Long-Term Monitoring Network Optimization Evaluation

for

Wash King Laundry Superfund Site
Lake County, Michigan

June 2006

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FINAL

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OPTIMIZATION EVALUATION

FOR

WASH KING LAUNDRY SUPERFUND SITE
LAKE COUNTY, MICHIGAN

June 2006

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µg/L	microgram(s) per liter
amsl	above mean sea level
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminant of concern
DCE	dichloroethene
ESRI	Environmental Systems Research Institute, Inc.
ft/day	foot per day
ft/ft	foot per foot
ft/yr	feet per year
GIS	geographical information system
GWE	groundwater extraction
LTM	long-term monitoring
LTMO	long-term monitoring optimization
MCL	maximum contaminant level
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
mg/L	milligrams per liter
MNO	monitoring network optimization
NAPL	non aqueous-phase liquid
ND	not detected
PCE	tetrachloroethene
RAO	remedial action objective
RI	remedial investigation
ROD	record of decision
TCE	trichloroethene
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VOCs	volatile organic compounds

SECTION 1

INTRODUCTION

Groundwater monitoring programs have two primary objectives (U.S. Environmental Protection Agency [USEPA], 1994; Gibbons, 1994):

1. Evaluate long-term temporal trends in contaminant concentrations at one or more points within or outside the remediation zone as a means of monitoring the performance of the remedial measure (*temporal objective*) and

2. Evaluate the extent to which contaminant migration is occurring, particularly if a potential exposure point for a susceptible receptor exists (*spatial objective*).

The relative success of any remediation system and its components (including the monitoring network) must be judged based on the degree to which it achieves the stated objectives of the system. Designing an effective groundwater monitoring program involves locating monitoring points and developing a site-specific strategy for groundwater sampling and analysis to maximize the amount of relevant information that can be obtained while minimizing incremental costs. Relevant information is that required to effectively address the temporal and spatial objectives of monitoring. The effectiveness of a monitoring network in achieving these two primary objectives can be evaluated quantitatively using statistical techniques. In addition, there may be other important considerations associated with a particular monitoring network that are most appropriately addressed through a qualitative assessment of the network. The qualitative evaluation may consider such factors as hydrostratigraphy, locations of potential receptor exposure points with respect to a dissolved contaminant plume, and the direction(s) and rate(s) of contaminant migration.

This report presents a description and evaluation of the groundwater monitoring program associated with the Wash King Superfund Site located in Pleasant Plains Township, Lake County, Michigan. This report does not address the larger issue of remedial process optimization for this site. A monitoring network consisting of 44 groundwater monitoring wells and five groundwater extraction wells was evaluated to identify potential opportunities to streamline monitoring activities while still maintaining an effective monitoring program. A three-tiered approach, consisting of a qualitative evaluation, a statistical evaluation of temporal trends in contaminant concentrations, and a spatial statistical analysis assessed the degree to which the monitoring network addresses the objectives of the monitoring program, as well as other important considerations. The qualitative evaluation addressed all 49 monitoring and extraction wells. The temporal evaluation addressed those wells with adequate historical analytical data (>4 sampling events) to conduct a trend analysis, and the spatial statistical evaluations included separate evaluations for those wells screened in the shallow and deep aquifers. The results of the three evaluations were combined and used to assess the optimal frequency of monitoring and the spatial distribution of the components of the monitoring network. The results of the analysis were then used to develop recommendations for optimizing the monitoring program at Wash King.

SECTION 2

SITE BACKGROUND INFORMATION

The location, operational history, environmental setting (*i.e.*, geology, hydrogeology, and surface water hydrology), and remediation history of Wash King are briefly summarized in the following subsections. This information was derived primarily from published and unpublished information received from the Michigan Department of Environmental Quality (MDEQ) and the Record of Decision (ROD) prepared for the site in 1993 (USEPA, 1993).

2.1 SITE LOCATION AND OPERATIONAL HISTORY

The Wash King Laundry site is located south of the city of Baldwin in Pleasant Plains Township, Lake County, Michigan. The site is bordered on the east by a line approximately 300 feet east of highway M-37, on the south by Star Lake Road (76th Street), on the west by the C&O Railroad, and on the north by the Middle Branch Pere Marquette River. At the time that the ROD was published in 1993, the Pere Marquette Subdivision Plat, which comprises the site, included 123 residential lots, most of which were not used on a year-round basis. Housing in the area consisted primarily of mobile homes, trailers, and cottages. Numerous commercially developed lots existed along Highway M-37. Current land use conditions are not known.

The former Wash King Laundry was granted permission to discharge soapy laundry wastewater to four nearby unlined seepage lagoons in 1962. The lagoons were located approximately 500 feet west of the laundry building in a wooded area. Dry cleaning services later supplemented laundry operations, and spent dry cleaning solvent (tetrachloroethene [PCE]) was discharged to the lagoons in the 1970s. All dry cleaning operations ceased in 1978, but detergent laundry operations continued, with lagoon discharge of the wash water, until 1991, when the owner filed for bankruptcy.

An underground storage tank (UST) was located approximately 20 feet south of the former Laundromat in September 1999. The tank contained approximately 170 gallons of fluid, believed to be mostly old boiler fuel and water; however, the possibility of solvent contamination could not be ruled out. The fluid was pumped into drums and disposed of off-site.

A chronological summary of investigative and remedial activities performed at the site is provided below.

August 1973: Laundry detergent wastes and PCE were first detected in the groundwater at the site via sampling of nearby water wells.

1976: Further groundwater contamination was discovered.

1977: Additional investigations were performed by the Michigan Department of Natural Resources (MDNR).

1979-1980: Additional investigations performed to clearly show that the laundry facility was the source of the PCE contamination (MDNR, 1980).

1982: The extent of groundwater contamination was further documented via additional investigative activities.

1988: A remedial investigation (RI) was initiated to define the nature and extent of contamination at the site and characterize the potential threats to public heath and the environment.

1992: A baseline risk assessment and feasibility study were completed.

1993: A ROD was issued presenting the selected remedial actions for the site. The selected remedy for groundwater consists of extraction and ex-situ treatment of groundwater, deed restrictions, and long-term monitoring (LTM). The ROD states that treated water would be discharged to the Middle Branch Pere Marquette River; however, treated water is actually discharged to the seepage lagoons. The selected remedy for contaminated sediments/soils within the lagoon consisted of excavation and off-site disposal. In addition, a soil vapor extraction system was installed to remediate volatile organic compounds (VOCs) in vadose zone soils; the dates of operation of this system and its current status are not known. Available data indicate that the original six-well groundwater extraction system (EW-1 through EW-6) was installed in the second half of 2000, and analytical results for the six original wells date back to April 2001. Extraction well EW-5A was installed in December 2000. Both EW-5 and EW-5A are reportedly pumped, but EW-5 is relatively low-yielding. EW-3 is reportedly not pumped. The extraction system reportedly pumps at a total combined rate of approximately 250 gallons per minute.

There is no current use of groundwater in the surficial aquifer by area residents or businesses. All area water supply wells are screened in the lower sandy aquifer below the clay aquitard; site-related contamination has not been detected in this lower aquifer.

2.2 ENVIRONMENTAL SETTING

2.2.1 Topography

The site is generally flat except for a steep embankment leading down to the Middle Branch Pere Marquette River on the north side of the site. The ground surface elevation at the majority of site wells ranges between 812 and 818 feet above mean sea level (amsl). In contrast, the ground surface elevation near the river at wells MW-102S/D and MW-202 is approximately 802 feet amsl.

2.2.2 Geology

The site soils are generally composed of fine- to medium-grained sands with some clay and/or silt lenses to a depth of approximately 75 to 100 feet below ground surface (bgs). The ROD (USEPA, 1993) indicates that these are predominantly glacial outwash deposits. These deposits are underlain by a thicker clay layer that subdivides the shallow sandy aquifer from a deeper, predominantly sandy aquifer that extends to a depth of approximately 350 feet bgs. The lateral extent and continuity of the clay layer that forms the base of the surficial aquifer is not well defined. The reported thickness of the clay layer is variable, ranging from 20 to 56 feet.

2.2.3 Hydrogeology

Figures 2.1 and 2.2 depict the potentiometric surfaces for the shallow and deep portions of the upper, unconfined aquifer, respectively based on water level data collected on April 6, 2006, while the groundwater extraction (GWE) system was operational. Groundwater in the upper, unconfined aquifer generally flows to the north-northeast, discharging into the Middle Branch Pere Marquette River. It is anticipated that localized cones of depression resulting from groundwater extraction are centered around the GWE wells. These cones of depression are not evident in all cases on Figures 2.1 and 2.2, most likely because the water level data set and contour interval used are not sufficiently detailed. On May 11, 2001, the depth to groundwater in the surficial aquifer ranged from approximately 17 to 30 feet bgs with an average depth of approximately 26 feet bgs. In March 2005, the depth to groundwater in this aquifer ranged from approximately 13 to 31 feet bgs with an average depth of approximately 25 feet bgs. The average depths to groundwater in December 2002, October 2003, and August 2004 were about 25 feet, 27 feet, and 25 feet bgs, respectively, indicating that seasonal fluctuations in the water table are relatively minor.

The RI report states that the estimated average groundwater flow velocity in the upper aquifer is 185 feet per year (ft/yr). Based on groundwater elevation data shown on Figure 2.1, the hydraulic gradient in the shallow portion of the surficial aquifer ranges from approximately 0.003 to 0.008 foot per foot (ft/ft) (average 0.0055 ft/ft). The hydraulic gradient in the deep portion of the surficial aquifer (Figure 2.2) had a similar range (0.004 to 0.007 ft/ft, average 0.0055 ft/ft). These gradients are the same order of magnitude as that calculated from April 1989 data during the RI (0.004 ft/ft). Using the groundwater flow velocity of 185 ft/yr (0.5 foot per day [ft/day]) presented in the ROD (USEPA, 1993), an estimated effective porosity for a predominantly sandy aquifer of 0.25, and the average hydraulic gradient of 0.0055 ft/ft, the hydraulic conductivity of the shallow and deep portions of the surficial aquifer is calculated to be approximately 23 ft/day. Hydraulic conductivity values derived from slug tests performed in 11 monitoring wells during the RI ranged from 0.9 to 340 ft/day, with an average value of 43 ft/day.

Comparison of water level elevations measured on 11 May 2001 in 10 monitoring well pairs, each consisting of a shallow and deep well, indicate that both upward and downward vertical hydraulic gradients were present on that date. The well pairs used in the vertical gradient calculations included MW-3S/D, MW-8S/D, MW-101S/D, MW-204S/D, MW-205S/D, MW-206S/D, MW-207S/D, MW-211S/D, MW-212S/D, and MW-213S/D. Four of the 10 vertical gradients were calculated to be upwardly directed

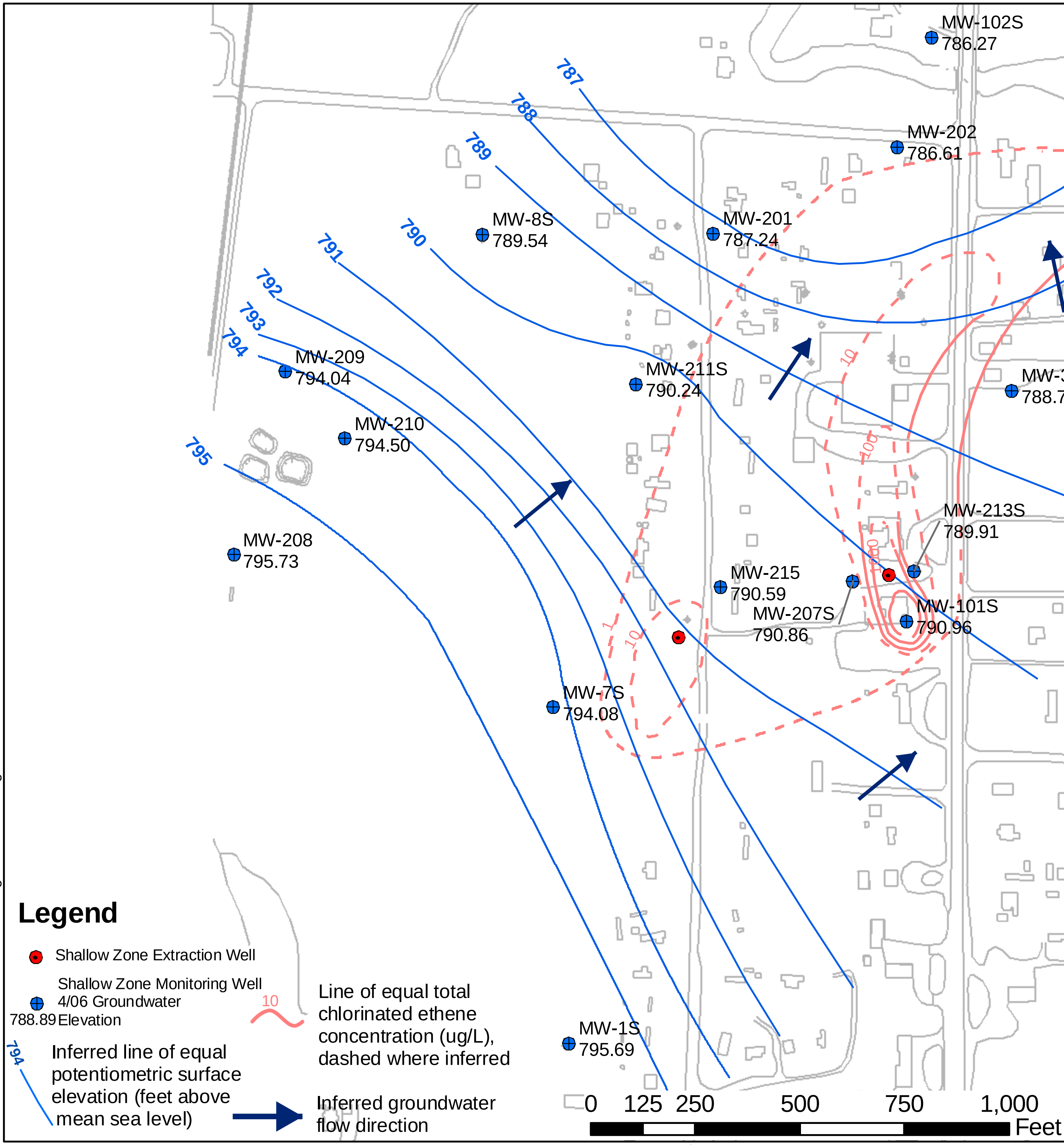

FIGURE 2.1
POTENTIOMETRIC SURFACE FOR SHALLOW ZONE
APRIL 6, 2006

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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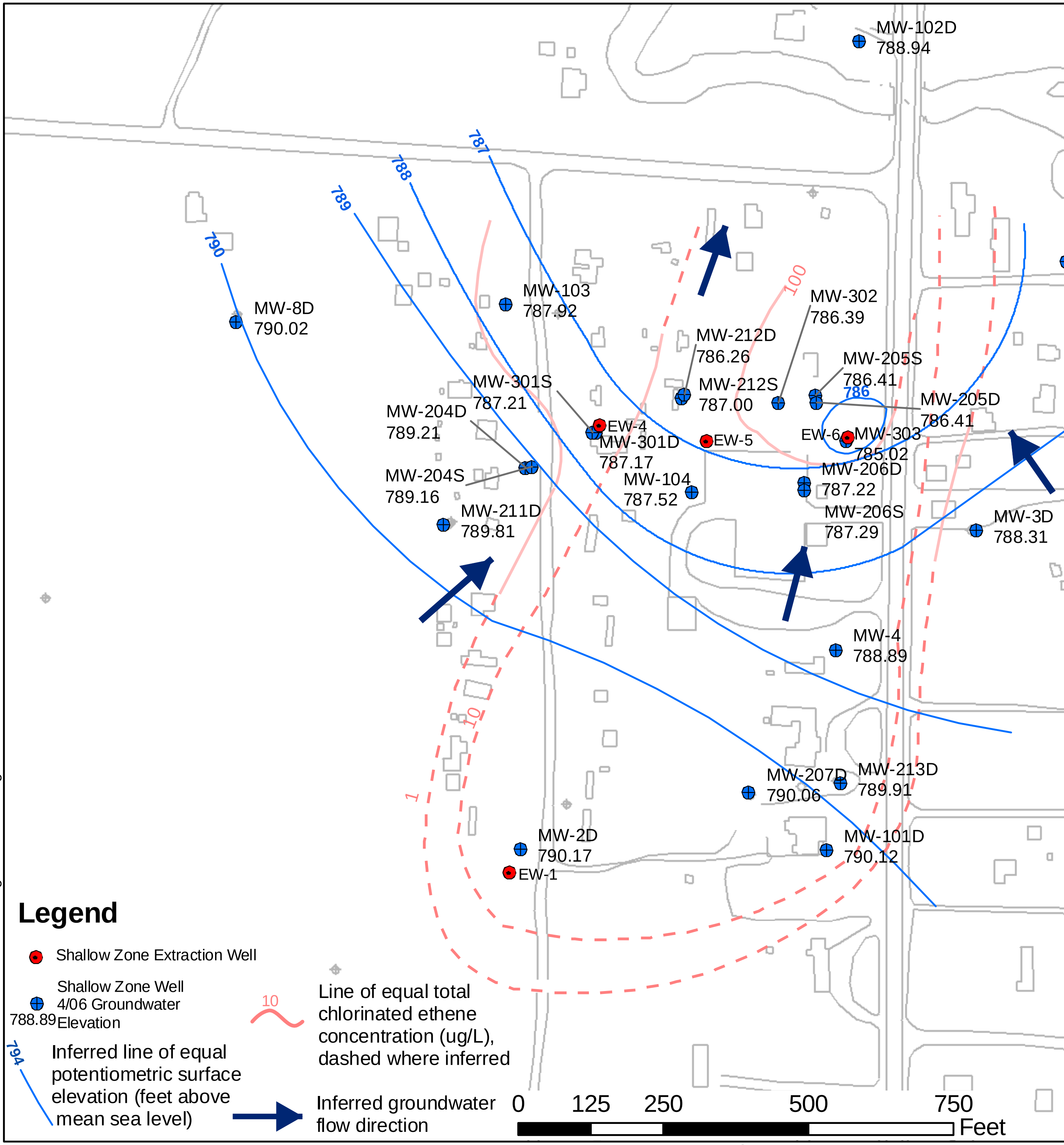

FIGURE 2.2
POTENTIOMETRIC SURFACE FOR DEEP ZONE
APRIL 6, 2006

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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(MW-204S/D, MW-205S/D, MW-206S/D, MW8S/D), with magnitudes ranging from 0.0003 ft/ft to 0.01 ft/ft (average 0.005 ft/ft). The remaining six gradients were downwardly directed, with magnitudes ranging from 0.002 ft/ft to 0.027 ft/ft (average 0.015 ft/ft). It is likely that upward vertical gradients become more prevalent near the Middle Branch Pere Marquette River given that groundwater in the surficial aquifer reportedly discharges into the river. The four well pairs that exhibited upward vertical gradients on 11 May 2001 are clustered nearer the river than the six pairs that exhibited downward gradients, which were more widely distributed in the southern and central portions of the site. These observations are consistent with data presented in the RI report, which indicated a slight downward gradient, averaging 0.0016 ft/ft, in the southern portion of the site, and a relatively strong upward gradient, averaging 0.022 ft/ft, in the northern portion of the site near the Pere Marquette River.

