance evapotranspiration in the radon barrier borrow pit area south of the disposal cell, and also between the disposal cell and the escarpment. The goal of phytoremediation in these areas is hydraulic control, to limit the spread of contaminants in groundwater.

3.2.1 Extraction Well Performance

During the current period, the terrace remediation well field consisted of wells 0818, 1070, 1071, 1078, 1091, 1092, 1093, 1095, and 1096 (Figure 1–1). Table 3–1 compares the average pumping rate and total groundwater volume removed from each extraction well for the current (2009-2010) and previous (2008–2009) reporting periods.

Table 3–1. Terrace Extraction Wells: Average Pumping Rates and Total Groundwater Volume Removed

Well	Previous Period (April 1, 2008, through March 31, 2009)		Current Period (April 1, 2009, through March 31, 2010)	
	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)	Average Pumping Rate (gpm)	Total Groundwater Volume Removed (gallons)
0818	0.13	67,413	0.44	227,890
1070	0.012	6307	0.015	6450
1071	0.0006	287	0.001	297
1078	0.28	148,730	0.25	136,510
1091	0.0004	189	0.019	4952
1092	0.00002	12	0.00001	7
1093R	0.75	396,577	0.6	124,030
1095	0.5	260,910	0.5	225,170
1096	0.5	266,560	0.38	135,670
Total	**2.2**	**1,146,985**	**2.2**	**860,976**

As shown in Table 3–1, the current-period average pumping rates ranged from 0.00001 gpm to 0.6 gpm, and the total groundwater volume removed from each well during this period ranged from only 7 gallons (well 1092) to approximately 228,000 gallons (well 0818). The cumulative total volume removed during the current period was approximately 25 percent less than during the previous reporting period. This decrease in annual extracted volume is expected to continue as more water is removed from the aquifer.

As discussed in greater detail in the recent review of the Shiprock remediation strategy (DOE 2010a), one of the initial objectives for the terrace remediation system was attainment of a cumulative 8 gpm extraction rate, a goal based on groundwater modeling conducted for the SOWP (see DOE 2000, DOE 2002, and DOE 2005). To help meet this objective, DOE expanded the terrace extraction well network between 2005 and 2007. Two new wells (1095 and 1096) were installed near the evaporation pond in March 2005. In September 2007, DOE installed a new large-diameter well (1093R) to increase the probability of collecting a larger volume of water. Despite these enhancements to the terrace extraction system, the 8 gpm objective has not been achieved. As shown in Figure 3–6, the combined pumping rate from terrace extraction wells has ranged between 2 and 4 gpm, below the 8 gpm objective.

Pumping rates and corresponding cumulative groundwater volumes removed from individual terrace extraction wells are presented in Figures 3–7 through 3–15. Although active remediation began in March 2003, these figures only plot data after 2004–2005, when site remediation system wells and drains were instrumented with LM's automated telemetry data collection system, referred to as System Operation and Analysis at Remote Sites (SOARS).