2.2.4 Surface Water Hydrology

Site-specific information regarding the hydrology of the Middle Branch Pere Marquette River was not available. However, it is assumed that the reach of the river adjacent to the site is gaining as a result of groundwater discharge from the surficial aquifer.

2.3 NATURE AND EXTENT OF CONTAMINATION

The primary contaminants of concern (COCs) at Wash King are PCE and trichloroethene (TCE) given their elevated concentrations in Wash King groundwater relative to cleanup goals, their potential to have significant negative impacts on potential receptors, or both. The cleanup goals presented in the ROD (USEPA, 1993) are 307 Type B Cleanup Criteria (0.7 micrograms per liter {µg/L} for PCE and 3 µg/L for TCE). For discussion purposes, the surficial aquifer, which extends to a depth of approximately 75 to 100 feet bgs, was subdivided into shallow and deep portions relating to the intervals monitored by the shallow and deep monitoring and extraction wells installed at the site.

The Wash King monitoring and extraction wells are listed in Table 2.1, along with their screen intervals, which are depicted graphically on Figure 2.3 As indicated on this figure, the portions of the surficial aquifer (in a vertical sense) that are monitored by the shallow and deep wells are not consistent across the site. It is assumed that previously-collected groundwater quality data (i.e., from vertical profiling activities and monitoring well sampling) were used to determine optimal screen intervals. Most “shallow” wells are screened above an elevation of 760 feet amsl, corresponding to an approximate depth of 42 to 60 feet bgs (the ground surface elevation across the site generally ranges from 802 to 820 feet amsl). The ground surface elevation at the majority of site wells ranges between 812 and 818 feet amsl. Given groundwater elevations that generally range from 785 to 790 feet bgs (using March 2005 data), the shallow wells are generally monitoring groundwater within the uppermost 25 to 30 feet of the saturated zone. In contrast, screens for “shallow” wells MW-205S, MW-212S, MW-301S, MW-204S, and MW-206D are relatively deep, and monitor a similar depth interval to that monitored by some “deep” wells; thus, these wells are included in the deep zone for purposes of the LTMO analysis.

TABLE 2.1
BASECASE GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Zone	Current Sampling Frequency	Earliest Sampling Data Available	Most Recent Data Used	Screen Interval
EW-1	Extraction	Quarterly	4/26/01	6/13/05	50-70
EW-2	Extraction	Quarterly	4/26/01	6/13/05	37-42
EW-4	Extraction	Quarterly	4/26/01	6/13/05	65-90
EW-5	Extraction	Quarterly	4/26/01	6/13/05	58.5-78.5
EW-6	Extraction	Quarterly	4/26/01	6/13/05	77-97
MW-101D	Deep	Semi-annual	10/22/97	8/30/05	89-94
MW-101S	Shallow	Semi-annual	10/22/97	8/30/05	43-48
MW-205D	Deep	Semi-annual	8/7/01	8/29/05	85-90
MW-205S	Deep	Semi-annual	8/7/01	8/29/05	70-75
MW-207D	Deep	Semi-annual	10/17/00	8/30/05	65-70
MW-207S	Shallow	Semi-annual	10/17/00	8/30/05	35-40
MW-208	Shallow	Semi-annual	10/19/00	8/29/05	30-35
MW-209	Shallow	Semi-annual	8/6/01	8/29/05	30-35
MW-210	Shallow	Semi-annual	8/6/01	8/30/05	30-35
MW-212D	Deep	Semi-annual	8/7/01	8/30/05	85-90
MW-212S	Deep	Semi-annual	2/27/02	8/30/05	65-70
MW-213D	Deep	Semi-annual	10/17/00	8/30/05	60-65
MW-213S	Shallow	Semi-annual	10/17/00	8/30/05	45-50
MW-301D	Deep	Semi-annual	9/4/02	8/24/05	80-90
MW-301S	Deep	Semi-annual	9/4/02	3/31/05	65-75
MW-302	Deep	Semi-annual	9/5/02	8/29/05	75-95
MW-303	Deep	Semi-annual	9/5/02	8/30/05	77-97
MW-304D	Deep	Semi-annual	9/4/02	8/30/05	97-102
MW-304I	Deep	Semi-annual	9/5/02	8/30/05	78-83
MW-304S	Shallow	Semi-annual	9/5/02	8/30/05	24-29
MW-305D	Deep	Semi-annual	9/3/02	8/29/05	105-110
MW-305I	Deep	Semi-annual	9/3/02	8/29/05	62-67
MW-305S	Shallow	Semi-annual	9/3/02	8/29/05	24-29
MW-3D	Deep	Semi-annual	10/22/97	8/29/05	65-75
MW-3S	Shallow	Semi-annual	10/22/97	8/29/05	25-35
Wells Not Currently Sampled					
MW-103	Deep	Not Sampled	10/22/97	10/23/03	80.3-85.3
MW-104	Deep	Not Sampled	10/22/97	10/23/03	63.5-70.5
MW-105	Deep	Not Sampled	10/19/00	10/22/03	68.5-73.5
MW-201	Shallow	Not Sampled	10/16/00	10/22/03	30-35
MW-202	Shallow	Not Sampled	9/4/02	10/22/03	30-35
MW-204D	Deep	Not Sampled	10/17/00	10/22/03	85-90
MW-204S	Deep	Not Sampled	10/17/00	10/22/03	55-60
MW-206D	Deep	Not Sampled	10/22/03	10/22/03	85-90
MW-206S	Deep	Not Sampled	12/3/02	10/22/03	65-70
MW-215	Shallow	Not Sampled	8/8/01	10/23/03	50-55
MW-2D	Deep	Not Sampled	10/22/97	10/23/03	65-75
MW-4	Deep	Not Sampled	10/22/97	10/23/03	65-75
MW-8D	Deep	Not Sampled	10/22/97	8/7/01	65-75
MW-8S	Shallow	Not Sampled	10/22/97	8/7/01	25-35
MW-7S	Shallow	Not Sampled	10/19/00	10/19/00	25-35
MW-102D	Deep	Not Sampled	10/22/97	5/13/99	91.1-96.1
MW-102S	Shallow	Not Sampled	10/22/97	5/12/99	17-22

Deep (shaded): Well has "S" designation, but classified as "deep" based on screen interval for LTMO

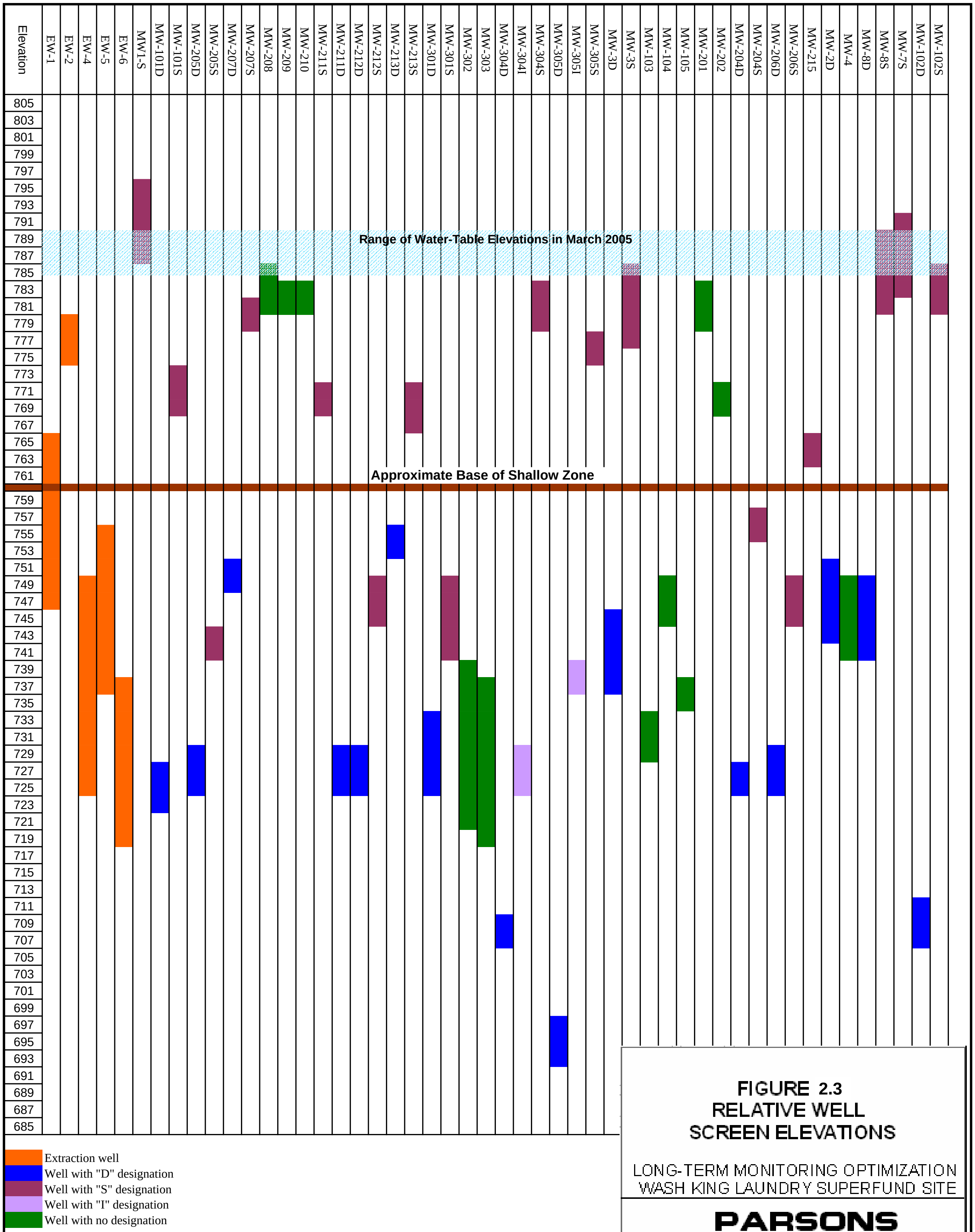

FIGURE 2.3
RELATIVE WELL SCREEN ELEVATIONS

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

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The vertical interval of the surficial aquifer monitored by the majority of “deep” (D) and “intermediate” (I) wells ranges from 755 amsl to 718 amsl (Figure 2.3). Given typical ground surface elevations of 812 to 818 feet amsl, the majority of “deep” and “intermediate” wells are screened within the 57- to 100-foot bgs depth interval; this corresponds to an interval extending from about 30 to 70 feet below the water table, based on March 2005 groundwater elevations.

Extraction well EW-2 is screened in the shallow portion of the surficial aquifer, while EW-4, EW-5A, and EW-6 are screened in the deep portion. The EW-1 screen has an intermediate location, spaning both the base of the shallow interval and the top of the deep interval (Figure 2.3). EW-5 is reportedly still pumped, but is relatively low-yielding compared to EW-5A.

2.3.1 Shallow Portion of the Surficial Aquifer

Figures 2.4 and 2.5 show the most recent COC results and associated chlorinated ethene plume for the shallow and deep zones, respectively. The VOC present at the highest concentrations in the shallow portion of the surficial aquifer at the Wash King site is PCE. It is interesting to note that the VOC plume appears to be primarily sourced in the immediate vicinity of the former laundry building rather than in the vicinity of the former seepage lagoons located approximately 500 feet west-southwest of the former laundry. The highest PCE concentrations detected in surficial aquifer groundwater (21,000 micrograms per liter [µg/L] in August 2005) were detected at well MW-101S, located immediately downgradient of the former laundry (Figure 2.4). Groundwater from nearby shallow extraction well EW-2 contained a PCE concentration of 2,500 µg/L in June 2005. In contrast, the shallow well nearest the former seepage lagoons (MW-215) contained a PCE concentration of only 5 µg/L in October 2003 (the most recent data available for that well). It should be noted that MW-215 is screened near the base of the shallow zone. The elevated PCE concentrations near the former laundry indicate the presence of a significant, continuing PCE source in this area. Cohen and Mercer (1993) state that, typically, dissolved contaminant concentrations greater than 1 percent of the aqueous solubility of the compound are highly suggestive of the presence of non aqueous-phase liquid (NAPL). The aqueous solubility of PCE is 150 milligrams per liter (mg/L); therefore, dissolved PCE concentrations exceeding approximately 1.5 mg/L (1,500 µg/L) may indicate the presence of NAPL.

The PCE plume in the shallow portion of the surficial aquifer, shown on Figure 2.4, extends to the north to near the Middle Branch Pere Marquette River, as evidenced by the detection of this compound at a concentration of 3.6 µg/L in downgradient well MW305S in August 2005. This well is located about 200 feet from the river; therefore, it is not known whether the shallow portion of the plume actually extends to and discharges into the river. VOCs have historically not been detected in groundwater samples from shallow well MW-102S, located north of the river. It should be noted that most of the “shallow” wells installed to define the VOC plume north of the former laundry (MW-205S, MW-202S, MW-206S, MW-204S, and MW-301S) are screened across relatively deep intervals, as discussed in Section 2.3 and depicted on Figure 2.3. Therefore, VOC concentrations within the uppermost 30 feet of the saturated zone north of the former laundry building are not well defined.

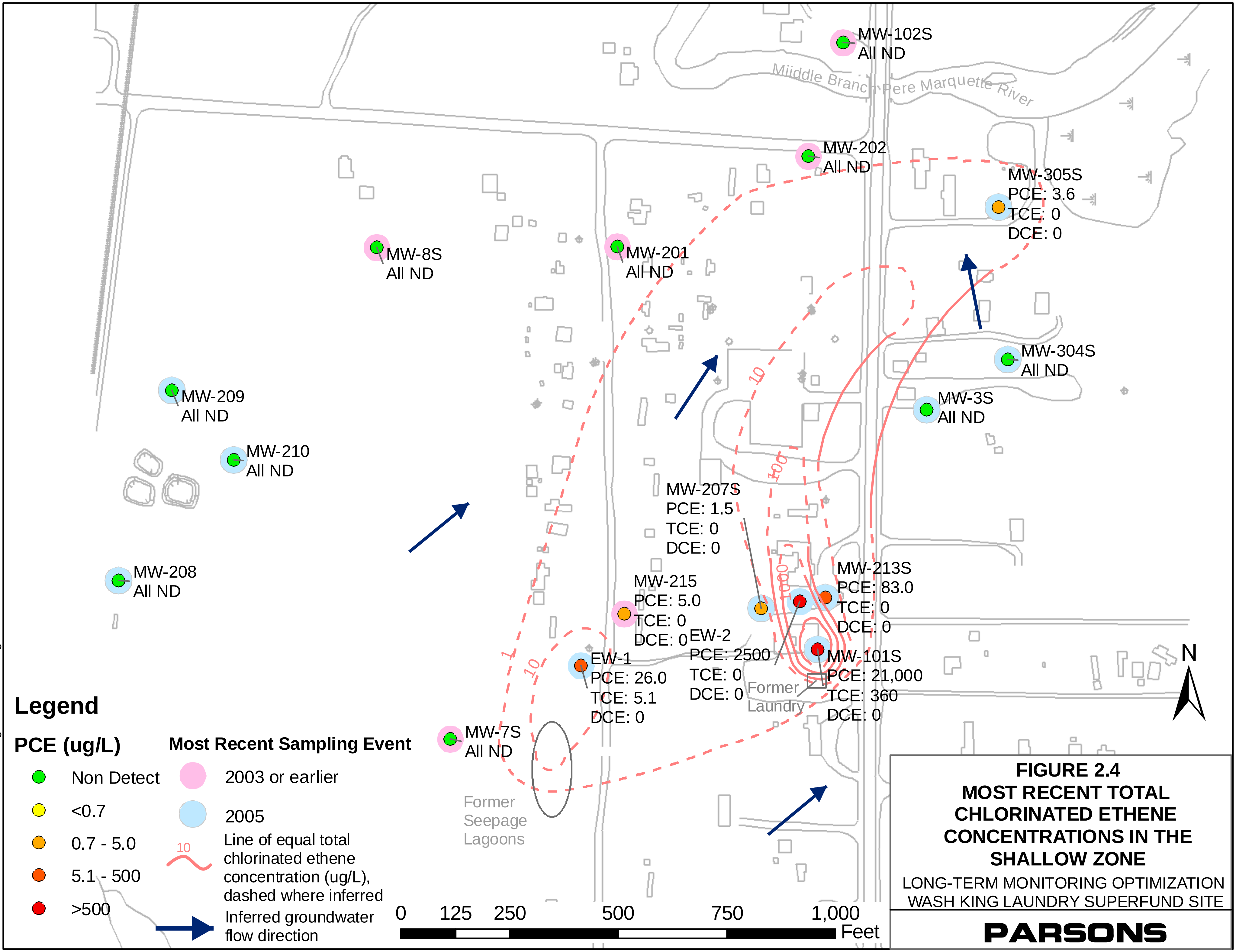

FIGURE 2.4
MOST RECENT TOTAL CHLORINATED ETHENE CONCENTRATIONS IN THE SHALLOW ZONE

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

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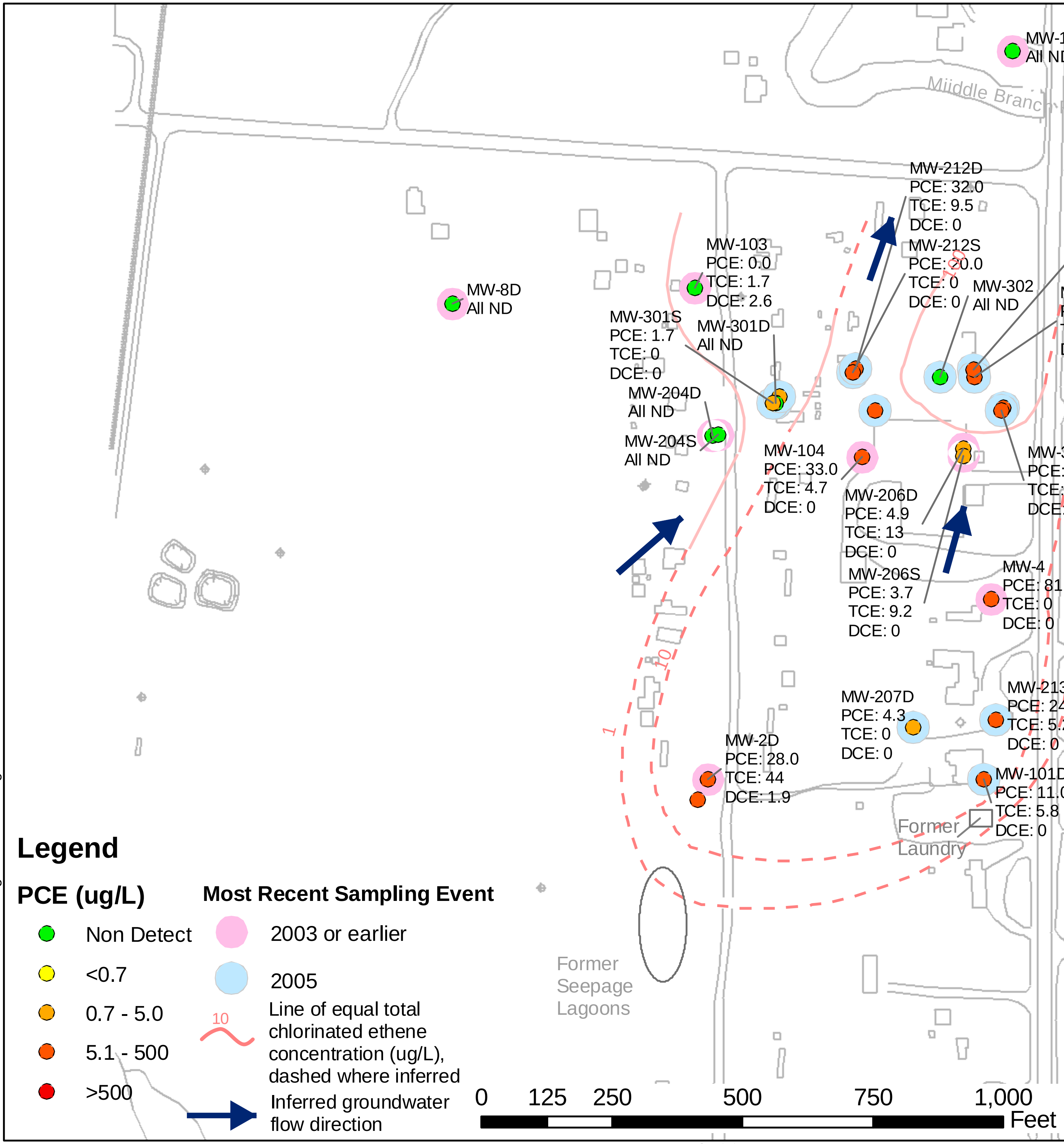

FIGURE 2.5
MOST RECENT TOTAL CHLORINATED ETHENE CONCENTRATIONS IN THE DEEP ZONE

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

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The presence of TCE and (occasionally) cis-1,2-dichloroethene (DCE) in shallow wells indicates that some reductive dechlorination of PCE to TCE is occurring. However, TCE and especially DCE concentrations are generally relatively low compared to concentrations of the parent solvent (PCE), indicating that geochemical conditions in the shallow zone are not well-suited for reductive dechlorination to occur. Groundwater in the shallow portion of the surficial aquifer is likely somewhat aerobic and oxidizing, although geochemical data are not available to confirm this supposition. Both PCE and TCE are generally resistant to biodegradation under these conditions; in contrast, DCE may be aerobically degraded.

2.3.2 Deep Portion of the Surficial Aquifer

Maximum PCE concentrations detected in the deep portion of the surficial aquifer are substantially lower than in the shallow portion (maximum of 360 µg/L in well MW-205S as of August 2005, Figure 2.4), indicating that, if significant NAPL is present at the site, it is restricted to more shallow depths. As described in Section 2.3, despite having an “S” designation, MW-205S is screened substantially below the depth interval in which most other “shallow” wells are screened and is therefore considered to be a deep well for purposes of this LTMO evaluation. This well is located approximately 850 feet north of the former Wash King laundry. PCE concentrations detected in MW-205S, MW-205D, MW-303, and EW-6 all indicate that the “hotspot” of the deep portion of the VOC plume is located in the vicinity of these wells, approximately 500 feet from the Middle Branch Pere Marquette River. There are no deep wells installed between the MW-205S/205D well pair and the river; therefore, VOC concentrations in the deep portion of the surficial aquifer between this well pair and the river are not being characterized.

Similar to the shallow portion of the aquifer, data for MW-102D, located on the north side of the river, suggest that the VOC plume in the deep portion of the aquifer does not extend beneath the river in this area. It should be noted however, that MW-102D is screened at a relatively deep interval (706 to 711 feet amsl, Figure 2.3), and a distance of approximately 69 feet separates the bottom of the MW-102S screen and the top of the MW-102D screen. Therefore, the data from well MW-102D do not definitively demonstrate that the deep portion of the plume does not underflow the river.

As with the shallow portion of the surficial aquifer, the relatively low magnitude of reductive dechlorination daughter product concentrations (TCE and DCE) at most wells relative to PCE concentrations indicates that geochemical conditions in the deep zone are not conducive to the widespread and sustained occurrence of reductive dechlorination. However, the presence of daughter products indicates that some reductive dechlorination of PCE and TCE is occurring, and that this process is more pronounced in localized areas (i.e., MW-303, MW-206D, MW-2D).

2.3.3 Middle Branch Pere Marquette River

According to the ROD (USEPA, 1993), sampling of surface water and sediment at three locations did not indicate levels of site-related contamination that would pose a risk to human health or the environment.

SECTION 3

LONG-TERM MONITORING PROGRAM AT WASH KING

The existing groundwater monitoring program at Wash King was examined to identify potential opportunities for streamlining monitoring activities while still maintaining an effective monitoring program. The monitoring program at Wash King is reviewed in the following subsections.

3.1 DESCRIPTION OF MONITORING PROGRAM

The Wash King monitoring program examined in this long-term monitoring optimization (LTMO) consists of 49 groundwater wells, including 5 extraction wells, 25 active (i.e., currently sampled) monitoring wells, and 19 inactive monitoring wells. The extraction wells are currently sampled quarterly, and the active monitoring wells are sampled semiannually. The wells included in this analysis are listed in Table 2.1 and shown on Figure 3.1 classified by their well type and sampling status (e.g., extraction well, currently sampled well, well not currently sampled). Table 3.1 displays the number of groundwater samples collected for VOC analysis from each well from 1997 to 2005. As shown in Table 3.1, limited analytical results exist for the period prior to the start-up of the extraction system in 2001. In addition, only one round of sampling was conducted in 2004 due to a transition in site management.

The objectives of the groundwater monitoring program at Wash King are not specified in the information reviewed for this LTMO evaluation. However, it is assumed that the objectives are consistent with the primary spatial and temporal objectives of groundwater monitoring programs outlined in Section 1 as summarized below:

- Evaluate groundwater at the Wash King Site for compliance with cleanup goals;
- Evaluate the effectiveness of natural attenuation processes, the groundwater extraction system, and source reduction/removal activities at decreasing VOC levels in groundwater; and
- Evaluate plume dynamics (i.e., is the plume increasing, stable, or decreasing in extent both laterally and vertically).

Likely additional objectives for the groundwater monitoring program are 1) to ensure that the remedy is protective of potential receptors, including the Middle Branch Pere Marquette River and area residents and businesses (via vapor intrusion into occupied

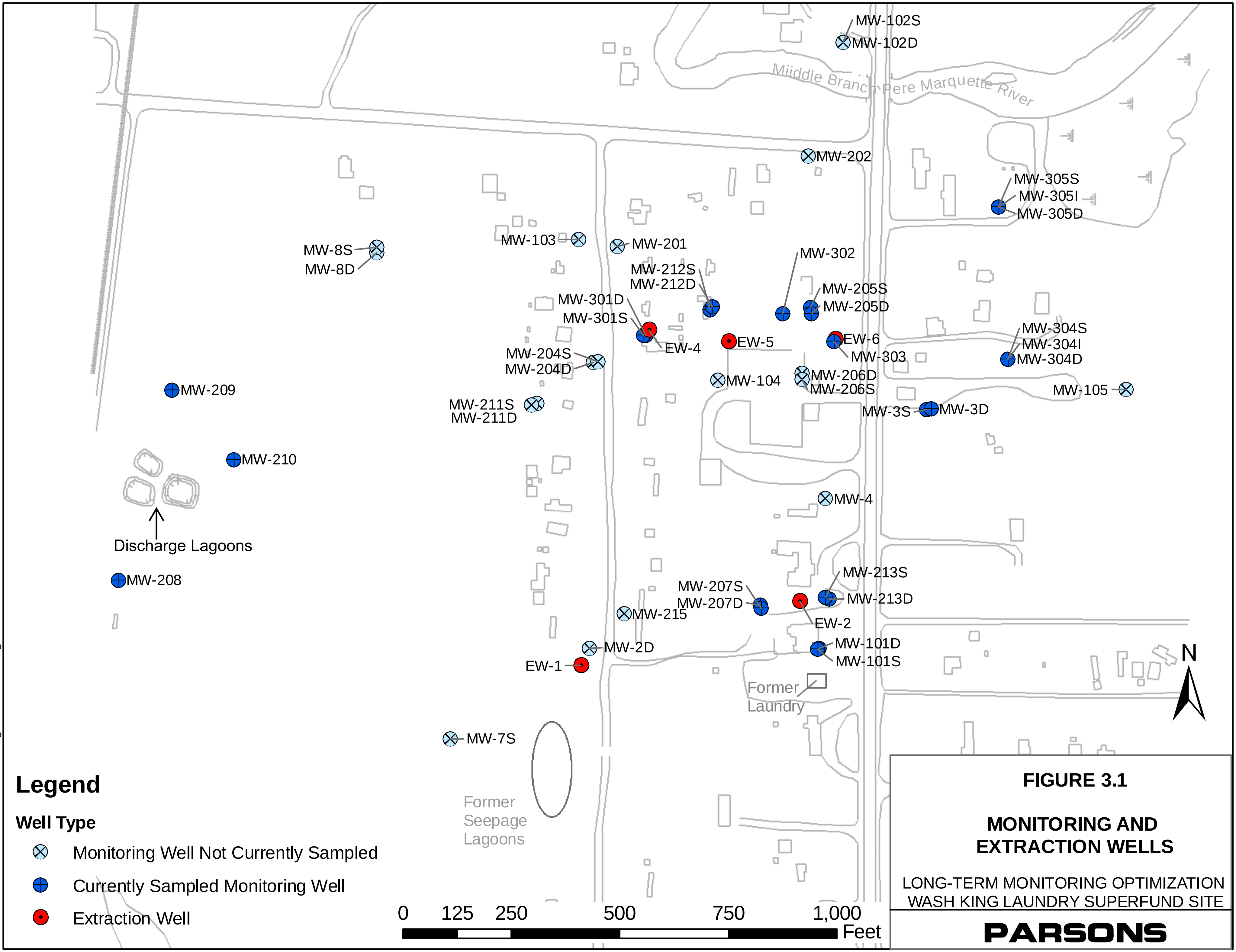

FIGURE 3.1

MONITORING AND EXTRACTION WELLS

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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TABLE 3.1
PCE DATA DATE DISTRIBUTION
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Number of PCE Samples per Year							
	1997	1998	1999	2000	2001	2003	2004	2005
EW-1					18	8	4	2
EW-2					17	8	3	2
EW-4					18	8	4	2
EW-5					18	8	4	2
EW-6					18	8	4	2
MW-101D	1	2		1		4		3
MW-101S	1	3	1	1		3		3
MW-205D					2	3	1	2
MW-205S					2	3	1	2
MW-207D				1	2	3	1	2
MW-207S				1	2	3	1	2
MW-208				1	2	3	1	2
MW-209					2	3		2
MW-210					2	1	1	2
MW-212D					2	2	1	2
MW-212S						2		2
MW-213D				1	2	3	2	2
MW-213S				1	2	4	1	2
MW-301D						3		2
MW-301S						3		1
MW-302						3	1	2
MW-303						3	1	2
MW-304D						3	1	2
MW-304I						3	1	2
MW-304S						3		1
MW-305D						3	1	2
MW-305I						3	1	1
MW-305S						3	1	2
MW-3D	1	2			2	3	1	2
MW-3S	1	2	1	1	2	3	1	2
Wells Not Currently Sampled								
MW-103	1	2				1		
MW-104	1	2		1		1		
MW-105				1		1		
MW-201				1		1		
MW-202						1		
MW-204D				1	2	1		
MW-204S				1	2	1		
MW-206D						1		
MW-206S						1		
MW-211S	Not sampled							
MW-211D	Not sampled							
MW-215					2	1		
MW-2D	1	2		1	1	1		
MW-4	1	2	1	1		1		
MW-8D	1	2	1	1	1			
MW-8S	1	2	1	1	1			
MW-7S				1				
MW-102D	1	2	1					
MW-102S	1	2	1					

Note: duplicate samples not counted
Only one sampling round conducted in 2004

structures); and 2) to provide data for five-year reviews of remedy implementation as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

3.2 SUMMARY OF ANALYTICAL DATA

The monitoring program for this plume was evaluated using results for sampling events performed from October 1997 through August 2005. Hardcopy data were received from the MDEQ, and were subsequently entered into an electronic database to facilitate performance of this LTMO evaluation. The database was processed to remove duplicate data by retaining the maximum result for each duplicate sample pair. As discussed in Section 2.3, the COCs identified for Wash King include PCE and TCE. Cis-1,2-DCE is also included in the analysis because it has been detected in site groundwater. Table 3.2 presents summaries of the occurrence of detected chlorinated ethenes based on all historical data collected from Wash King for monitoring and extraction wells. For all data groupings, PCE is the primary COC, with the highest percentage of detections and 307 Type B criterion exceedances, followed by TCE. PCE has exceeded the 0.7-µg/L standard in 54% of samples and at 23 of the 42 monitoring wells. Although DCE has been detected, concentrations have never exceeded the 70-µg/L USEPA MCL (a Type B criterion for cis-1,2-DCE is not specified in the ROD); therefore, this compound is not considered to be a significant COC in site groundwater.

Table 3.3 and Figures 2.4 and 2.5 present the most recent concentrations of PCE, TCE, and cis-1,2-DCE for the groundwater monitoring and extraction wells screened in the shallow and deep zones, respectively. Wells depicted on Figures 2.4 and 2.5 are classified based on their most recent PCE values (e.g., PCE concentrations greater than 1,000 µg/L are identified at EW-2 and MW-101S by their red color) and most recent sampling event (currently sampled wells are circled by blue and inactive wells by pink). Samples from 15 of the 30 currently sampled monitoring and extraction wells (50%) have at least one COC that exceeds a 307 Type B criterion and/or MCL based on the most recent data available for each well (all 15 have PCE exceedances and 8 have TCE exceedances). Six of the 17 wells that have available groundwater quality data and are not currently sampled had at least one COC that exceeded a cleanup goal during their most recent sampling event; all six had a PCE exceedance, and four also had a TCE exceedance.

TABLE 3.2
SUMMARY OF OCCURRENCE OF GROUNDWATER CONTAMINANTS OF CONCERN
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Parameter	Total Samples[a/]	Range of Detects (μg/L)[b/]			Percentage of Detects	Percentage of Samples with Standard[c/] Exceedances	Standard (mg/L)	Number of Wells with Results	Number of Wells with Detections	Number of Wells with MCL Exceedances
Extraction Wells										
PCE	208	4	-	4200	100.0%	100.0%	0.7	5	5	5
TCE	208	0	-	21	74.0%	56.7%	3	5	5	5
cis-DCE	207	0	-	33	29.5%	0.0%	70	5	4	
All Monitoring Wells										
PCE	324	0	-	35000	54.6%	54.0%	0.7	42	23	23
TCE	324	0	-	360	25.0%	20.4%	3	42	16	15
cis-DCE	324	0	-	21	12.7%	0.0%	70	42	9	

[a/] Analytical data analyzed includes sampling results from October 1997 through August 2005.

TABLE 3.3
MOST RECENT GROUNDWATER COC CONCENTRATIONS
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Most Recent Sampling Event	PCE	TCE	cis-DCE
		Standard=0.7µg/L	Standard=3µg/L	MCL=70µg/L
EW-1	6/13/05	26	5.1	ND
EW-2	6/13/05	2500	ND	ND
EW-4	6/13/05	4.3	ND	ND
EW-5	6/13/05	71	21	7.4
EW-6	6/13/05	270	ND	33
MW-101D	8/30/05	11	5.8	ND
MW-101S	8/30/05	21000	360	ND
MW-207D	8/30/05	4.3	ND	ND
MW-207S	8/30/05	1.5	ND	ND
MW-210	8/30/05	ND	ND	ND
MW-212D	8/30/05	32	9.5	ND
MW-212S	8/30/05	20	ND	ND
MW-213D	8/30/05	24	5.2	ND
MW-213S	8/30/05	83	ND	ND
MW-303	8/30/05	34	86	1.3
MW-304D	8/30/05	ND	ND	ND
MW-304I	8/30/05	ND	ND	ND
MW-304S	8/30/05	ND	ND	ND
MW-205D	8/29/05	140	14	3.8
MW-205S	8/29/05	360	ND	ND
MW-208	8/29/05	ND	ND	ND
MW-209	8/29/05	ND	ND	ND
MW-302	8/29/05	ND	ND	ND
MW-305D	8/29/05	ND	ND	ND
MW-305I	8/29/05	ND	ND	ND
MW-305S	8/29/05	3.6	ND	ND
MW-3D	8/29/05	ND	ND	ND
MW-3S	8/29/05	ND	ND	ND
MW-301D	8/24/05	ND	ND	ND
MW-301S	3/31/05	1.7	ND	ND
Wells Not Currently Sampled				
MW-103	10/23/03	ND	1.7	2.6
MW-104	10/23/03	33	4.7	ND
MW-215	10/23/03	5	ND	ND
MW-2D	10/23/03	28	44	1.9
MW-4	10/23/03	81	ND	ND
MW-105	10/22/03	ND	ND	ND
MW-201	10/22/03	ND	ND	ND
MW-202	10/22/03	ND	ND	ND
MW-204D	10/22/03	ND	ND	ND
MW-204S	10/22/03	ND	ND	ND
MW-206D	10/22/03	4.9	13	ND
MW-206S	10/22/03	3.7	9.2	ND
MW-8D	8/7/01	ND	ND	ND
MW-8S	8/7/01	ND	ND	ND
MW-7S	10/19/00	ND	ND	ND
MW-102D	5/13/99	ND	ND	ND
MW-102S	5/12/99	ND	ND	ND

[a/] ND = analyte not detected

[b/] Results in µg/L

[c/] Exceedances highlighted in yellow

SECTION 4

QUALITATIVE LTMO EVALUATION

An effective groundwater monitoring program will provide information regarding contaminant plume migration and changes in chemical concentrations through time at appropriate locations, enabling decision-makers to verify that contaminants are not endangering potential receptors, and that remediation is occurring at rates sufficient to achieve remedial action objectives (RAOs) within a reasonable time frame. The design of the monitoring program should therefore include consideration of existing receptor exposure pathways as well as exposure pathways arising from potential future use of the groundwater.