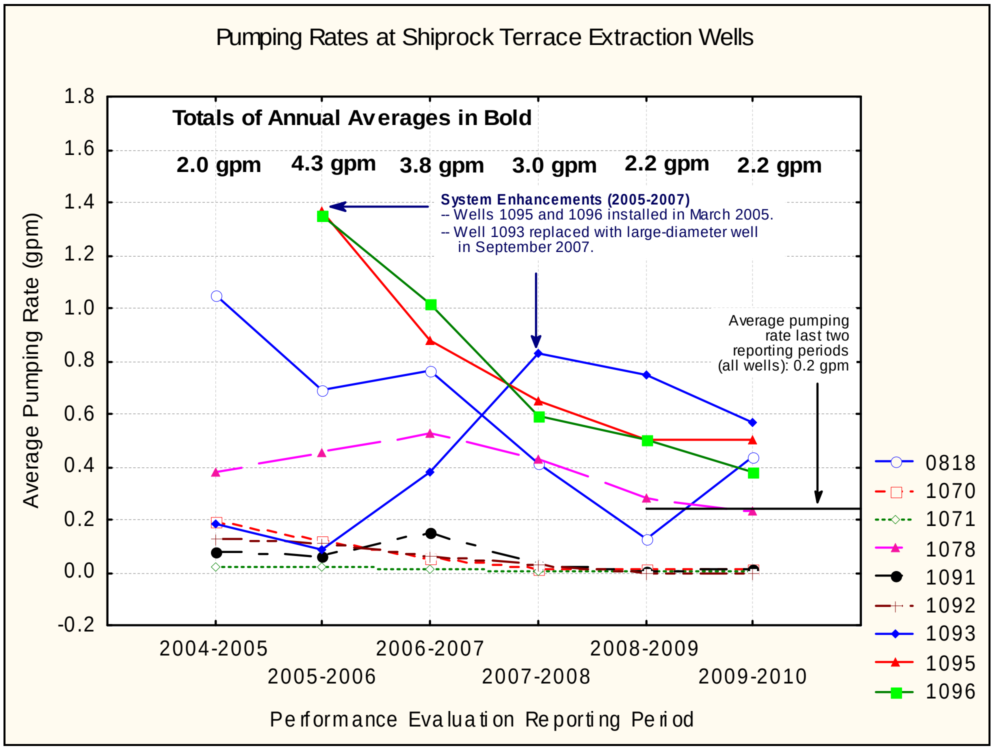

Figure 3–6. Historical Pumping Rate Summary for Terrace Extraction Wells

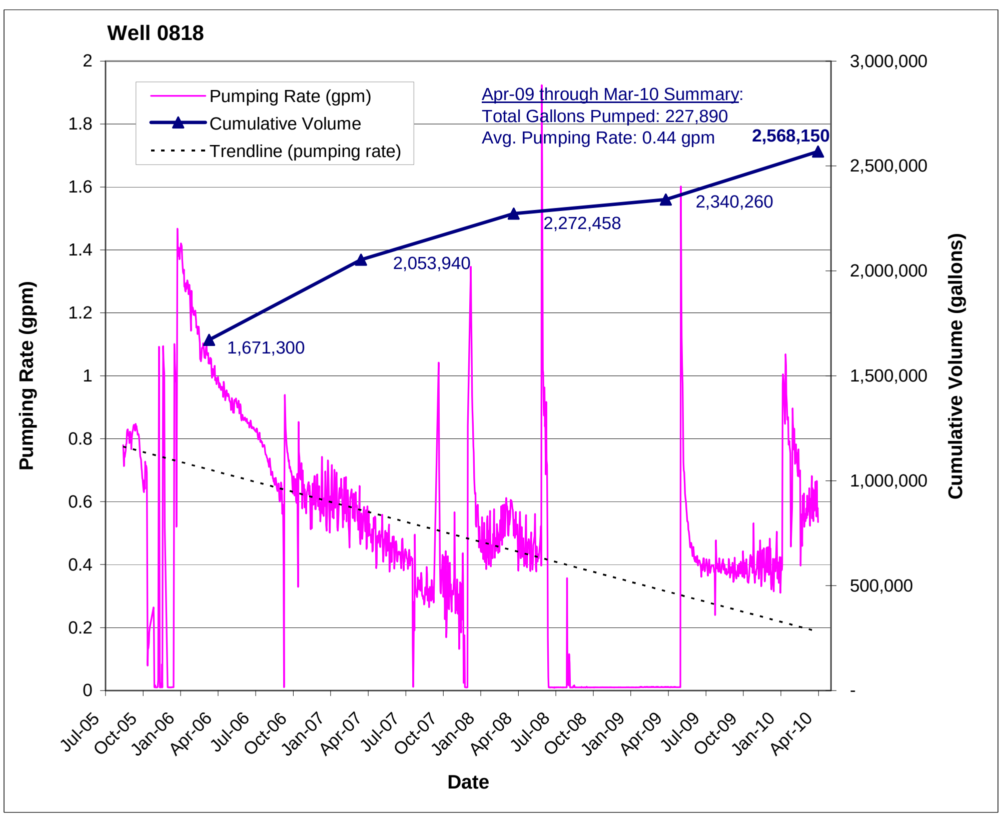

Figure 3–7. Terrace Well 0818 Pumping Rate and Cumulative Groundwater Volume Extracted

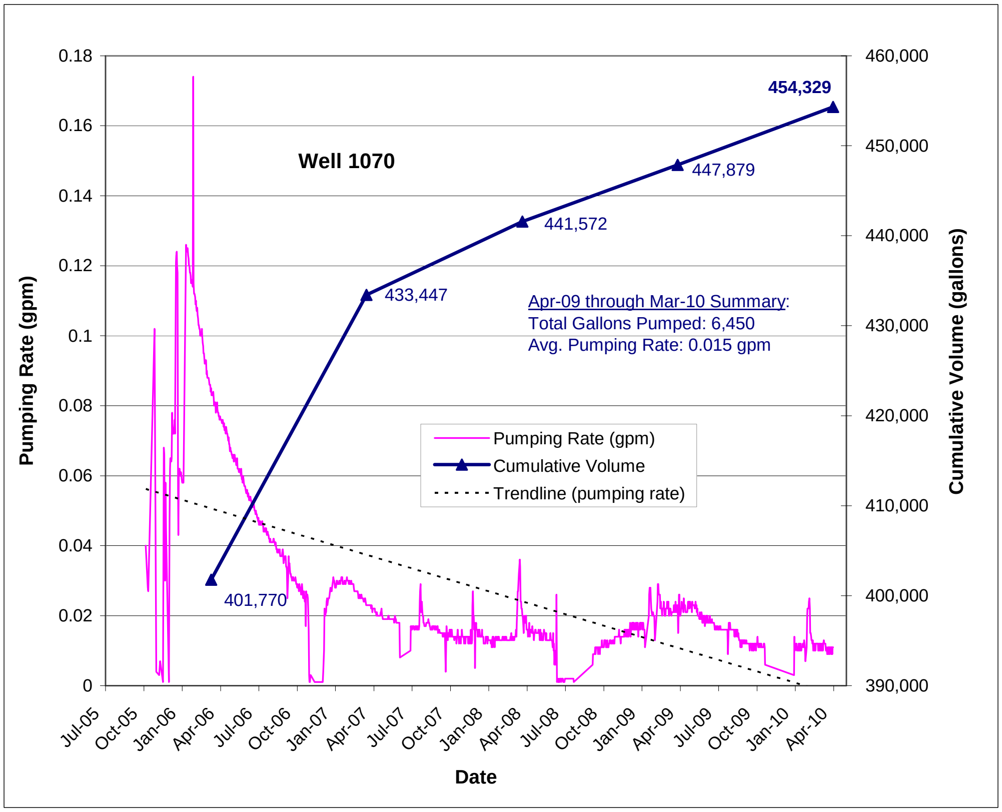

Figure 3–8. Terrace Well 1070 Pumping Rate and Cumulative Groundwater Volume Extracted