Performance monitoring wells located within and downgradient from a contaminated area provide a means of evaluating the effectiveness of a groundwater remedy relative to performance criteria. LTM of these wells also provides information about migration of the contamination and temporal trends in chemical concentrations. Groundwater monitoring wells located downgradient from the leading edge of a contaminated area (*i.e.*, sentry wells) are used to evaluate possible changes in the extent of the plume and, if warranted, to trigger a contingency response action if contaminants are detected.

Primary factors to consider when developing a groundwater monitoring program include at a minimum:

- Aquifer heterogeneity,
- Types of contaminants,
- Distance to potential receptor exposure points,
- Groundwater seepage velocity and flow direction(s),
- Potential surface-water impacts, and
- The effects of the remediation system.

These factors will influence the locations and spacing of monitoring points and the sampling frequency. Typically, the greater the seepage velocity and the shorter the distance to receptor exposure points, the more frequently groundwater sampling should be conducted.

One of the most important purposes of LTM is to confirm that the contaminant plume is behaving as predicted. Graphical and statistical tests can be used to evaluate plume stability. If a groundwater remediation system or strategy is effective, then over the long term, groundwater-monitoring data should demonstrate a clear and meaningful decreasing trend in concentrations at appropriate monitoring points. The groundwater monitoring program at Wash King was evaluated to identify potential opportunities for streamlining monitoring activities while still maintaining an effective performance and compliance monitoring program.

4.1 METHOD FOR QUALITATIVE EVALUATION OF MONITORING NETWORK

The qualitative LTMO evaluation included 47 groundwater monitoring and extraction wells with historical data located in the Wash King area. These sampling points, their associated depth zones and basecase monitoring frequencies, and the earliest and most recent sampling data used in the LTMO analysis are listed in Table 2.1; their locations are depicted on Figure 3.1.

Multiple factors were considered in developing recommendations for continuation or cessation of groundwater monitoring at each well. In some cases, a recommendation was made to continue monitoring a particular well, but at a reduced frequency. A recommendation to discontinue monitoring at a particular well based on the information reviewed does not necessarily constitute a recommendation to physically abandon the well. A change in site conditions might warrant resumption of monitoring at some time in the future at wells that are not currently recommended for continued sampling. Typical factors considered in developing recommendations to retain a well in, or remove a well from, an LTM program are summarized in Table 4.1. Typical factors considered in developing recommendations for monitoring frequency are summarized in Table 4.2.

TABLE 4.1
MONITORING NETWORK OPTIMIZATION DECISION LOGIC
LONG-TERM MONITORING OPTIMIZATION
WASH KING SUPERFUND SITE

Reasons for Retaining a Well in Monitoring Network	Reasons for Removing a Well from Monitoring Network
Well is needed to further characterize the site or monitor changes in contaminant concentrations through time	Well provides spatially redundant information with a neighboring well (*e.g.*, same constituents, and/or short distance between wells)
Well is important for defining the lateral or vertical extent of contaminants.	Well has been dry for more than two years[a/]
Well is needed to monitor water quality at a compliance or receptor exposure point (*e.g.*, water supply well)	Contaminant concentrations are consistently below laboratory detection limits or cleanup goals
Well is important for defining background water quality	Well is completed in same water-bearing zone as nearby well(s)

a/ Periodic water-level monitoring should be performed in dry wells to confirm that the upper boundary of the saturated zone remains below the well screen. If the well becomes re-wetted, then its inclusion in the monitoring program should be evaluated.

4.2 RESULTS OF QUALITATIVE LTMO EVALUATION FOR GROUNDWATER

The results of the qualitative evaluation of monitoring wells at the Wash King site are described in this subsection. The evaluation included the 47 groundwater monitoring wells listed in Table 2.1. The qualitative LTMO evaluation for groundwater considered historical analytical results for the three primary COCs (PCE, TCE, cis-1,2-DCE) and whether continued monitoring of each well was desirable in light of the Wash King groundwater monitoring goals listed in Section 3.1. In addition, potential data gaps were considered.

TABLE 4.2
MONITORING FREQUENCY DECISION LOGIC
LONG-TERM MONITORING OPTIMIZATION
WASH KING SUPERFUND SITE

Reasons for Increasing Sampling Frequency	Reasons for Decreasing Sampling Frequency
Groundwater velocity is high	Groundwater velocity is low
Change in contaminant concentration would significantly alter a decision or course of action	Change in contaminant concentration would not significantly alter a decision or course of action
Well is necessary to monitor source area or operating remedial system	Well is distal from source area and remedial system
Cannot predict if concentrations will change significantly over time, or recent significant increasing trend in contaminant concentrations at a monitoring location resulting in concentrations approaching or exceeding a cleanup goal, possibly indicating plume expansion	Concentrations are not expected to change significantly over time, or contaminant levels have been below groundwater cleanup objectives for some prescribed period of time

Table 4.3 includes recommendations for retaining or removing each well, the recommended sampling frequency, and the rationale for the recommendations. The qualitative analysis results are depicted on Figures 4.1 and 4.2 for the shallow and deep zone wells, respectively, and are summarized by well type and aquifer zone in the following subsections.

4.2.1 Extraction Wells

Five GWE wells were considered during the qualitative evaluation, including EW-1, 2, 4, 5, and 6. Sampling results for EW-3 were not available and this well was not included in the evaluation. EW-3 is reportedly not located in an optimum location and is not always pumped. A sixth GWE well, EW-5A, exists and reportedly is the primary operating well of the EW-5/EW-5A pair. Both wells are operational, but EW-5 reportedly is relatively low-yielding. However, sampling results received from the MDEQ indicate that they are for EW-5; sample IDs containing “EW-5A” were not

TABLE 4.3
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
EW-1	Extraction	Quarterly		X	Semiannual	Data can be used to monitor mass removal rates over time, optimize pumping strategy, and evaluate remedial progess; only 4 ug/L variation over last 6 sampling events--asymptotic behavior justifies lower sampling frequency
EW-2	Extraction	Quarterly		X	Semiannual	Data can be used to monitor mass removal rates over time, optimize pumping strategy, and evaluate remedial progess; relatively stable trend over last 4 sampling events justifies lower sampling frequency
EW-4	Extraction	Quarterly		X	Semiannual	Only 1.1 ug/L variation over last 6 sampling events, and COCs < MCLs but PCE exceeds 307 Type B cleanup criterion listed in ROD; minimal mass removal occurring; evaluate need for continued pumping of this well; recent stable trend justifies lower sampling frequency
EW-5	Extraction	Quarterly		X	Semiannual	Data can be used to monitor mass removal rates over time, optimize pumping strategy, and evaluate remedial progess; fluctuating in narrow range (140 to 210 ug/L) over 22 of last 23 sampling events justifying lower sampling frequency. Recent jump in TCE < 10 ug/L.
EW-6	Extraction	Quarterly		X	Semiannual	Data can be used to monitor mass removal rates over time, optimize pumping strategy, and evaluate remedial progess; slow, consistent decreasing trend over last 8 events justifies lower sampling frequency
MW-101D	Deep	Semiannual		X	Annual	Decreasing PCE and TCE concentrations in source area well; active source remediation not occurring; sampled 8 times since Feb 02; more frequent sampling not necessary unless more active source area remedy is implemented
MW-101S	Shallow	Semiannual		X	Annual	Retain due to source area location and greatly elevated PCE levels. Annual frequency justified by lack of significant trend in PCE concentrations over 7 events since Dec 02 and lack of active source area remediation; more frequent sampling not necessary unless significant change in site conditions occurs (more active source area remedy is implemented, etc.)
MW-205D	Deep	Semiannual		X	Annual	Retain due to relatively elevated PCE/TCE levels in plume core area near downgradient extent of monitoring well network. Annual frequency justified by apparent decreasing trend in PCE concentrations over 7 events since Dec 02 and lack of trend in TCE concentrations over entire sampling history; more frequent sampling not necessary unless significant change in site conditions occurs (pumping strategy changes, different remedy implemented, etc.). Large distance to river (~600 ft) relative to groundwater velocity (185 ft/yr) indicates that annual frequency is protective
MW-205S	Deep	Semiannual		X	Annual	Retain due to relatively elevated PCE levels in plume core area near downgradient extent of monitoring well network. Substantial decreasing PCE trend since Sept 02, most likely due to GWE system, justifying annual frequency. More frequent sampling not necessary unless significant change in site conditions occurs (pumping strategy changes, different remedy implemented, etc.). Large distance to river (~600 ft) relative to estimated groundwater velocity (185 ft/yr) indicates that annual frequency is protective
MW-207D	Deep	Semiannual		X	Biennial	PCE > 307 Type B criterion but < MCL since Sept 02; maximum PCE level over 10 events since Aug 01 = 5.3 ug/L; no apparent increasing trend, and well not in primary plume flowpath from source area; retain due to cleanup goal exceedance but at very low frequency due to low concentrations and lack of temporal trend
MW-207S	Shallow	Semiannual		X	Biennial	PCE > 307 Type B criterion but < MCL since Aug 01; very stable trend; well not in primary plume flowpath from source area; retain due to cleanup goal exceedance but at very low frequency due to low concentrations and lack of temporal trend
MW-208	Shallow	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 11 events since Aug 01; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern
MW-209	Shallow	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 10 events since Aug 01; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern
MW-210	Shallow	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 9 events since Aug 01; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern
MW-212D	Deep	Semiannual		X	Annual	PCE and TCE > MCL and 307 Type B criterion, but exhibit decreasing trends since Dec 02 (PCE) or Nov 01 (TCE); continued monitoring facilitates evaluation of remedial progress, but decreasing trends justify lower frequency
MW-212S	Deep	Semiannual		X	Annual	PCE > MCL and 307 Type B criterion, but exhibits decreasing trend since Sept 02; continued monitoring facilitates evaluation of remedial progress but decreasing trend justifies lower frequency
MW-213D	Deep	Semiannual		X	Annual	PCE > MCL and 307 Type B criterion, but exhibits decreasing trend since Feb 02; TCE > MCL and Type B criterion for first time in Aug 05 after 11 non-detect results; continued monitoring facilitates evaluation of remedial progress for PCE and potential increasing TCE trend; decreasing PCE trend justifies lower frequency

TABLE 4.3
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
MW-213S	Shallow	Semiannual		X	Annual	PCE > MCL and 307 Type B criterion, but exhibits decreasing trend since Jun 03; continued monitoring facilitates evaluation of remedial progress
MW-301D	Deep	Semiannual	X		Exclude	At W. edge of VOC plume; non-detect for COCs throughout monitoring history (since Sept 02); nearby well MW204D (screened at similar depth) monitors cross-gradient extent of plume in this area; continued monitoring will not provide useful information to achieve monitoring objectives
MW-301S	Deep	Semiannual	X		Exclude	At W. edge of VOC plume adjacent to EW-4; PCE concentrations near or below MCL (but > 307 Type B criterion) and decreasing; nearby well MW204S (screened at similar depth) monitors cross-gradient exent of plume in this area, and EW-4 contains very similar PCE concentrations; continued monitoring will not provide useful information to meet monitoring objectives; EW-4 data indicate remedial progress in this area
MW-302	Deep	Semiannual	X		Exclude	Only 1 historic detection of 1 VOC (PCE, 2.3 ug/L, Sept 02), otherwise all non-detect despite presence of VOCs in nearby well MW-205D; continued monitoring of this well does not yield useful information about plume; monitoring of MW-205D will allow assessment of remedial progress in this area
MW-303	Deep	Semiannual		X	Semiannual	Co-located with EW-6; PCE > MCL and 307 Type B criterion, but exhibits substantial decreasing trend since Sept 02; PCE temporal trend and concentration magnitude similar to that of EW-6, so continued monitoring of MW-303 to track PCE trends probably not necessary. However, TCE > MCL and Type B criterion for first time in Aug 05 (86 ug/L) after 7 trace to non-detect results; continued monitoring facilitates assessment of potential increasing TCE trend; abrupt increase in TCE levels justifies continued semiannual frequency; remove from LTM program if future monitoring indicates return to previous conditions, and/or if future sampling of EW-6 indicates that this well is adequately mirroring TCE concentrations in MW-303.
MW-304D	Deep	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 8 events since Sept 02; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern; nearby well pair MW-3S/3D adequately monitors easterly extent of plume in this area
MW-304I	Deep	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 8 events since Sept 02; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern; nearby well pair MW-3S/3D adequately monitors easterly extent of plume in this area
MW-304S	Shallow	Semiannual	X		Exclude	All non-detect for chlorinated ethenes over 7 events since Sept 02; substantially cross-gradient of VOC plume and not monitoring groundwater in area of concern; nearby well pair MW-3S/3D adequately monitors easterly extent of plume in this area
MW-305D	Deep	Semiannual		X	Annual	Non-detect for COCs since sampling began in Sept 02; retain only if this well is screened in the sandy aquifer benearth the clay aquitard and functions as a vertical sentry well for this drinking water aquifer; otherwise, discontinue sampling (screen depth suggests well is screened beneath clay aquitard)
MW-305I	Deep	Semiannual		X	Annual	Non-detect for COCs since sampling began in Sept 02; acts as downgradient sentry well for deeper portion of surfical aquifer
MW-305S	Shallow	Semiannual		X	Annual	Monitors PCE levels near downgradient extent of plume; stable trend and low-magnitude concentrations support annual frequency
MW-3D	Deep	Semiannual		X	Biennial	Only 1 MCL and 2 Type B criterion exceedances since Feb 02 (TCE, 2.4 ug/L in Aug 01 and 5.3 ug/L in Mar 03); monitors easterly extent of plume over time; cross-gradient location and monitoring history support low (biennial) frequency
MW-3S	Shallow	Semiannual		X	Biennial	All non-detect for COCs over 14 events since April '98; monitors easterly extent of plume over time; cross-gradient location, monitoring history, and apparent lateral plume stability in the shallow zone support low (biennial) frequency
Wells Not Currently Sampled						
MW-103	Deep	Not Sampled		X	Biennial	Monitors westerly extent of plume in deep zone over time in this area; cross-gradient location justifies lower frequeqncy
MW-104	Deep	Not Sampled		X	Annual	Not sampled since Oct 03, when PCE detected at 33 ug/L; resume sampling to evaluate remedial progress, then dicontinue if VOCs < cleanup goals over 2 consecutive events
MW-105	Deep	Not Sampled	X		Exclude	Substantially cross-gradient (east) of VOC plume; COCs all non-detect during 3 historic sampling events; does not monitor groundwater in area of concern; MW-3S/3D better suited to monitor easterly extent of plume over time
MW-201	Shallow	Not Sampled		X	Biennial	Only sampled once in Oct 03 (all non-detect); monitors westerly extent of plume over time; cross-gradient location justifies lower frequency if new data continue to indicate VOCs < cleanup goals
MW-202	Shallow	Not Sampled		X	Annual	Sampled twice in 2002 and 2003; acts as downgradient sentry well (note: well was reportedly destroyed and should be replaced)
MW-204D	Deep	Not Sampled		X	Biennial	All non-detect for COCs over 6 events since Oct 00+G20; monitors westerly extent of plume over time; cross-gradient location, monitoring history, and apparent lateral plume stability in the lower part of deep zone in this area support low (biennial) frequency if new data continue to indicate VOCs < cleanup goals