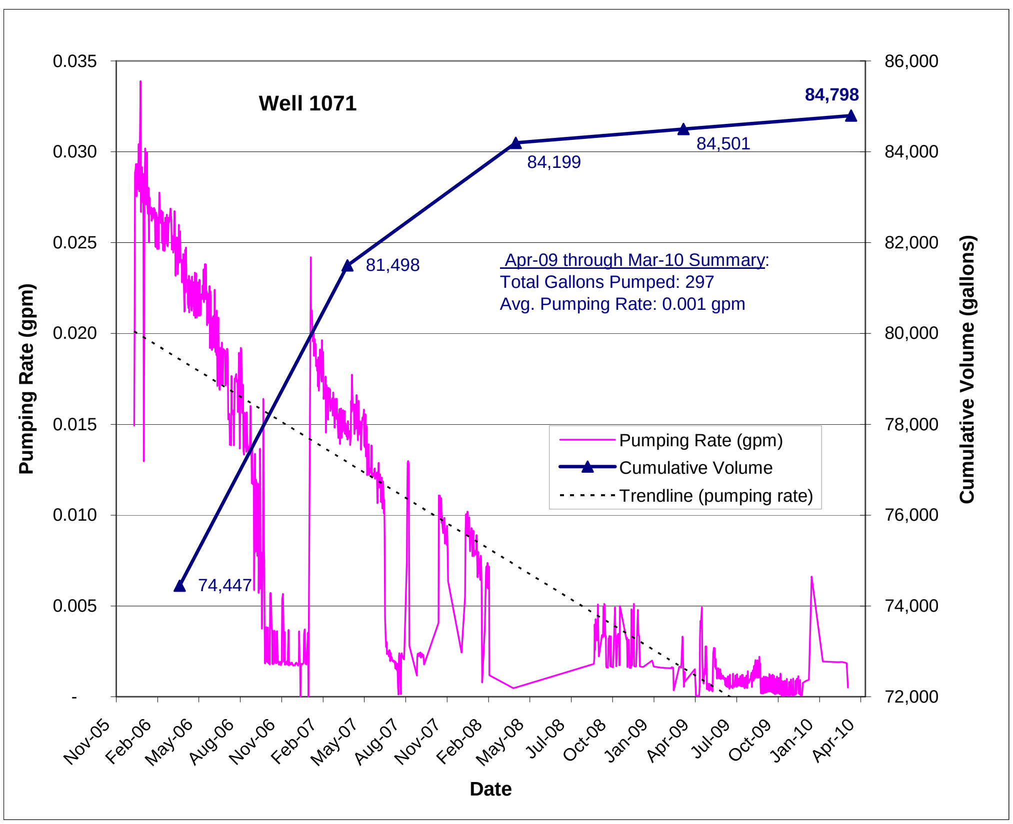

Figure 3–9. Terrace Well 1071 Pumping Rate and Cumulative Groundwater Volume Extracted

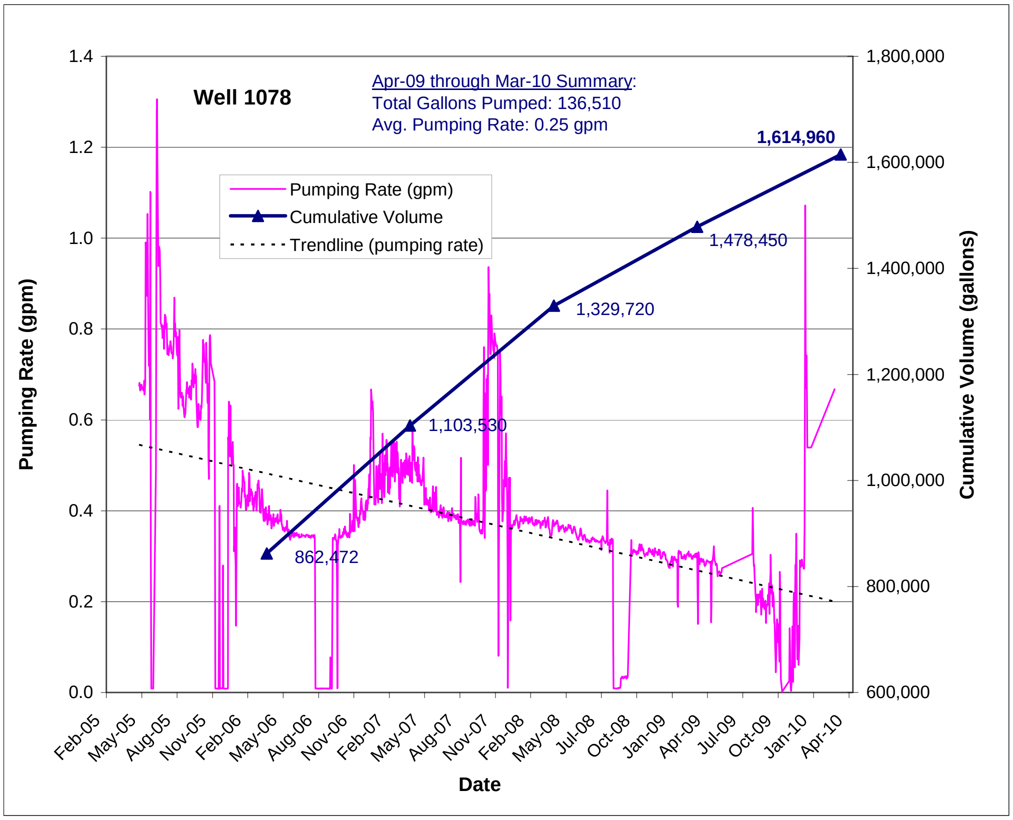

Figure 3–10. Terrace Well 1078 Pumping Rate and Cumulative Groundwater Volume Extracted

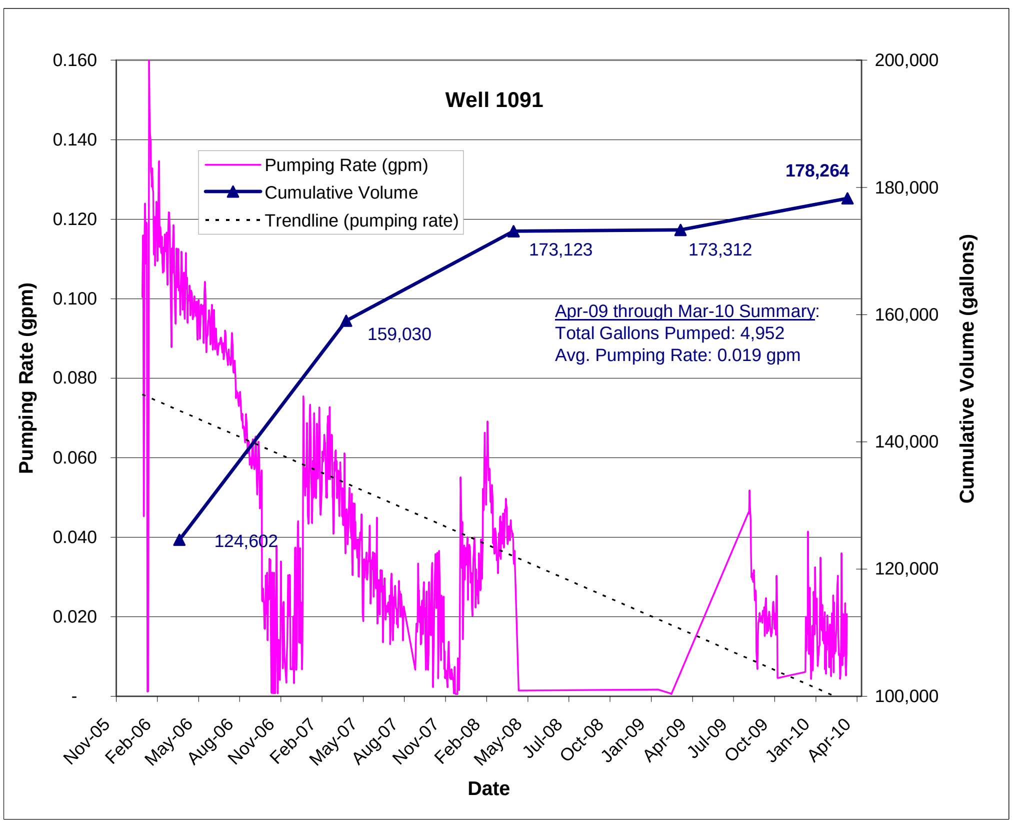

Figure 3–11. Terrace Well 1091 Pumping Rate and Cumulative Groundwater Volume Extracted