TABLE 4.3
QUALITATIVE EVALUATION OF GROUNDWATER MONITORING NETWORK
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Hydrologic Unit	Current Sampling Frequency	Qualitative Analysis			
			Exclude	Retain	Monitoring Frequency Recommendation	Rationale
MW-204S	Deep	Not Sampled		X	Biennial	All non-detect for COCs over 6 events since Oct 00; monitors westerly extent of plume over time; cross-gradient location, monitoring history, and apparent lateral plume stability in the upper part of the deep zone in this area support low (biennial) frequency if new data continue to indicate VOCs < cleanup goals
MW-206D	Deep	Not Sampled		X	Annual	Sampled once in Oct 03 (TCE and PCE > 307 Type B criterion and TCE > MCL); resume sampling to evaluate remedial progress, then discontinue if VOCs < cleanup goals over 2 consecutive events
MW-206S	Deep	Not Sampled		X	Annual	Sampled twice in 2002 and 2003 (TCE and PCE > 307 Type B criterion and TCE > MCL); resume sampling to evaluate remedial progress, then discontinue if VOCs < cleanup goals over two consecutive events
MW-211D	Deep	Not Sampled	X		Exclude	Redundant with MW-204D, which is used to define western boundary of VOC plume in this area
MW-211S	Shallow	Not Sampled		X	Biennial	Appears to be cross-gradient (west) of VOC plume but there are no historic groundwater quality data for this well to confirm. Finalize sampling frequency based on results of initial sampling event (biennial if VOCs less than cleanup goals, otherwise annual to assess remedial progress)
MW-215	Shallow	Not Sampled		X	Annual	Last sampled in Oct 03 (PCE low but > 307 Type B criterion); if levels belowType B criterion over two consecutive events then discontinue sampling; otherwise continue on annual basis to evaluate remedial progress
MW-2D	Deep	Not Sampled		X	Annual	Last sampled in Oct 03 (PCE/TCE = 28/44 ug/L); if levels below cleanup goals over two consecutive annual events then discontinue sampling; otherwise continue on annual basis to evaluate remedial progress downgradient of historic source area (seepage lagoons)
MW-4	Deep	Not Sampled		X	Annual	Last sampled in Oct 03 (PCE = 81 ug/L); if levels below cleanup goals over two consecutive annual events then discontinue sampling; otherwise continue on annual basis to evaluate remedial progress downgradient of former laundry
MW-8D	Deep	Not Sampled	X		Exclude	Substantially cross-gradient (west) of VOC plume and non-detect for COCs in Aug 01; does not monitor groundwater in area of concern
MW-8S	Shallow	Not Sampled	X		Exclude	Substantially cross-gradient (west) of VOC plume and non-detect for COCs in Aug 01; does not monitor groundwater in area of concern
MW-7S	Shallow	Not Sampled	X		Exclude	Sampled once in Oct 00 (all COCs non-detect); cross-gradient from VOC plume and does not monitor groundwater in area of concern; the only reason to resume sampling this well would be to assess upgradient groundwater quality given that this is the closest to an upgradient well present at the site--if evaluation of upgradient groundwater quality is desired to facilitate background geochemical or chemical concentrations, then monitoring of this well should resume.
MW-102D	Deep	Not Sampled		X	Biennial	Sampled 4 times from Oct 97 to May 99 (all COCs non-detect); continue monitoring at low frequency to verify lack of plume underflow beneath the river and protectiveness of remedy
MW-102S	Shallow	Not Sampled		X	Biennial	Sampled 4 times from Oct 97 to May 99 (all COCs non-detect); continue monitoring at low frequency to verify lack of plume underflow beneath the river and protectiveness of remedy
Recommended New Wells						
S-1	Shallow			X	Annual	Better define plume and track remedial progress over time
S-2	Shallow			X	Annual	Better define plume and track remedial progress over time
S-3	Shallow			X	Annual	Better define plume and track remedial progress over time
S-4	Shallow			X	Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from S-2 and S-3
S-5	Shallow			X	Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from S-2 and S-3
S-6	Shallow			X	Annual	Better define plume and track remedial progress over time
S-7	Shallow			X	Annual	Better define plume and track remedial progress over time
D-1	Deep			X	Annual	Better define plume and track remedial progress over time
D-2	Deep			X	Annual	Better define plume and track remedial progress over time
D-3	Deep			X	Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from D-2
D-4	Deep			X	Annual	Better define plume and track remedial progress over time
D-5	Deep			X	Annual	Better define plume and track remedial progress over time
D-6	Deep			X	Annual	Better define plume and track remedial progress over time

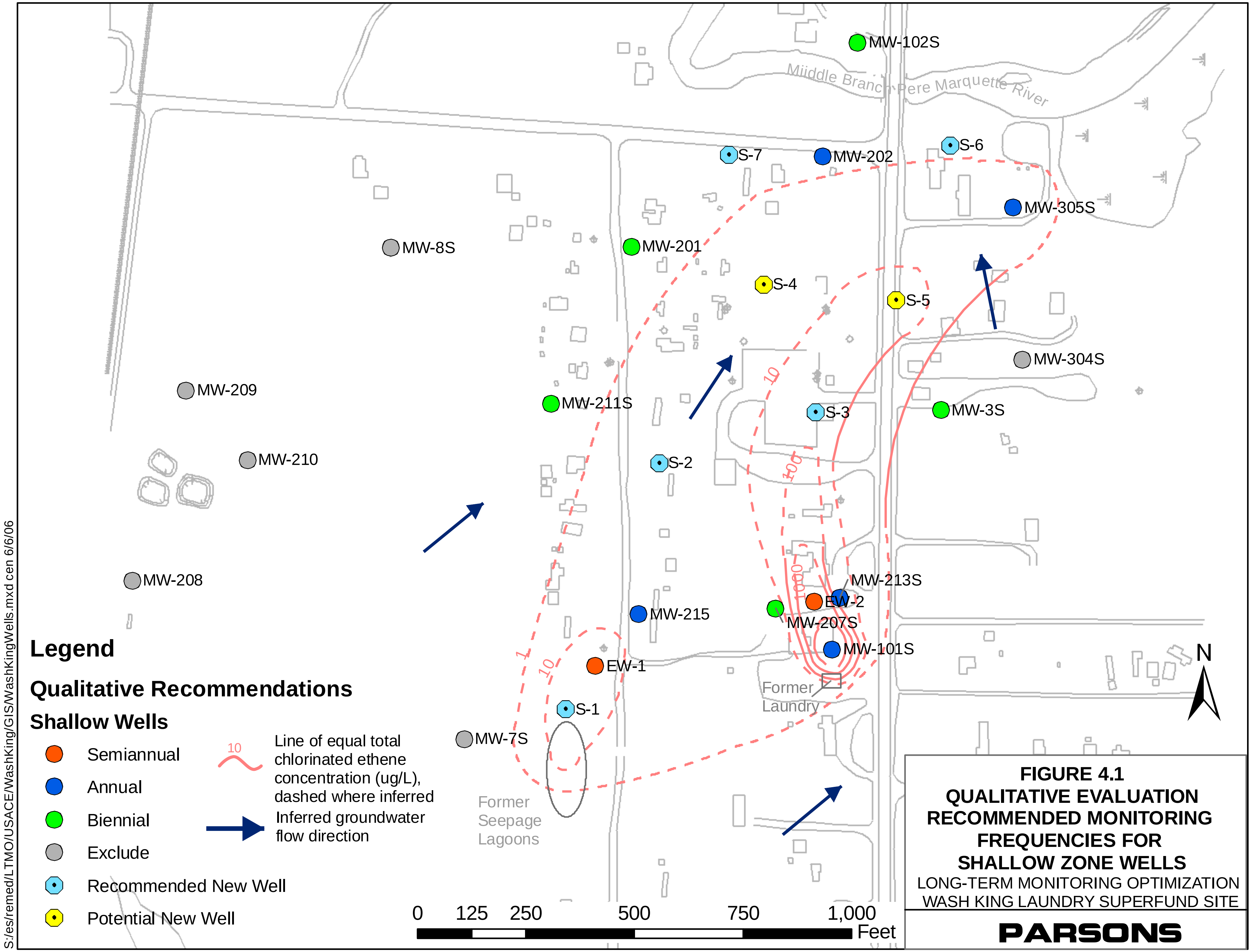
FIGURE 4.1
QUALITATIVE EVALUATION
RECOMMENDED MONITORING
FREQUENCIES FOR
SHALLOW ZONE WELLS
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE
PARSONS
Legend
Qualitative Recommendations
Shallow Wells
Semiannual
Annual
Biennial
Exclude
Recommended New Well
Potential New Well
10
Line of equal total chlorinated ethene concentration (ug/L), dashed where inferred
Inferred groundwater flow direction
0
125
250
500
750
1,000
Feet
N
Miiddle Branch Pere Marquette River
MW-102S
MW-202
S-7
S-6
MW-305S
MW-201
S-4
S-5
MW-304S
MW-8S
MW-209
MW-211S
S-3
MW-3S
MW-210
S-2
MW-208
MW-215
MW-213S
EW-2
MW-207S
MW-101S
EW-1
S-1
MW-7S
Former Laundry
Former Seepage Lagoons
1
10
100
1000
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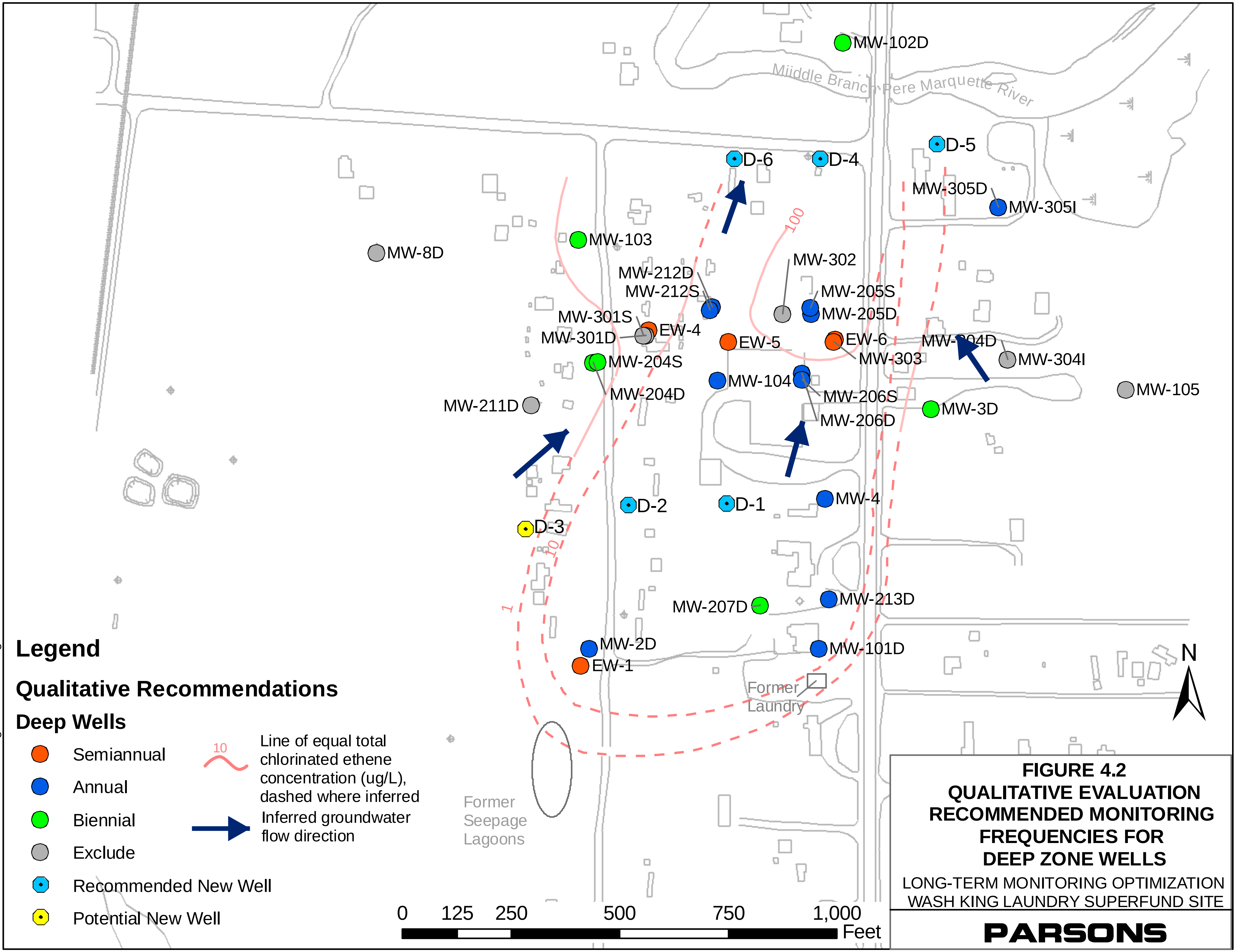

FIGURE 4.2
QUALITATIVE EVALUATION
RECOMMENDED MONITORING
FREQUENCIES FOR
DEEP ZONE WELLS

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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received. It is assumed that EW-5 and EW-5A are spatially co-located and screened at approximately the same depths.

Graphs of PCE concentrations versus time for the extraction wells are shown on Figure 4.3. These wells are currently sampled quarterly. As shown on Figure 4.3, PCE concentrations in wells EW-1, 2, 4, and 5 exhibit relatively stable trends. The PCE concentrations in EW-1 and EW-4 have not varied by more than 4 µg/L and 1.6 µg/L, respectively, over the most recent six sampling events. The PCE concentration at EW-5 fluctuated between 130 and 210 µg/L over 22 sampling events from February 2002 to March 2005. The most recent four data points for EW-2 suggest that the PCE concentration may be stabilizing, and data for EW-6 exhibit a steady decreasing trend.

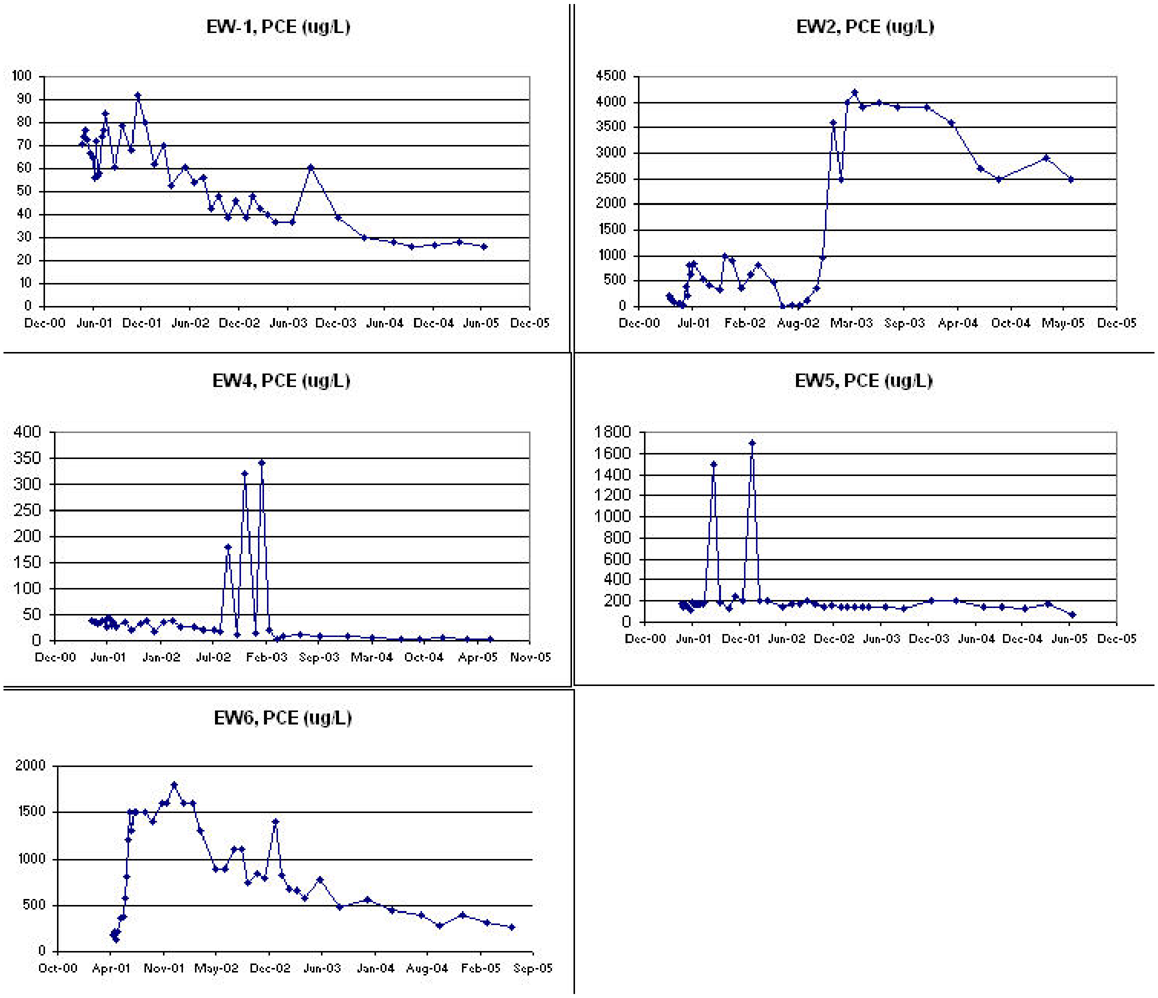
The recent stable trends in four of the five GWE wells (described above) indicate that the sampling frequency at these wells can be reduced with little loss of important information. Continued frequent monitoring at locations where no temporal trend in contaminant concentrations is present serves merely to confirm the results of previous monitoring activities at that location; results of continued monitoring through time are likely to fall within the historic range of concentrations that have already been detected. Therefore, reduction in the monitoring frequency for EW-1, 2, 4, and 5 to semiannual is recommended. Historic data for EW-6 indicate that either the deceasing trend will continue in the future or PCE concentrations will begin to stabilize. Given the lack of significant fluctuations in contaminant concentrations in this well over the past two years, and the likelihood that future contaminant concentrations will fall within a relatively narrow and predictable range, semiannual sampling of this well is also deemed to be appropriate. Semiannual sampling of these wells should allow for adequate definition of mass removal rates and remedial progress over time. However, if future concentrations deviate significantly from the expected trends, then resumption of quarterly sampling should be considered.

Mass removal rates at EW-4 are currently extremely low given the low magnitude of VOC concentrations in the extracted water (PCE at 3 to 5 µg/L over the most recent six sampling events). However, the PCE concentrations do exceed the 307 Type B Cleanup criterion of 0.7 µg/L; therefore, continued sampling of this well at a lower frequency is recommended to track future progress on achieving cleanup goals in this area.

4.2.2 Monitoring Wells Screened in the Shallow Portion of the Surficial Aquifer

A total of 16 monitoring wells screened in the shallow portion of the surficial aquifer were evaluated qualitatively. The shallow portion of the surficial aquifer is defined for purposes of this LTMO evaluation to extend vertically downward to an elevation of approximately 760 feet amsl, roughly corresponding to the uppermost 25 to 30 feet of the saturated zone. Nine of the 16 wells are currently sampled on a semiannual basis, six of the remaining seven wells are not sampled on a regular basis, and there are no available sampling results for one well (MW-211S). As described in Section 2.3, five wells containing an “S” designation (MW-204S, 205S, 206S, 212S, and 301S) appear to actually be screened at elevations more similar to some of the “deep” wells (Figure 2.3); therefore, they were considered to be deep wells for the purposes of the LTMO evaluation.

FIGURE 4.3
GWE PCE CONCENTRATIONS OVER TIME
LONG-TERM MONITORING OPTIMIZATION
WASH KING SUPERFUND SITE



Four of the nine shallow wells that are currently sampled are recommended for deletion from the LTM program because they are cross-gradient and distant from the VOC plume; these wells include MW-208, 209, 210, and 304S (Table 4.3 and Figure 4.1). Shallow wells MW-7S and 8S are also recommended for deletion for the same reason. Chlorinated ethenes have never been detected in these wells, and continued sampling of these wells does not provide any information about the remaining areas of concern.