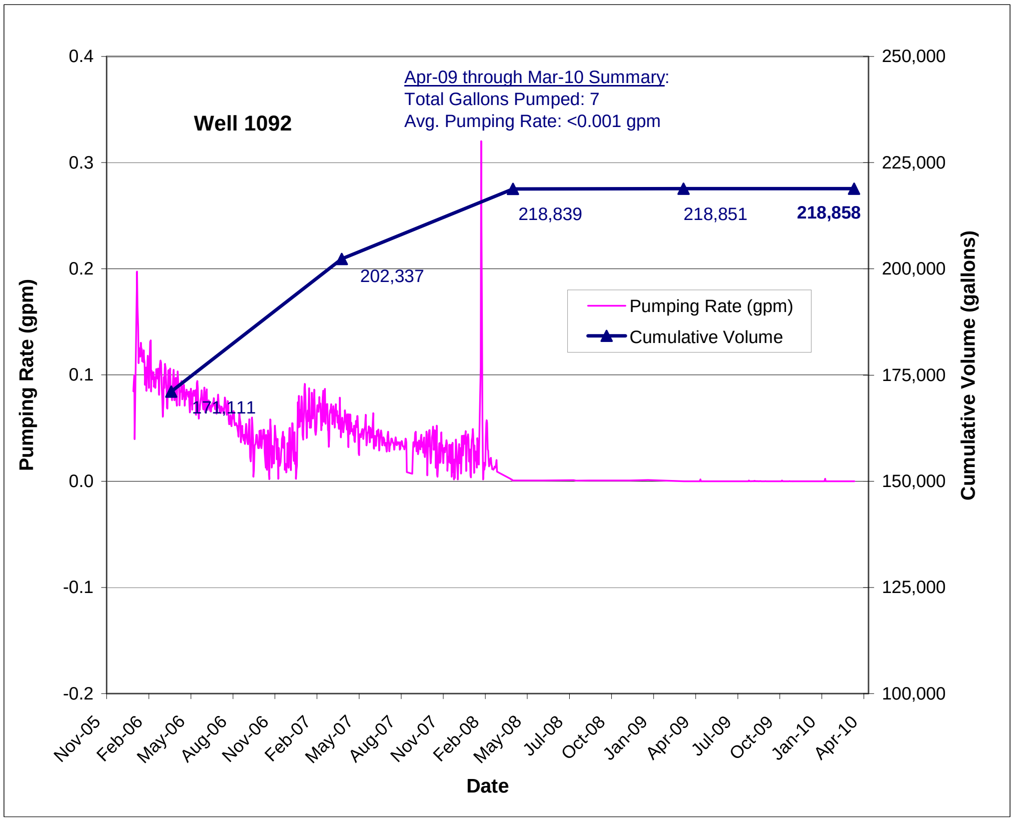

Figure 3–12. Terrace Well 1092 Pumping Rate and Cumulative Groundwater Volume Extracted

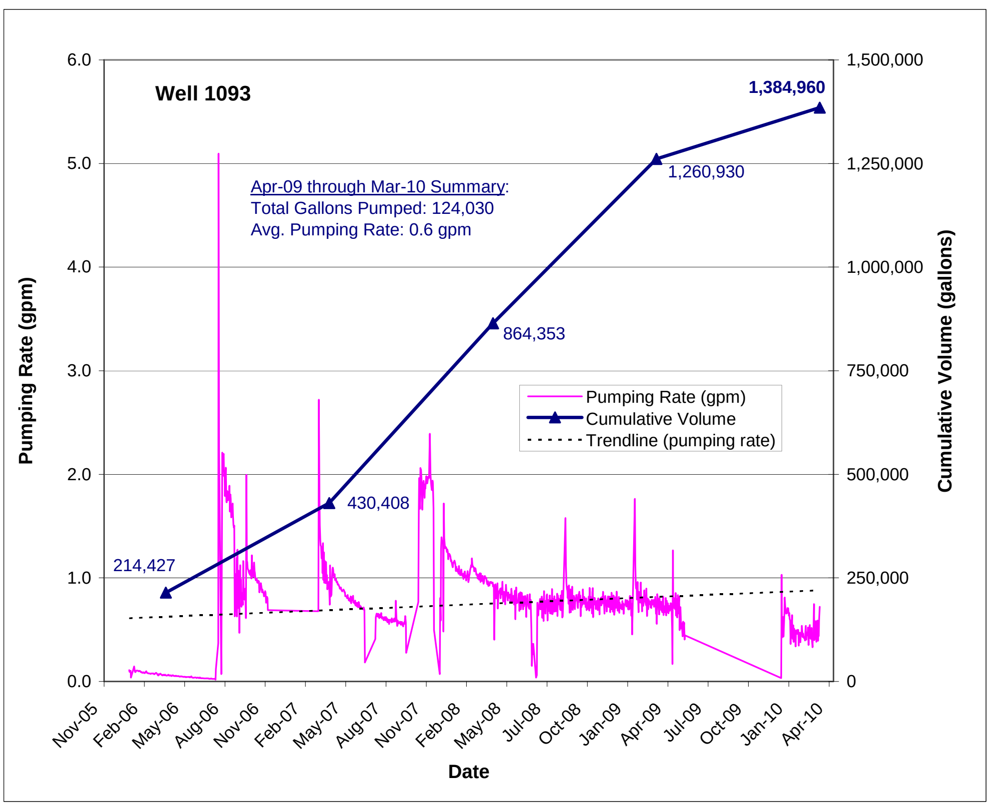

Figure 3–13. Terrace Well 1093 Pumping Rate and Cumulative Groundwater Volume Extracted

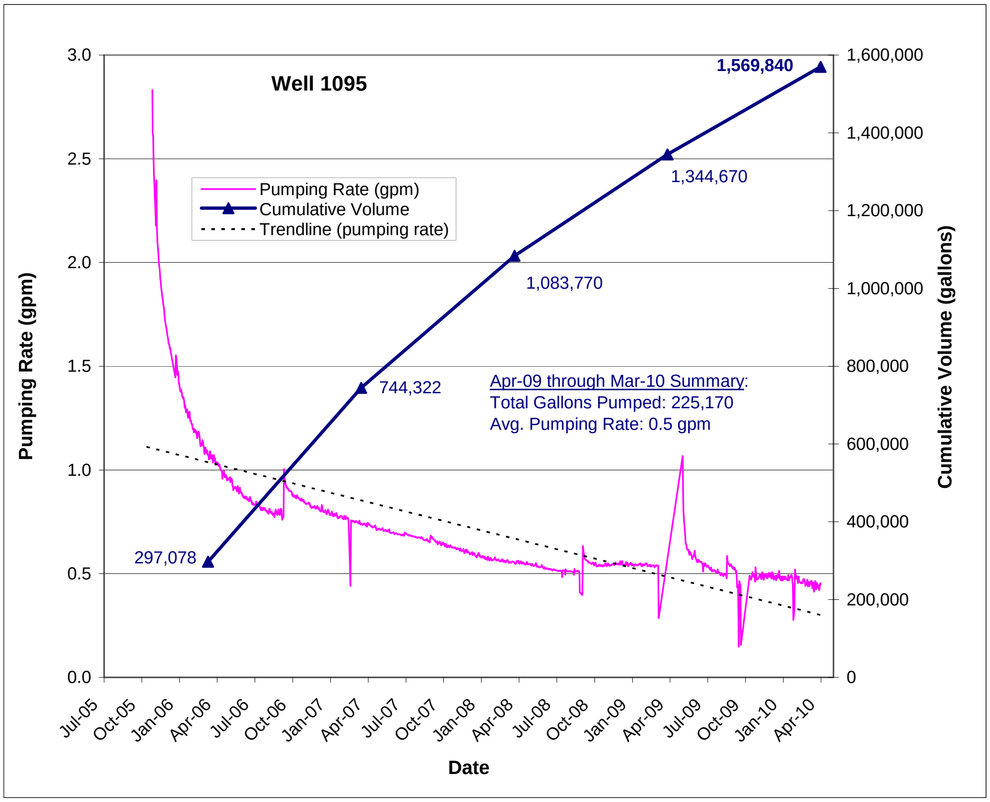

Figure 3–14. Terrace Well 1095 Pumping Rate and Cumulative Groundwater Volume Extracted

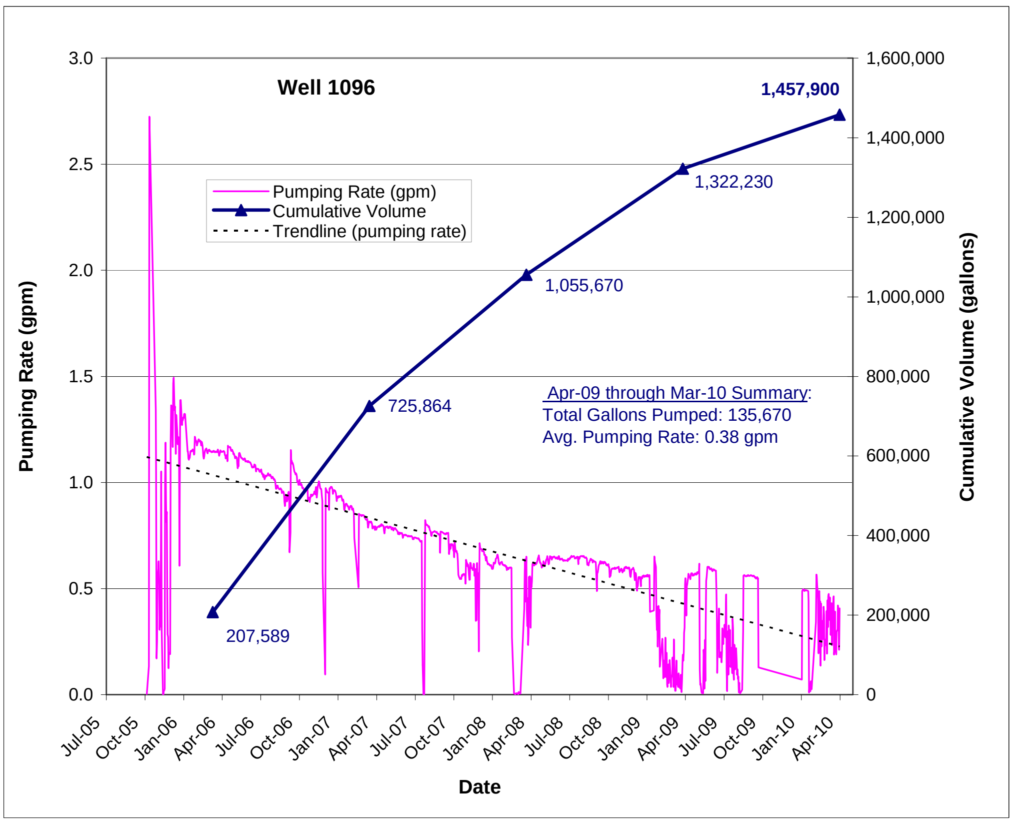

Figure 3–15. Terrace Well 1096 Pumping Rate and Cumulative Groundwater Volume Extracted

3.2.2 Terrace Drain System Performance

The terrace extraction system collects seepage from Bob Lee Wash and Many Devils Wash using subsurface interceptor drains. These drains, which consist of perforated pipe surrounded by drain rock and lined with impermeable geomembrane and geotextile filter fabric, are offset from the centerline of each wash to minimize the infiltration of surface water. All water collected by these drains is pumped through a pipeline to the evaporation pond.

Extraction rates and cumulative flow volumes for the pump installed in the Bob Lee Wash (location 1087) drain are plotted in Figure 3–16. During the current performance period, the average pumping rate from Bob Lee Wash was 2.6 gpm, and the groundwater interceptor drain removed approximately 1.4 million gallons of water.

The pumping rates and volume of water removed from the groundwater interceptor drain in Many Devils Wash (location 1088) are plotted in Figure 3–17. During the current performance period, the average pumping rate from Many Devils Wash was 0.96 gpm, and the groundwater interceptor drain removed approximately 468,000 gallons of water. As discussed in the previous section, because of increasing flows and apparent decreased effectiveness of the drain, DOE installed a diversion structure in August 2009.