If collection of background groundwater geochemical data is desired in the future to support a natural attenuation evaluation, then all or a subset of the cross-gradient wells could be sampled for that purpose. Similarly, if data regarding upgradient groundwater quality were desired in the future (e.g., if there is reason to believe that an upgradient source of chlorinated ethenes is present that is contributing to the Wash King plume), then MW-7S could be sampled for that purpose.

Future sampling of 10 existing shallow wells on an annual to biennial (every other year) basis is recommended, as detailed in Table 4.3 and on Figure 4.1. Five of these wells (MW-101S, 207S, 213S, 305S, and 3S) are currently sampled semiannually as part of ongoing LTM activities. The remaining five wells (MW-201, 202, 211S, 215, and 102S) are not currently sampled and are recommended for future inclusion in the monitoring program.

MW-3S, MW-201, MW-211S, and MW-202 are recommended for future sampling to assist in the definition of the lateral plume boundaries over time in the shallow zone. The recommended sampling frequency for MW-3S, MW-201, and MW-211S is biennial given their inferred cross-gradient location relative to the VOC plume and the apparently stable to diminishing extent of the plume footprint over the last several years; this frequency should be conditional on new data continuing to indicate VOC concentrations less than cleanup goals for wells that have not been sampled recently. However, if hydraulic conditions change (e.g., change in on-site pumping conditions or initiation of off-site groundwater extraction in the vicinity), or the sampling results indicate plume expansion, then more frequent sampling should be considered. Annual sampling of MW-202 is recommended given its location at the downgradient end of the plume near the river.

Five of the remaining six shallow wells (MW-101S, 207S, 213S, 305S, and 215) are recommended for continued sampling because their plume-interior locations facilitate assessment of remedial progress over time. MW-305S is the furthest downgradient well containing a detectable concentration of a COC, and continued monitoring of this well provides some indication of plume stability. MW-215 was last sampled in October 2003 and contained a PCE concentration that exceeded the 307 Type B cleanup level. If current VOC concentrations in this well are below cleanup levels over at least two consecutive monitoring events then removal of this well from the LTM program could be considered. An annual to biennial sampling frequency for these five plume-interior wells is recommended (annual for all wells except MW-207S). A reduction in sampling frequency relative to the current semiannual program is supported by the lack of increasing trends in these wells, the generally stable to diminishing nature of the plume, and the perceived low degree of risk posed by the plume to potential receptors.

Shallow well MW-102S functions as a downgradient sentry well and provides useful information regarding the northern extent of the plume. Chlorinated ethenes have never been detected in this well, and there is no reason to believe that this will change given that groundwater in the shallow zone likely discharges to the Pere Marquette River. Therefore, a relatively low (biennial) sampling frequency is recommended.

4.2.3 Monitoring Wells Screened in the Deep Portion of the Surficial Aquifer

A total of 28 monitoring wells screened in the deep portion of the surficial aquifer were evaluated qualitatively. The deep portion of the surficial aquifer is defined for purposes of this LTMO evaluation to extend from roughly 25 to 30 feet below the water table to the clay aquitard that is believed to separate the surficial aquifer from the underlying sandy drinking water aquifer (i.e., from roughly 30 to at least 60 or 65 feet below the water table). Sixteen of the 28 wells are currently sampled on a semiannual basis, 11 of the remaining 12 wells are not sampled on a regular basis, and there are no available sampling results for one well (MW-211D) . The five wells containing an “S” (shallow) designation (MW-204S, 205S, 206S, 212S, and 301S) that are actually screened at deeper elevations than the other “shallow” wells, and the two wells containing an “I” (intermediate) designation (MW-304I and 305I) are lumped into the “deep” zone for purposes of the LTMO evaluation (see Figure 2.3 for depiction of screen intervals).

Two of the 16 deep wells that are currently sampled are recommended for deletion from the LTM program because they are cross-gradient and distant from the VOC plume; these wells include MW-304I and 304D (Table 4.3 and Figure 4.2). Chlorinated ethenes have never been detected in these wells, and continued sampling of these wells does not provide any useful information about the remaining areas of concern.

Deep zone wells MW-301S and 301D are located adjacent to GWE well EW-4, near the inferred western edge of the VOC plume. MW301D has been non-detect for COCs throughout its monitoring history (since September 2002), and there is no reason to believe that this will change unless hydraulic conditions in the surficial aquifer change. Monitoring of nearby well MW204D, screened in a similar depth interval, would allow assessment of the western plume boundary over time in this area. The screen interval of MW-301S corresponds to the uppermost 10 feet of the screen interval of EW-4, and PCE concentrations in both wells are similar. Continued monitoring of EW-4 should indicate future remedial progress in this area, eliminating the need to continue sampling MW-301S.

Well MW302 is spatially redundant with well pair MW-205S/205D; the latter wells contain elevated concentrations of COCs, while MW-302 (which has a relatively long screen interval) has been non-detect for COCs over seven monitoring events since December 2002 and is not providing useful information. Therefore, continued monitoring of MW-205S/205D and removal of MW302 from the monitoring program is recommended.

MW-211D is spatially redundant with MW-204D and they are screened at similar depths as shown on Figure 2.3. Sampling of both of these wells is not required to define the western plume boundary in this area; continued sampling of MW-204D is recommended.

Future sampling of 20 existing deep zone wells on an annual to biennial basis is recommended, as detailed in Table 4.3. Eleven of these 20 wells (MW-101D, 205D, 205S, 207D, 212D, 212S, 213D, 303, 305D, 305I, and 3D) are currently sampled semiannually as part of ongoing LTM activities. The remaining nine wells (MW-103, 104, 204D, 204S, 206D, 206S, 2D, 4, and 102D) are not currently sampled and are recommended for future inclusion in the monitoring program.

MW-3D, 103, 204S, 204D, 305I, and 305D are recommended for future sampling to assist in the definition of the lateral plume boundaries over time in the deep zone. The recommended sampling frequency for these wells is annual (MW-305I/D only) to biennial given their inferred cross-gradient location relative to the VOC plume and the apparently stable to diminishing extent of the plume footprint over the last several years. However, if hydraulic conditions change (e.g., change in on-site pumping conditions or initiation of off-site groundwater extraction in the vicinity), or if new sampling results for wells not sampled recently indicate plume expansion, then more frequent sampling should be considered.

Thirteen of the remaining 14 deep wells (MW-101D, 205D, 205S, 207D, 212D, 212S, 213D, 303, 104, 206D, 206S, 2D, and 4) are recommended for continued sampling because their plume-interior locations facilitate assessment of remedial progress over time. The most recent sampling event performed in each of these wells has indicated the presence of at least one COC at concentrations that exceed 307 Type B cleanup goals. Available data indicate that five of these 13 wells (MW-104, 206D, 206S, 2D, and 4) were last sampled in October 2003; those sampling results indicate PCE concentrations ranging from 3.7 to 81 µg/L (compared to the Type B cleanup criterion of 0.7 µg/L) and TCE concentrations ranging from non-detect to 44 µg/L (compared to a Type B cleanup criterion of 3 µg/L). If current VOC concentrations in these five wells are below cleanup levels over at least two consecutive monitoring events, then removal of these wells from the LTM program could be considered. An annual sampling frequency for 11 of the 13 plume-interior wells (all except for MW-303 and MW-207D, see Table 4.3 for details) is recommended. A reduction in sampling frequency relative to the current semiannual program is supported by the lack of increasing trends in these wells and the fact that there are no nearby receptors (the distance from the most downgradient of these well to the Pere Marquette River is approximately 500 feet, versus an estimated average groundwater flow velocity of 185 feet per year). The plume in the deep zone appears to be generally stable to diminishing under the influence of the GWE system and natural attenuation processes.

The last deep well recommended for continued sampling (MW-102D) is located on the north (downgradient) side of the river, and was non-detect for COCs during four sampling events performed from October 1997 to May 1999. Additional sampling of this well at a low (biennial) frequency is recommended given that it serves as a sentry well to verify the lack of plume underflow beneath the river in the deep zone of the surficial aquifer.

4.3 DATA GAPS

Specific data gaps in the groundwater monitoring network were assessed during performance of the qualitative evaluation, as summarized in the following subsections. It is our understanding that additional groundwater quality data (apart from the monitoring and extraction well data assessed for this LTMO evaluation) were collected during previous site characterization activities. For example, the database contains vertical profiling VOC data for “GP”-series sampling points (perhaps referring to Geoprobe points). However, the locations of these additional samples were not provided to Parsons. Therefore, the validity of the recommendations for additional well installations provided below should be weighed in light of all available data.

4.3.1 Shallow Portion of the Surficial Aquifer

COC concentrations in the shallow portion of the surficial aquifer are not well defined downgradient of the source area, as shown on Figures 2.4 and 4.1. This is partly because five of the wells designated as being “shallow“ are screened in what appears to be the upper portion of the “deep” zone, as shown on Figure 2.3. Therefore, there are no plume interior wells installed between EW-2 (located near the source area) and MW-305S (located near the downgradient plume toe). As a result, the current extent and magnitude of the plume in the shallow zone downgradient of the source area is not well defined, and remedial progress in this area cannot be assessed (assuming that there is significant groundwater contamination present in this area—the presence of PCE concentrations exceeding the 307 Type B criterion in MW-305S suggests that there is). The only GWE well screened entirely in the shallow zone is EW-2; EW-1 is screened in the lower portion of the shallow zone and the upper portion of the deep zone (Figure 2.3). As a result, much of the shallow zone between EW-2 and the river may not be impacted by the GWE system, depending on the capture zones of the deeper extraction wells..

Installation of up to approximately seven new shallow zone monitoring wells (S-1 through S-7) at the locations shown on Figure 4.1 would better define the extent and magnitude of the shallow zone plume and facilitate assessment of progress in achieving cleanup goals in the shallow zone across the site. This information would permit more accurate assessment of the schedule and cost to complete site remediation. The screen intervals of these wells should be based on the results of historical COC data for monitoring wells as well as vertical profiling data collected in the 1990s during site characterization activities. In addition, the MDEQ has indicated that MW-202 has reportedly been destroyed; this well should be replaced with a new well at the same location.

Installation of wells S-4 and S-5 should be conditional on sampling results from S-2 and S-3. If S-2 and S-3 appear to bound the higher-concentration portion of the dissolved contaminant plume, then installation of S-4 and/or S-5 may not be necessary. If installed, it is assumed that these wells would be sampled annually for at least three years, followed by re-evaluation of the monitoring frequency based on results obtained.

4.3.2 Deep Portion of the Surficial Aquifer

Groundwater quality in the deep portion of the surficial aquifer is well characterized along an east-west-trending band located approximately 500 feet from the Pere Marquette River. Several wells screened in the deep zone have been installed in the general vicinity of GWE wells EW-4, 5, and 6 to define dissolved chlorinated ethene concentrations and the lateral plume boundaries in this area (Figure 4.2). The next best-characterized area in terms of groundwater quality is located near the southern edge of the plume, where four monitoring wells and one GWE well have been installed. There is a large area between the two areas described above that is relatively devoid of deep zone wells, and installation of up to three deep monitoring wells in this area (D-1, D-2, and D-3), as shown on Figure 4.2, would allow better definition of the extent and magnitude of the plume to monitor remedial progress over time. Installation of D-3 could be optional and dependent on sampling results from D-2.

Installation of a fourth new well (D-4) directly downgradient of the elevated VOC concentrations detected at the MW-305S/306D well pair is recommended to better define the downgradient extent of elevated VOC concentrations and the proximity of the plume toe to the river. The degree to which the plume is discharging to the river is not known at this time. Installation of two additional new deep zone wells (D-5 and D-6) is also recommended to pair the recommended new shallow wells S-6 and S-7 and better define groundwater quality near the river. If installed, it is assumed that these wells would be sampled annually for at least three years, followed by re-evaluation of the monitoring frequency based on results obtained.

4.4 ANALYTICAL PROGRAM

Groundwater samples are analyzed by the MDEQ Environmental Laboratory for a total of 66 VOCs using method 8260. In addition, analysis for metals is routinely performed, although it is not clear if all samples are analyzed for metals during every sampling event. Generation of significant metals contamination at a laundry/dry-cleaner site would not typically be expected, and the degree to which detected metal concentrations may be representative of background conditions in the aquifer is not well understood. The following recommendations pertaining to the groundwater analytical program should be considered:

1) Discuss optimizing the target VOC list to a short-list of key compounds (i.e., the chlorinated ethenes PCE, TCE, DCE, and vinyl chloride) with the analytical laboratory. Potential advantages include lower laboratory analytical costs and lower data management/validation/reporting costs.

2) Compare detected metal concentrations to background concentrations from upgradient and cross-gradient wells to assess the degree to which they are representative of background conditions. If adequate background wells do not exist, consider installing a small number of background wells to allow this question to be definitively addressed.

3) Confirm that wells with elevated metal concentrations do not have metal screens that could be contributing to the elevated concentrations detected in groundwater samples.

3) If background comparisons indicate that detected metal concentrations are site-related as opposed to representative of background conditions (and if metal screens are not an issue), then optimize the metals analysis program to a short-list of key analytes and sampling points using the principles and procedures outlined in this report.

4) If sufficient dissolved oxygen and oxidation-reduction potential data are not available, then obtain field data for these parameters in the source area to support evaluation of appropriate source remediation approaches (such as *in situ* chemical oxidation).

4.5 LTM PROGRAM FLEXIBILITY

The LTM program recommendations summarized in Table 4.3 are based on available data regarding current (and assumed future) site conditions. Changing site conditions (*e.g.*, periods of drought or excessive rainfall or changes in hydraulic stresses such as number and location of pumping wells or pumping rates) could affect contaminant fate and transport. Therefore, the LTM program should be reviewed if hydraulic conditions change significantly, and revised as necessary to adequately track changes in the magnitude and extent of COCs in environmental media over time.

SECTION 5

TEMPORAL STATISTICAL EVALUATION

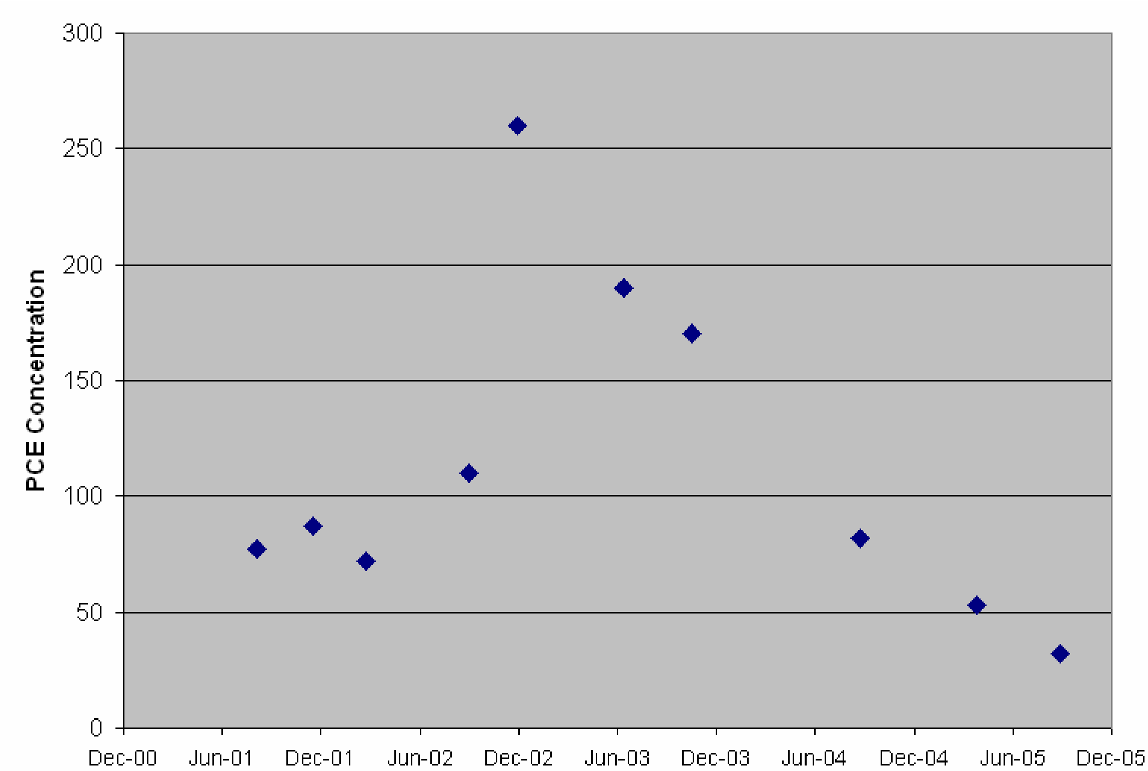
Chemical concentrations measured at different points in time (temporal data) can be examined graphically or using statistical tests, to evaluate dissolved-contaminant plume stability. If removal of chemical mass is occurring in the subsurface as a consequence of attenuation processes or operation of a remediation system, mass removal will be apparent as a decrease in chemical concentrations through time at a particular sampling location, as a decrease in chemical concentrations with increasing distance from chemical source areas, and/or as a change in the suite of chemicals detected through time or with increasing migration distance.

5.1 METHODOLOGY FOR TEMPORAL TREND ANALYSIS OF CONTAMINANT CONCENTRATIONS

Temporal chemical-concentration data can be evaluated for trends by plotting contaminant concentrations through time for individual monitoring wells (*e.g.*, Figure 5.1), or by plotting contaminant concentrations versus downgradient distance from the contaminant source for several wells along the groundwater flowpath over several monitoring events. Plotting temporal concentration data is recommended for any analysis of plume stability (Wiedemeier and Haas, 2000); however, visual identification of trends in plotted data may be a subjective process, particularly if (as is likely) the concentration data do not exhibit a uniform trend, but are variable through time (Figure 5.2).

The possibility of arriving at incorrect conclusions regarding the fate and transport of dissolved contaminants on the basis of visual examination of temporal concentration data can be reduced by examining temporal trends in chemical concentrations using various statistical procedures, including regression analyses and the Mann-Kendall test for trends. The Mann-Kendall nonparametric test (Gibbons, 1994) is well-suited for evaluation of environmental data because the sample size can be small (as few as four data points), no assumptions are made regarding the underlying statistical distribution of the data, and the test can be adapted to account for seasonal variations in the data. The Mann-Kendall test statistic can be calculated at a specified level of confidence to evaluate whether a statistically significant temporal trend is exhibited by contaminant concentrations detected through time in samples from an individual well. A negative slope (indicating decreasing contaminant concentrations through time) or a positive slope (increasing concentrations through time) provides statistical confirmation of temporal trends that may have been identified visually from plotted data (Figure 5.2). In this analysis, a 90% confidence level is used to define a statistically significant trend.