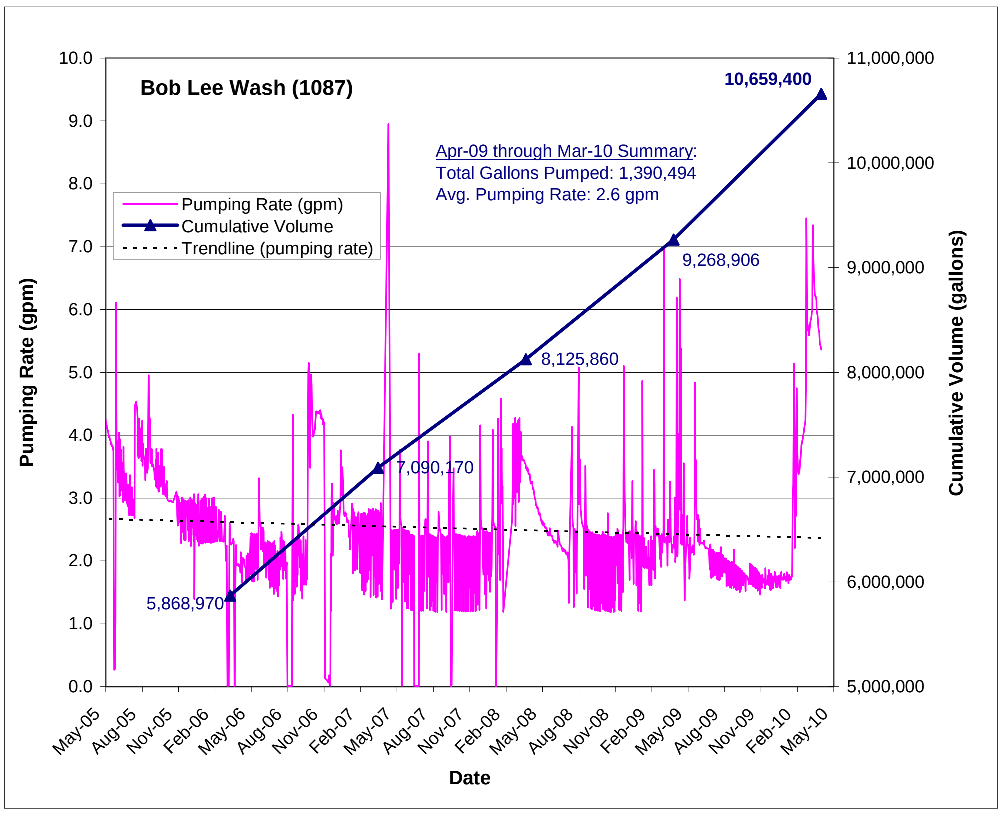

Figure 3–16. Bob Lee Wash Pumping Rate and Cumulative Groundwater Volume Extracted

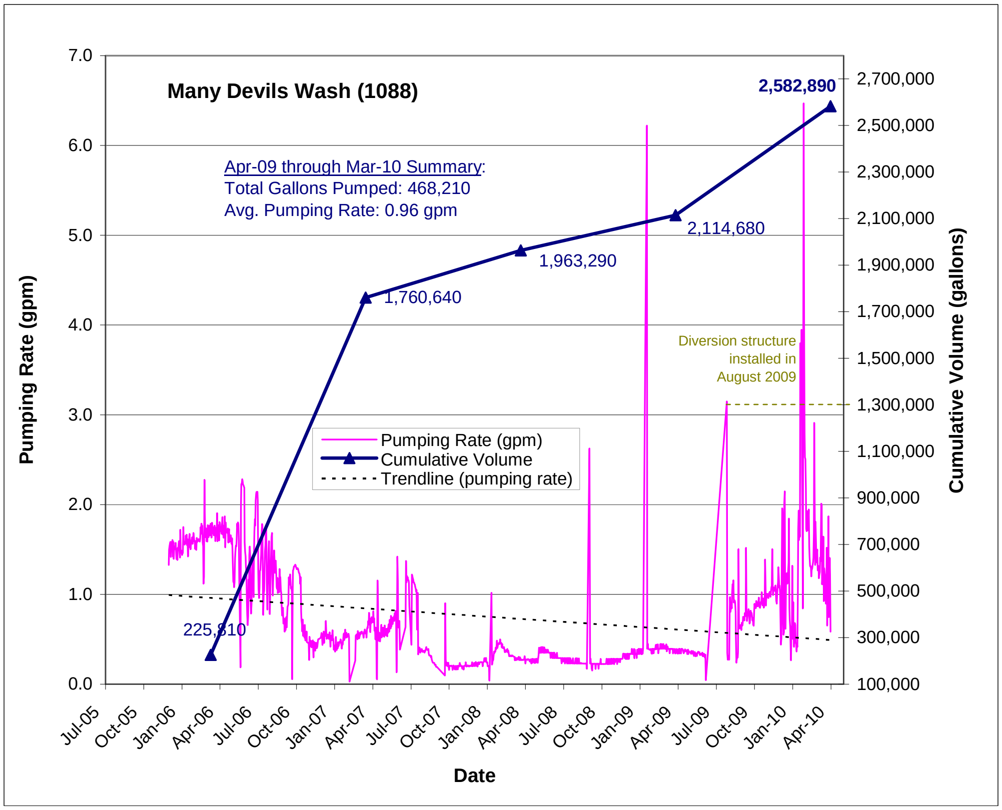

Figure 3–17. Many Devils Wash Pumping Rate and Cumulative Groundwater Volume Extracted

3.2.3 Evaporation Pond

The selected method for handling groundwater from the interceptor drains and extraction wells is solar evaporation. The contaminated groundwater is pumped to a lined evaporation pond in the south part of the radon cover borrow pit area (Figure 1–1). The average water level in this 11-acre pond was 5.2 ft in March 2010 (measured as the distance above transducers), leaving approximately 2.8 ft of unfilled pond capacity.

From April 2009 through March 2010, approximately 12.4 million gallons of extracted groundwater were pumped to the evaporation pond. The majority (78 percent) of the influent liquids entering the pond were from the floodplain aquifer, whereas 22 percent of the inflow originated from the terrace groundwater system. This annual input to the pond is markedly lower than the 20 million gallons reported for 2008–2009. As discussed in Section 3.1.2, pumping at Trench 2 was shut down periodically to increase pond capacity and to maintain safe water levels in the pond.