FIGURE 5.1
PCE CONCENTRATIONS THROUGH TIME
AT WELL MW-212D
LONG-TERM MONITORING NETWORK OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE



The relative value of information obtained from periodic monitoring at a particular monitoring well can be evaluated by considering the location of the well with respect to the dissolved contaminant plume and potential receptor exposure points, and the presence or absence of temporal trends in contaminant concentrations in samples collected from the well. The degree to which the amount and quality of information that can be obtained at a particular monitoring point serves the two primary (*i.e.*, temporal and spatial) objectives of monitoring (Section 1) must be considered in this evaluation. For example, the continued non-detection of a target contaminant in groundwater at a particular monitoring location provides no information about temporal trends in contaminant concentrations at that location, or about the extent to which contaminant migration is occurring, unless the monitoring location lies along a groundwater flowpath between a contaminant source and a potential receptor exposure point (*e.g.*, downgradient of a known contaminant plume). Therefore, a monitoring well having a history of contaminant concentrations below detection limits may be providing little or no useful information, depending on its location.

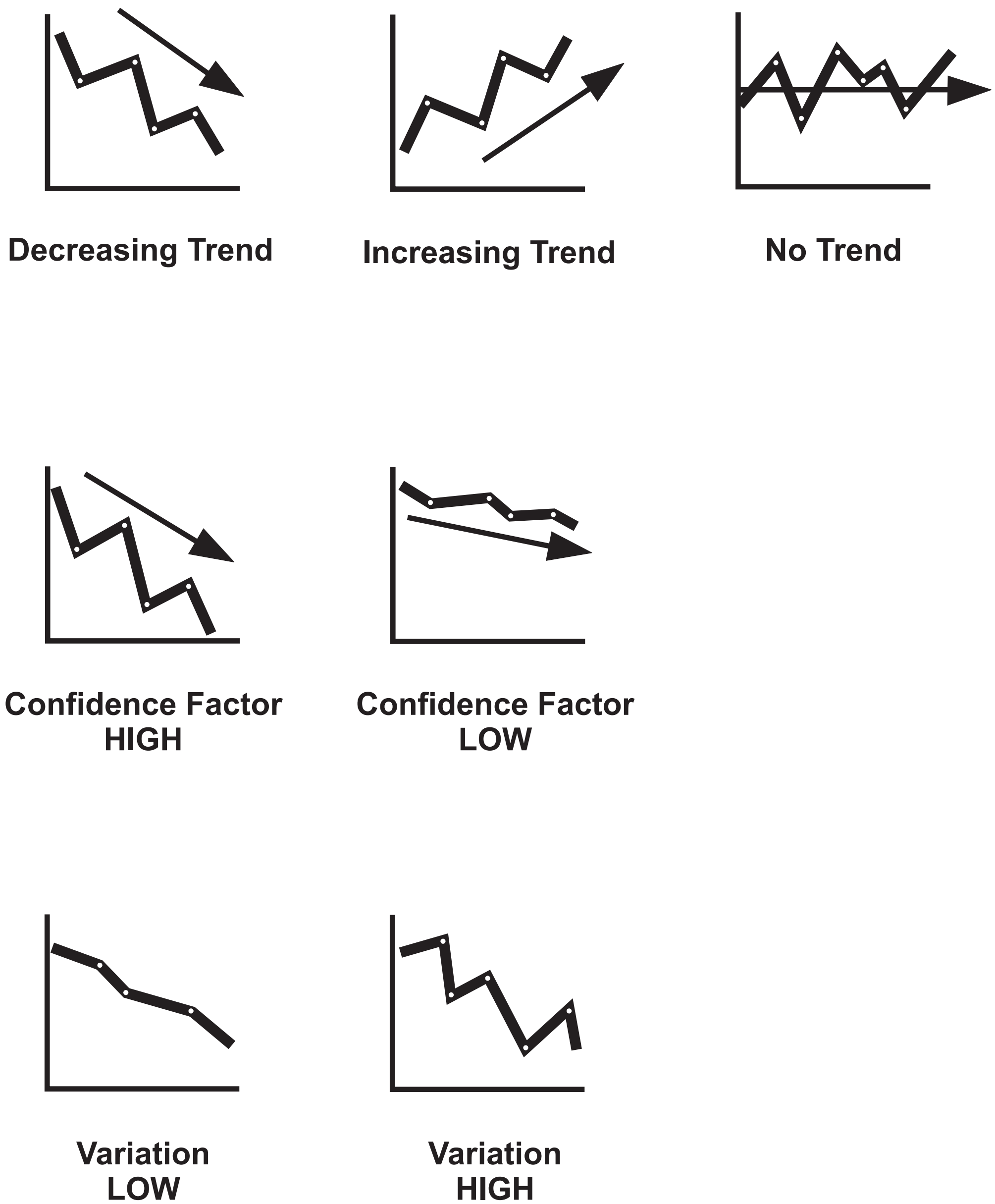


FIGURE 5.2

CONCEPTUAL REPRESENTATION OF TEMPORAL TRENDS AND TEMPORAL VARIATIONS IN CONCENTRATIONS

Long-Term Monitoring Optimization
Wash King Laundry Superfund Site

A trend of increasing contaminant concentrations in groundwater at a location between a contaminant source and a potential receptor exposure point may represent information critical in evaluating whether contaminants are migrating to the exposure point, thereby completing an exposure pathway. Identification of a trend of decreasing contaminant concentrations at the same location may be useful in evaluating decreases in the areal extent of dissolved contaminants, but does not represent information that is critical to the protection of a potential receptor. Similarly, a trend of decreasing contaminant concentrations in groundwater near a contaminant source may represent important information regarding the progress of remediation near, and downgradient from, the source. By contrast, the absence of a statistically significant (as defined by the Mann-Kendall test with a 90% confidence level) temporal trend in contaminant concentrations at a particular location within or downgradient from a plume indicates that virtually no additional information can be obtained by frequent monitoring of groundwater at that location, in that the results of continued monitoring through time are likely to fall within the historic range of concentrations that have already been detected (Figure 5.3). Continued monitoring at locations where no temporal trend in contaminant concentrations is present serves merely to confirm the results of previous monitoring activities at that location.

The temporal trends and relative location of wells can be weighed to determine if a well should be retained, excluded, or continued in the program with reduced sampling. Figure 5.4 presents a flowchart demonstrating the method for using trend results to draw these conclusions.

5.2 TEMPORAL EVALUATION RESULTS FOR GROUNDWATER WELLS

The analytical data for groundwater samples collected from the 47 groundwater monitoring and extraction wells in the Wash King LTM program from April 2001 through August 2005 were examined for temporal trends using the Mann-Kendall test. Note that only recent (i.e. post-extraction well start up) analytical results were used in this analysis. The temporal analysis is intended to measure trends obtained from a "steady state" system, so using results obtained before the extraction system was implemented could lead to spurious trends. The objective of the evaluation was to identify those wells having increasing or decreasing concentration trends for each COC, and to consider the quality of information represented by the existence or absence of concentration trends in terms of the location of each monitoring point. Increasing or decreasing trends are those identified as having positive or negative slopes, respectively, by the Mann-Kendall trend analysis with a confidence level of 90%.

Summary results of Mann-Kendall temporal trend analyses for COCs in groundwater samples from Wash King are presented in Table 5.1. Table 5.1 also contains the relative location designation assigned to each well and the number of results used in the analysis. Trends for the three COCs (PCE, TCE, and DCE) were evaluated to assess the value of temporal information provided by each well. As implemented, the algorithm used to evaluate concentration trends assigned a value of "ND" (not detected) to those wells with sampling results that were consistently below analytical detection limits through time, rather than assigning a surrogate value corresponding to the detection limit – a procedure that could generate potentially misleading and anomalous "trends" in concentrations.

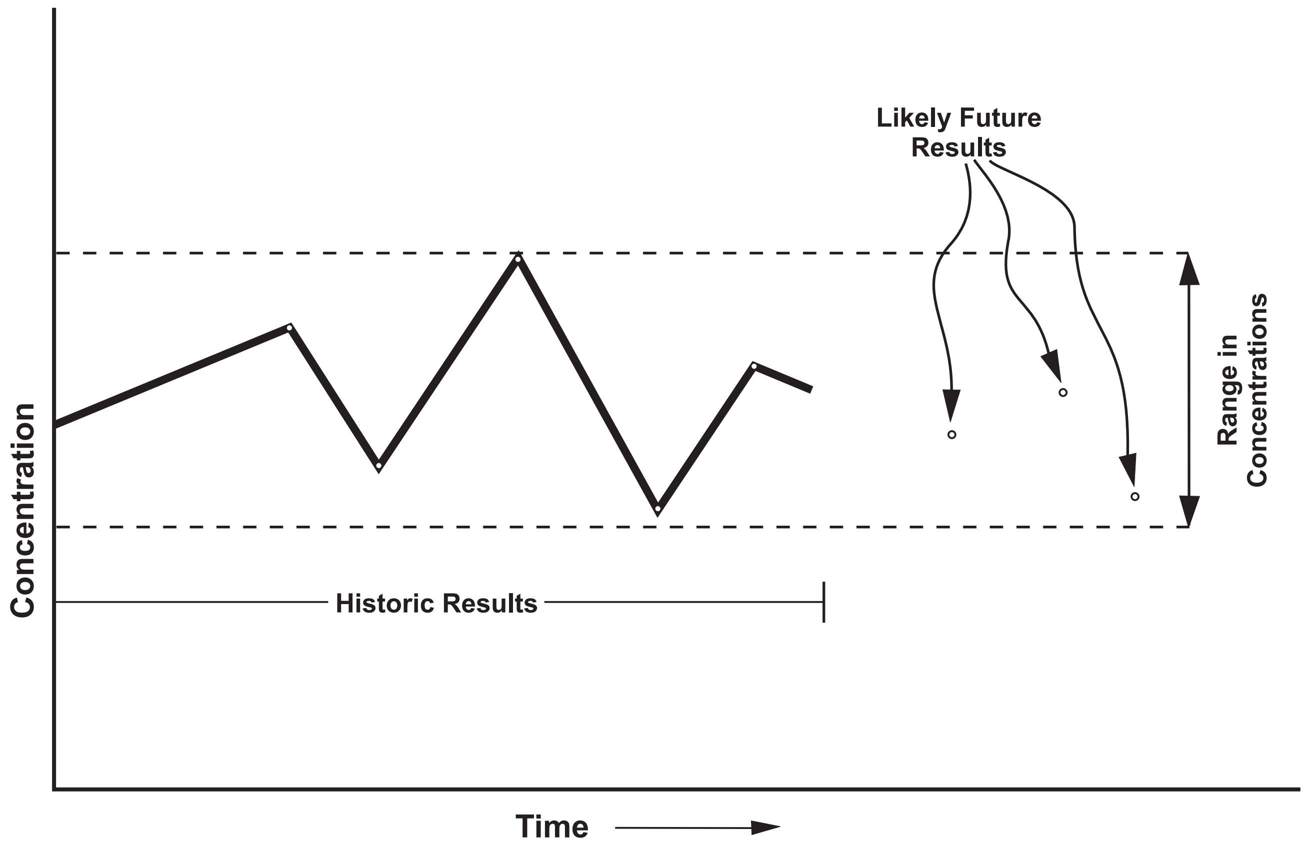


FIGURE 5.3

CONCEPTUAL REPRESENTATION OF CONTINUED MONITORING AT LOCATION WHERE NO TEMPORAL TREND IN CONCENTRATIONS IS PRESENT

Long-Term Monitoring Optimization
Wash King Laundry Superfund Site

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FIGURE 5.4
TEMPORAL TREND DECISION RATIONALE FLOWCHART
LONG-TERM MONITORING NETWORK OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