At the end of the 2009–2010 reporting period, a cumulative volume of nearly 87 million gallons of water has been pumped to the evaporation pond from all sources since the start of operations in March 2003 (cumulative contributions of 25 and 75 percent from the terrace and floodplain, respectively). Figure 3–18 plots the total volume of water pumped to the pond and the relative contributions from the floodplain and terrace systems.

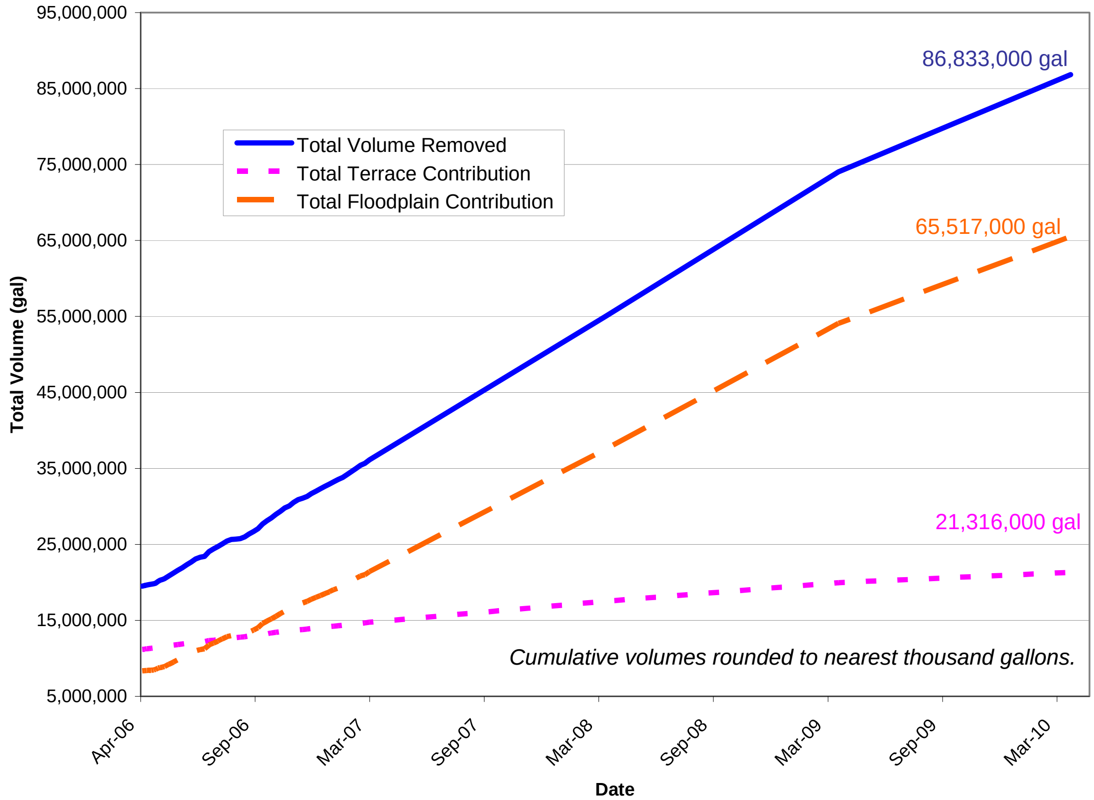

Figure 3–18. Total Groundwater Volume Pumped to the Evaporation Pond

The estimated masses of nitrate, sulfate, and uranium entering the evaporation pond from the floodplain extraction wells and trenches and terrace groundwater extraction system are summarized in Table 3–2. As shown in this table, approximately 21,000 pounds of nitrate, 727,000 pounds of sulfate, and 70 pounds of uranium were pumped to the evaporation pond during the 2009–2010 performance evaluation period. These estimates were computed from the average concentrations measured in each extraction well and the corresponding annual cumulative volume pumped. Sulfate is the dominant COC (in terms of mass) that enters the evaporation pond because of its high concentrations in both the floodplain and terrace groundwater systems.

Table 3–2. Estimated Total Mass of Selected Constituents Pumped from Terrace and Floodplain

Location	Annual cumulative volume (gal)[a]	Percent contribution	Nitrate - Average Concentration (mg/L)	Nitrate Mass Contribution per Location (kg)[b]	Nitrate Mass Contribution per Location (lb)[c]	Sulfate - Average Concentration (mg/L)	Sulfate Mass Contribution per Location (kg)[b]	Sulfate Mass Contribution per Location (lb)[c]	Uranium - Average Concentration (mg/L)	Uranium Mass Contribution per Location (kg)[b]	Uranium Mass Contribution per Location (lb)[c]
Terrace											
0818	227,890	1.8	855	737	1626	12,000	10,351	22,819	0.096	0.083	0.183
1070	6450	0.05	740	18.1	39.8	16,000	391	861	0.098	0.002	0.005
1071	297	0.002	1100	1.2	2.7	6450	7.3	16.0	0.135	0.0002	0.0003
1078	136,510	1.1	630	326	718	14,500	7492	16,517	0.150	0.078	0.171
1091	4952	0.04	1050	19.68	43.39	14,000	262.4	578.50	0.125	0.0023	0.00517
1092	7.0	0.0001	1950	0.05	0.11	7300	0.19	0.43	0.049	0.000001	<0.001
1093	124,030	1.0	2500	1174	2587	6250	2934	6468	0.135	0.063	0.140
1095	225,170	1.8	1650	1406	3100	5500	4687	10,334	0.049	0.042	0.092
1096	135,670	1.1	635	326	719	14,000	7189	15,849	0.110	0.056	0.125
1087 (BLW)	1,390,494	11.2	315	1658	3655	7900	41,578	91,663	0.615	3.237	7.136
1088 (MDW)	468,210	3.8	700	1241	2735	23,000	40,760	89,860	0.200	0.354	0.781
Floodplain											
1089	3,022,100	24.5	13.2	151	333	6750	77,211	170,219	0.79	9.04	19.9
1104	296,970	2.4	34.0	38	84	8000	8992	19,824	1.15	1.29	2.85
Trench 1 (1110)	3,844,900	31.1	115	1674	3690	7500	109,147	240,626	1.095	15.94	35.1
Trench 2 (1109)	2,296,600	18.6	90.5	787	1734	1600	13,908	30,662	0.26	2.26	4.98
Seep sump (1118)	182,187	1.5	34.0	23	52	6900	4758	10,490	0.655	0.45	0.996
			Total Masses:	9579	21,119		329,668	726,787		32.9	72.5
Total Terrace	2,719,680	22.0									
Total Floodplain	9,642,757	78.0									
Total to Pond	12,362,437										

[a] Annual cumulative volumes derived from data used to generate plots in Figure 3–1 through Figure 3–15 (data from April 1, 2009, through March 31, 2010).
[b] Mass in kilogram (kg) derived = annual volume × 3.785 (liters to gallons) × average concentration × (1/1,000,000)
[c] Conversion to pounds (lb) = kg × 2.2046
MDW = Many Devils Wash; BLW = Bob Lee Wash

3.2.4 Passive and Enhanced Phytoremediation

Passive phytoremediation (no human intervention) and hydraulic control are ongoing at the Shiprock site. DOE began phytoremediation pilot studies in 2006 to evaluate the feasibility of using deep-rooted native plants to enhance evapotranspiration in the radon cover borrow pit south of the disposal cell, where nitrate levels are elevated in alluvial sediments (Figures 1–5b through 1–12), and also on the terrace between the disposal cell and the escarpment north of the disposal cell, where a uranium plume enters the floodplain (see Figures 1–9b through 1–16). The goal of phytoremediation in these areas is hydraulic control (as opposed to contaminant removal), to limit the spread of contaminants in groundwater. The four irrigated phytoremediation test plots, established in 2006 and measuring 15 meters by 15 meters, are shown on Figure 1–1 and in the Figure 3–19 schematic below. To date, all work has been done in concert with Diné College.

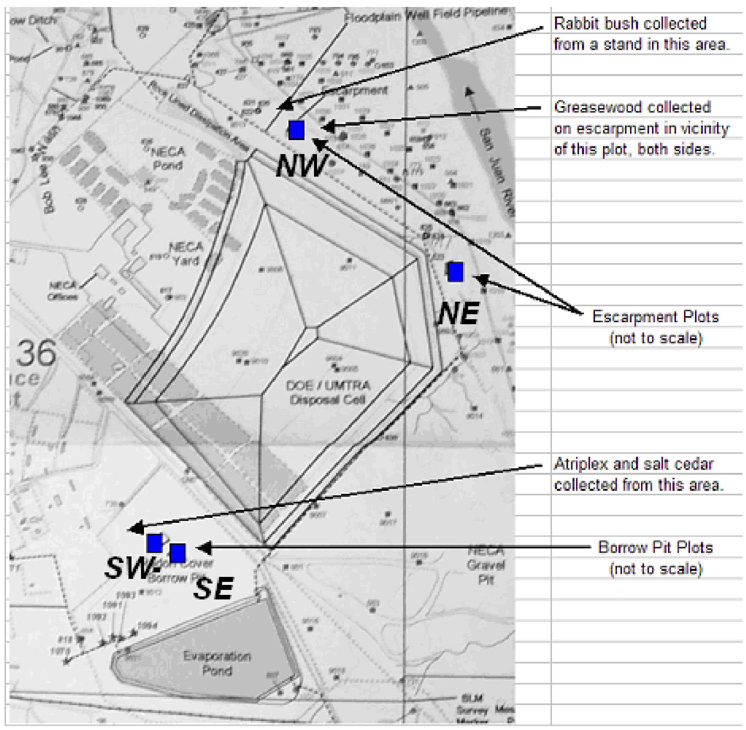

Figure 3–19. Map of Phytoremediation Test Plots in the Radon Barrier Borrow Pit and on the Terrace above the San Juan River Escarpment

Volunteer tamarisk, black greasewood, and four-wing saltbush currently growing in the borrow pit area are likely extracting groundwater, nitrate, and possibly other groundwater constituents. A few scattered black greasewood plants that have established on the terrace are also likely removing water that might otherwise daylight in contaminated seeps at the base of the escarpment. Higher rates of water extraction by woody plants in both locations may improve hydraulic control. More recently, DOE began evaluating the feasibility of enhanced phytoremediation, which entails deliberate planting of the areas (versus the volunteer growth). This technique, still in early experimental stages, may be an economical addition to the current groundwater compliance strategy.

Three objectives of the phytoremediation pilot studies have been established. These objectives and the associated findings and progress to date are summarized below.

Objective 1—Establish native phreatophytic shrubs by transplanting seedlings started in a greenhouse and then irrigating transplants until roots have accessed plume groundwater.

Findings and status:

- Diné College students irrigate and maintain the plantings and annually measure plant growth. Irrigated transplants have grown larger in the escarpment plots than in the radon cover borrow pit plots.
- On the escarpment, oxygen and deuterium isotope studies indicate that volunteer black greasewood plants, typically difficult to establish from transplants, are rooted down to groundwater. To date, analyses indicate that transplanted black greasewood and fourwing saltbush growing in the test plots have not intercepted contaminated groundwater.
- In contrast, plants are not doing well in the radon cover borrow pit area, where oxygen and deuterium isotope studies indicate that volunteer saltbush and rabbitbrush have not reached groundwater, and irrigated transplants are not expected to. Given these findings, the objective of these plots has changed. The objective now is to establish native vegetation, control the soil water balance, and limit recharge and, hence, the volume of the plume water.

Objective 2—Once plant roots have accessed groundwater, evaluate the human health and ecological risks associated with uptake of groundwater constituents and accumulation in aboveground plant tissue.

Findings and status:

- Diné College students harvested plant tissue from both the volunteer and transplanted phreatophytic shrubs in the escarpment plots in 2010. Although these results are still being evaluated, little contaminant uptake is evident to date, indicating no potential human health or ecological risks associated with a bio-uptake pathway.
- Plants in the radon cover borrow pit plots were not sampled because they are not rooted in groundwater.

Objective 3—Evaluate the potential beneficial effects of phytoremediation on plume water volume, plume migration, and flow in existing contaminated seeps at the base of the escarpment and in floodplain groundwater.

If results from the escarpment studies addressing objectives 1 and 2 are favorable, DOE will calculate potential annual transpiration rates based on plant leaf area and biomass, and coordinate with project hydrologists to evaluate potential benefits with respect to the hydrologic control of terrace groundwater and its potential impact on the seeps and floodplain groundwater plume.

In summary, as part of the overall phased remediation approach, DOE is applying at the Shiprock site, the phytoremediation pilot study will continue. DOE will evaluate a specific plan for phytoremediation pending analysis of overall findings and data when pilot studies end.