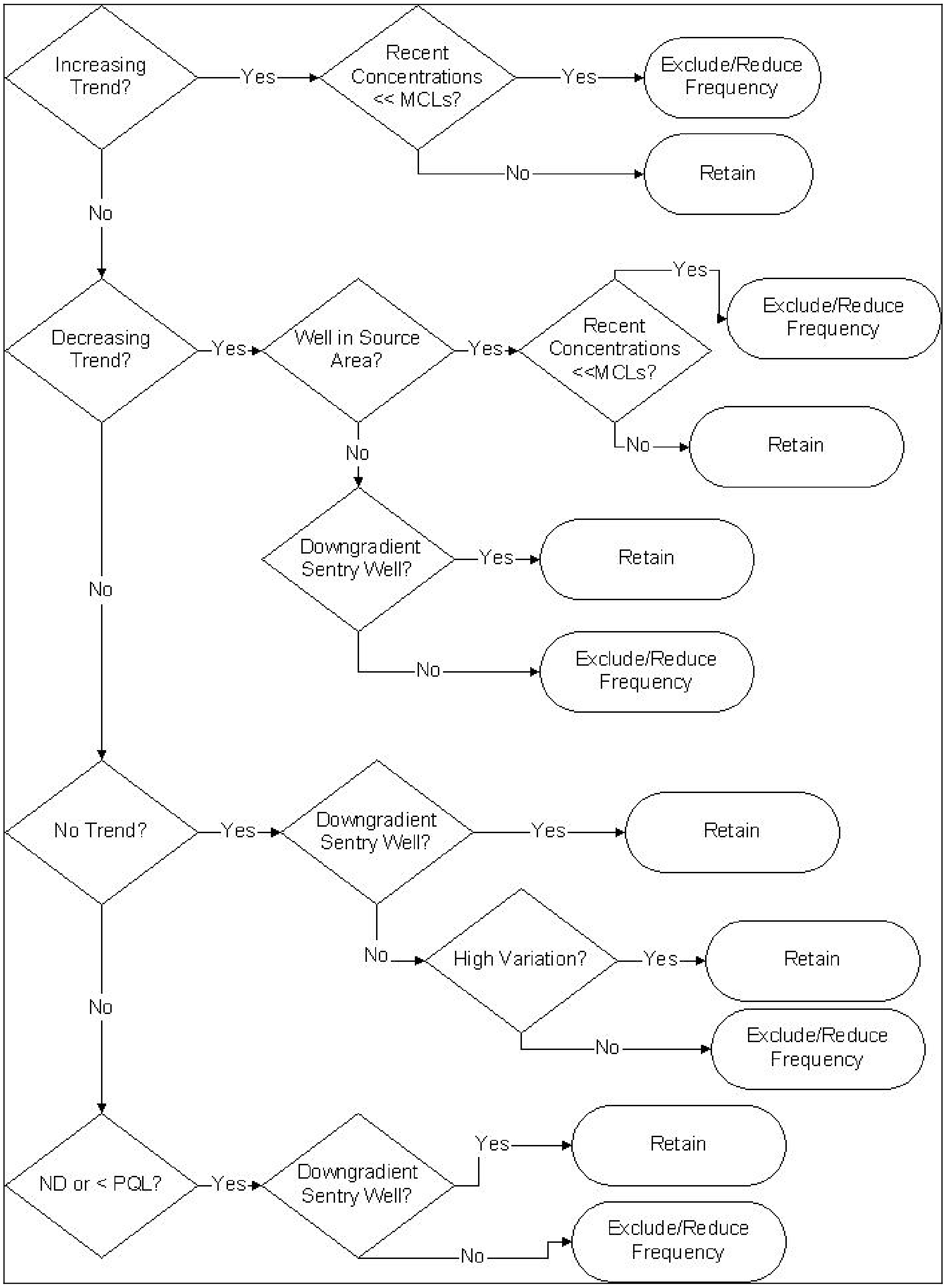


TABLE 5.1

TEMPORAL TREND ANALYSIS OF GROUNDWATER MONITORING RESULTS

LONG-TERM MONITORING OPTIMIZATION

WASH KING LAUNDRY SUPERFUND SITE

Well Name	Hydraulic Unit	Relative Location	Number of Results	PCE	TCE	cis-DCE	Exclude/ Reduce	Retain	Rationale
EW-1	Extraction	Downgradient	42	Decreasing	No Trend	ND	X		Decreasing PCE > standard, low variation TCE downgradient.
EW-2	Extraction	Downgradient	40	Increasing	*Decreasing*	*Decreasing*		X	Increasing PCE downgradient >> standard.
EW-4	Extraction	Downgradient	42	Decreasing	Decreasing	*Decreasing*	X		Decreasing PCE downgradient near standard. TCE and DCE recent NDs.
EW-5	Extraction	Downgradient	42	Decreasing	Increasing	Decreasing		X	Increasing TCE > standard downgradient.
EW-6	Extraction	Downgradient	42	Decreasing	*No Trend*	*Decreasing*	X		Decreasing PCE > standard and low variation TCE downgradient.
MW-101D	Deep	Downgradient	10	Decreasing	Probably Decreasing	ND	X		Decreasing trend in PCE > standard vertically downgradient.
MW-101S	Shallow	Source	9	No Trend	*No Trend*	ND		X	TCE jump from ND >> standard in most recent sampling event. Low variation PCE > standards in source area.
MW-205D	Deep	Downgradient	11	No Trend	No Trend	Decreasing	X		Low variation PCE and TCE downgradient. Decreasing DCE << standard.
MW-205S	Shallow	Downgradient	11	No Trend	*Probably Decreasing*	*No Trend*		X	High variation PCE downgradient.
MW-207D	Deep	Downgradient	10	No Trend	ND	ND	X		Low variation PCE < standards downgradient.
MW-207S	Shallow	Downgradient	10	No Trend	ND	ND	X		Low variation PCE < standards downgradient.
MW-208	Shallow	Crossgradient	11	ND	ND	ND	X		Non-detect cross gradient.
MW-209	Shallow	Crossgradient	10	ND	ND	ND	X		Non-detect cross gradient.
MW-210	Shallow	Crossgradient	9	ND	ND	ND	X		Non-detect cross gradient.
MW-212D	Deep	Downgradient	10	No Trend	Decreasing	No Trend	X		Low variation PCE and DCE, decreasing TCE > standards downgradient.
MW-212S	Shallow	Downgradient	7	Decreasing	Decreasing	*Decreasing*	X		PCE decreasing > standard. TCE recent NDs.
MW-213D	Deep	Downgradient	12	Decreasing	*Probably Increasing*	ND		X	TCE jump from ND to > standard in most recent sampling event. Decreasing PCE > standard.
MW-213S	Shallow	Downgradient	12	No Trend	ND	ND	X		Low variation PCE > standard downgradient.
MW-301D	Deep	Crossgradient	7	ND	ND	ND	X		Non-detect cross gradient.
MW-301S	Shallow	Downgradient	6	Probably Decreasing	*No Trend*	ND	X		Decreasing PCE < standard downgradient. One detect of TCE < standard in 12/02.
MW-302	Deep	Downgradient	8	Probably Decreasing	ND	ND	X		PCE ND since 12/02. Decreasing or ND downgradient.
MW-303	Deep	Downgradient	8	Decreasing	*No Trend*	*Probably Increasing*		X	TCE jump from ND >> standard in most recent sampling event. Decreasing PCE > standard. One DCE dection <<standard in 8/05
MW-304D	Deep	Crossgradient	8	ND	ND	ND	X		Non-detect cross gradient.
MW-304I	Intermediate	Crossgradient	8	ND	ND	ND	X		Non-detect cross gradient.
MW-304S	Shallow	Downgradient	6	ND	ND	ND	X		Non-detect down gradient.
MW-305D	Deep	Downgradient Sentry	8	ND	ND	ND		X	Non-detect sentry well.
MW-305I	Intermediate	Downgradient Sentry	7	ND	ND	ND		X	Non-detect sentry well.
MW-305S	Shallow	Downgradient	8	No Trend	ND	ND	X		Low variation PCE downgradient < standards. TCE and DCE ND.
MW-3D	Deep	Crossgradient	11	Decreasing	*No Trend*	ND	X		Decreasing, low variation no trend down gradient. Recent NDs PCE & TCE.
MW-3S	Shallow	Crossgradient	10	ND	ND	ND	X		Non-detect cross gradient.
Wells Not Currently Sampled									
MW-103	Deep	Downgradient	3	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-104	Deep	Downgradient	1	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-105	Deep	Crossgradient	3	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-201	Shallow	Crossgradient	1	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-202	Shallow	Downgradient Sentry	2	<4meas	<4meas	<4meas		X	Downgradient sentry well.
MW-204D	Deep	Crossgradient	5	ND	ND	ND	X		Non-detect cross gradient.
MW-204S	Shallow	Crossgradient	5	ND	ND	ND	X		Non-detect cross gradient.
MW-206D	Deep	Downgradient	1	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-206S	Shallow	Downgradient	2	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-215	Shallow	Downgradient	5	No Trend	Probably Decreasing	ND	X		Low variation no trend or decreasing trends (TCE around standard) downgradient
MW-2D	Deep	Downgradient	3	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-4	Deep	Downgradient	2	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-8D	Deep	Crossgradient	1	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-8S	Shallow	Crossgradient	1	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-7S	Shallow	Crossgradient	0	<4meas	<4meas	<4meas			No recommendation. Fewer than 4 measurements.
MW-102D	Deep	Downgradient Sentry	0	<4meas	<4meas	<4meas		X	Downgradient sentry well.
MW-102S	Shallow	Downgradient Sentry	0	<4meas	<4meas	<4meas		X	Downgradient sentry well.

ND	= Constituent has not been detected during history of monitoring at inidcated well.
No Trend	= No statistically significant temporal trend in concentrations.
Increasing	= Statistically significant (>95% confidence) increasing trend in concentrations.
Probably Increasing	= Statistically significant (90-95% confidence) increasing trend in concentrations.
Decreasing	= Statistically significant (>95% confidence) decreasing trend in concentrations.
Probably Decreasing	= Statistically significant (90-95% confidence) decreasing trend in concentrations.
<4Meas	= Fewer than 4 measurements for COC.

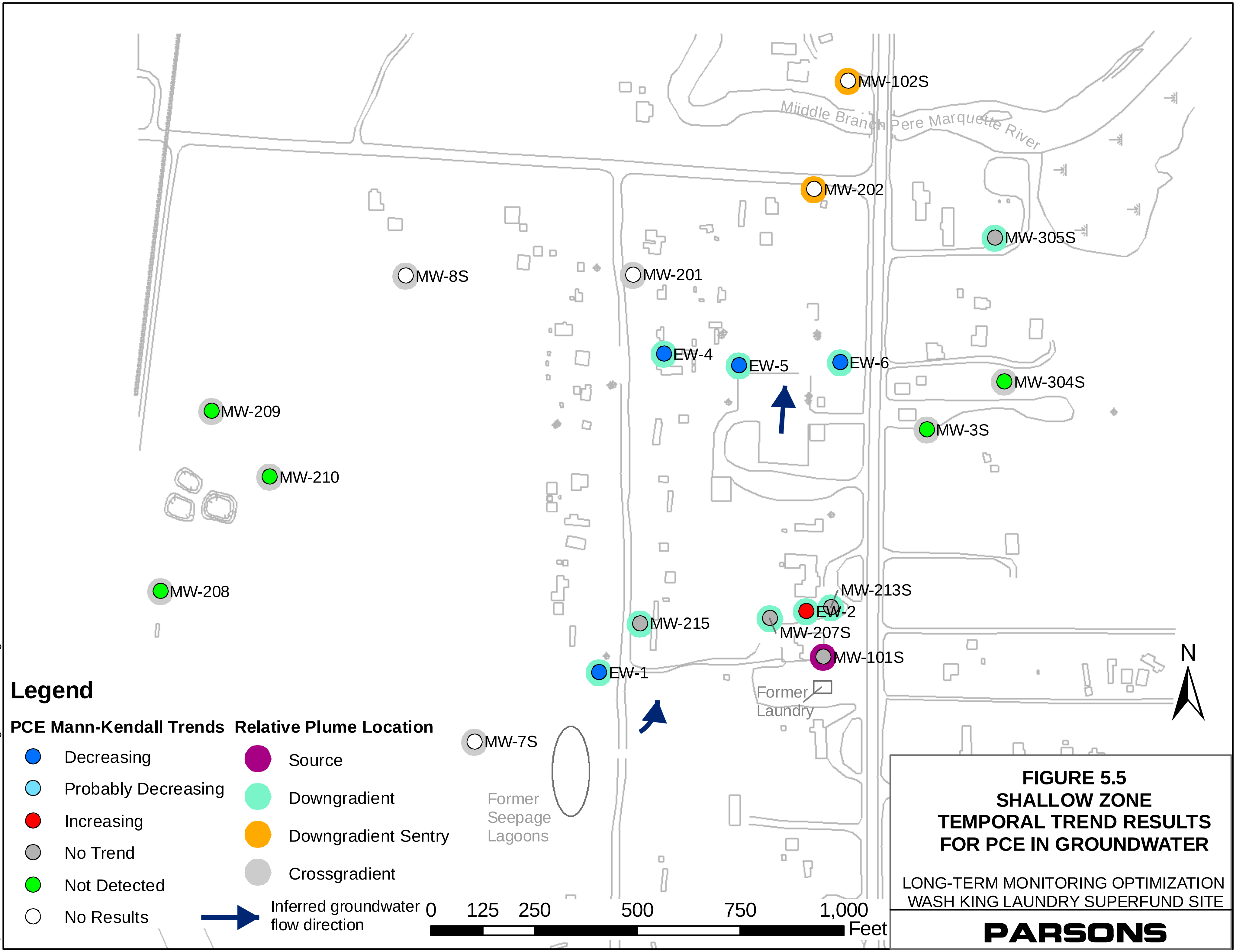
The color-coding of Table 5.1 entries denotes the presence or absence of temporal trends, and allows those monitoring points having nondetectable concentrations, decreasing or increasing concentrations, or no discernible trend in concentrations to be readily identified. Those trend that have confidence levels between 90 and 95% are indicated by the “probably increasing” and “probability decreasing” classifications (“increasing” and “decreasing” classifications correspond to confidence levels of over 95%). Trend results with bold borders indicate those analytical results that contained over 50% non-detections, historically. Although these chemical trends are not deserving of the “ND” classification and resulting decision process, decisions made based on these trends should take the high number of non-detects into consideration.

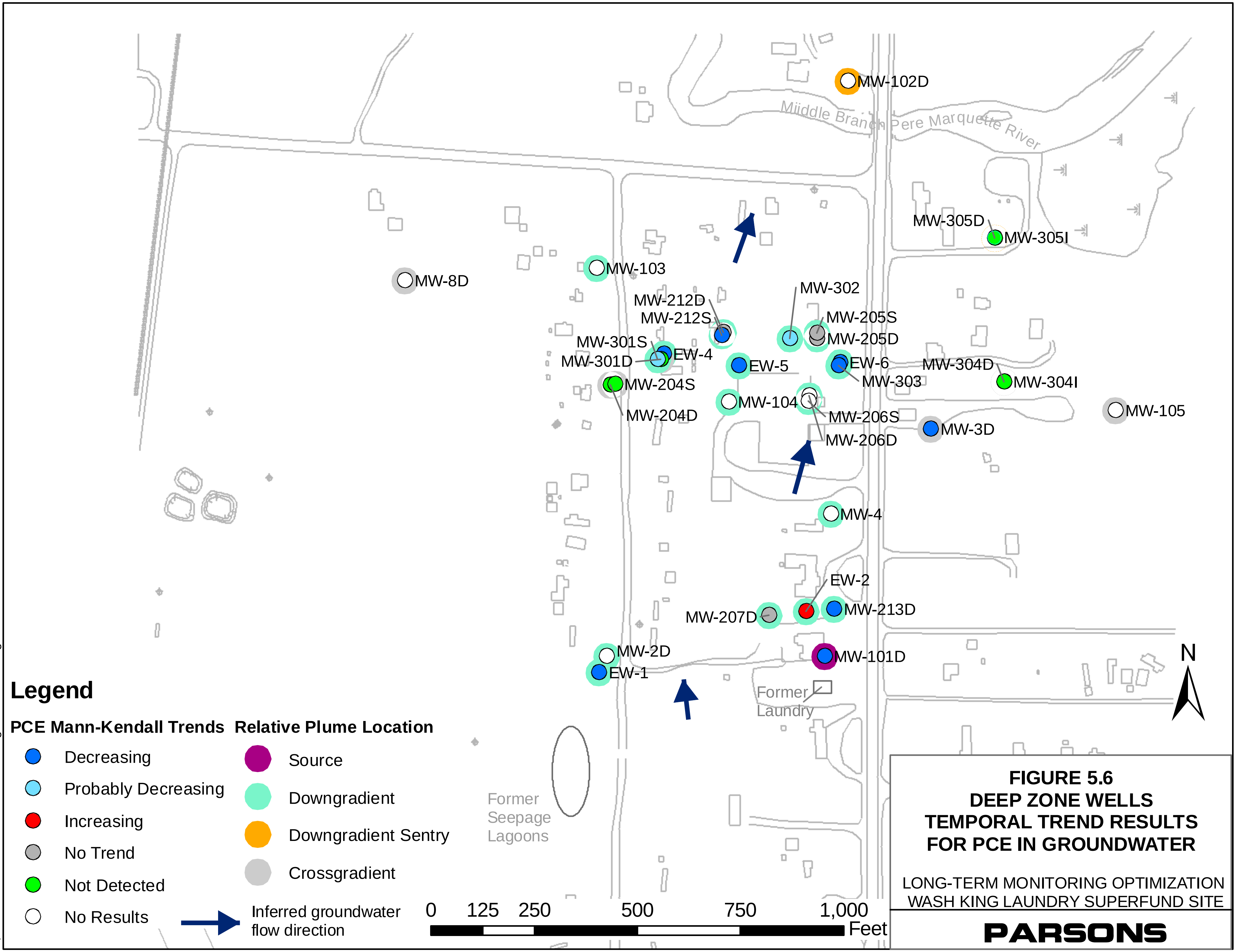
Fourteen of the seventeen monitoring wells that are not currently sampled had fewer than four analytical results for each of the COCs could not be analyzed using the Mann-Kendall trend analysis, and have a “<4Meas” designation. Figures 5.5 and 5.6 display the Mann-Kendall results for PCE thematically by well, along with the relative plume location for the shallow and deep zone wells, respectively.

The basis for the decision to exclude, reduce the sampling frequency, or retain a well in the monitoring program based on the value of its temporal information is described in the “Rationale” column of Table 5.1, and a flow chart of the decision logic applied to the temporal trend analysis results is presented on Figure 5.4. Trend results for PCE were given more weight than those from the other COCs, given its relatively higher impact; however, the most conservative trend was used in all cases (*e.g.*, if TCE trend resulted in a recommendation to retain a well, that well would be recommended for retention.)

Wells that have decreasing trends in a source area in which concentrations are above standards (*e.g.*, MW-101D) are valuable because they provide information on the effectiveness of the remedial actions performed to date and are thus recommended for retention in the monitoring system; conversely, wells located downgradient area that have either decreasing concentrations (*e.g.*, MW-212S, EW-4) will provide limited valuable temporal information in the future and are recommended for exclusion or reduced sampling. Downgradient wells with increasing concentrations (e.g., EW-2, EW-4 and MW-213D) are valuable because they identify areas where the plume may be expanding or where remedial systems are not effective. Wells with stable (low variation), ‘no trend’ results (*e.g.*, MW-205D and MW-305S) were recommended for exclusion or monitoring reduction because continued frequent sampling would not likely yield new information, while wells with highly variable COC concentrations (*e.g.*, wells MW-101S and MW-303) were recommended for retention.

Table 5.1 summarizes recommendations to retain 10 and exclude or reduce the frequency for 26 of the 36 wells analyzed in the temporal evaluation (not including the non-sentry wells with fewer than four measurements). The recommendations provided in Table 5.1 are based on the evaluation of ***temporal statistical results only***, and must be used in conjunction with the results of the qualitative and spatial evaluations to generate final recommendations regarding retention of monitoring points in the LTM program, and the frequency of monitoring at particular locations in Wash King.


MW-102S
Middle Branch Pere Marquette River
MW-202
MW-305S
MW-8S
MW-201
EW-4
EW-5
EW-6
MW-304S
MW-209
MW-3S
MW-210
MW-208
MW-213S
EW-2
MW-215
MW-207S
MW-101S
EW-1
Former Laundry
MW-7S
Former Seepage Lagoons
N
Legend
PCE Mann-Kendall Trends
Decreasing
Probably Decreasing
Increasing
No Trend
Not Detected
No Results
Relative Plume Location
Source
Downgradient
Downgradient Sentry
Crossgradient
Inferred groundwater flow direction
0 125 250 500 750 1,000 Feet
FIGURE 5.5
SHALLOW ZONE
TEMPORAL TREND RESULTS
FOR PCE IN GROUNDWATER
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE
PARSONS
S:/es/remed/LTMO/USACE/WashKing/GIS/WashKingWells.mxd cen 12/14/05



MW-102D
Middle Branch Pere Marquette River
MW-305D
MW-305I
MW-8D
MW-103
MW-302
MW-212D
MW-212S
MW-205S
MW-205D
MW-301S
EW-4
MW-301D
EW-5
EW-6
MW-304D
MW-304I
MW-204S
MW-303
MW-104
MW-105
MW-204D
MW-206S
MW-3D
MW-206D
MW-4
EW-2
MW-207D
MW-213D
MW-2D
MW-101D
EW-1
Former Laundry
N
Legend
PCE Mann-Kendall Trends
Decreasing
Probably Decreasing
Increasing
No Trend
Not Detected
No Results
Relative Plume Location
Source
Downgradient
Downgradient Sentry
Crossgradient
Inferred groundwater flow direction
Former Seepage Lagoons
0
125
250
500
750
1,000
Feet
FIGURE 5.6
DEEP ZONE WELLS
TEMPORAL TREND RESULTS
FOR PCE IN GROUNDWATER
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE
PARSONS
S:/es/remed/LTMO/USACE/WashKing/GIS/WashKingWells.mxd cen 12/14/05

SECTION 6

SPATIAL STATISTICAL EVALUATION

Spatial statistical techniques also can be applied to the design and evaluation of groundwater monitoring programs to assess the quality of information generated during monitoring and to evaluate monitoring networks. Geostatistics, or the theory of regionalized variables (Clark, 1987; Rock, 1988; American Society of Civil Engineers Task Committee on Geostatistical Techniques in Hydrology, 1990a and 1990b), is concerned with variables having values dependent on location, and which are continuous in space but vary in a manner too complex for simple mathematical description. Geostatistics is based on the premise that the differences in values of a spatial variable depend only on the distances between sampling locations, and the relative orientations of sampling locations – that is, the values of a variable (*e.g.*, chemical concentration) measured at two locations that are spatially close together – will be more similar than values of that variable measured at two locations that are far apart.

6.1 GEOSTATISTICAL METHODS FOR EVALUATING MONITORING NETWORKS

Ideally, application of geostatistical methods to the results of the groundwater monitoring program at Wash King could be used to estimate COC concentrations at every point within the dissolved contaminant plume, and also could be used to generate estimates of the "error," or uncertainty, associated with each estimated concentration value. Thus, the monitoring program could be optimized by using available information to identify those areas having the greatest uncertainty associated with the estimated plume extent and configuration. Conversely, sampling points could be successively eliminated from simulations, and the resulting uncertainty examined, to evaluate if significant loss of information (represented by increasing error or uncertainty in estimated chemical concentrations) occurs as the number of sampling locations is reduced. Repeated application of geostatistical estimating techniques, using tentatively identified sampling locations, then could be used to generate a sampling program that would provide an acceptable level of uncertainty regarding the distribution of COCs with the minimum possible number of samples collected. Furthermore, application of geostatistical methods can provide unbiased representations of the distribution of COCs at different locations in the subsurface, enabling the extent of COCs to be evaluated more precisely. The application of geostatistics at hazardous, toxic, and radioactive waste sites is discussed in greater depth in USACE Engineer Technical Letter 1110-1-175 (1997).

Fundamental to geostatistics is the concept of semivariance [$\gamma(h)$], which is a measure of the spatial dependence between sample variables (*e.g.*, chemical concentrations) in a specified direction. Semivariance is defined for a constant spacing between samples (*h*) by:

$$\gamma(h) = \frac{1}{2n} \sum [g(x) - g(x + h)]^2 \qquad \textit{Equation 6-1}$$

Where:

$\gamma(h)$ = semivariance calculated for all samples at a distance *h* from each other;

$g(x)$ = value of the variable in sample at location *x*;

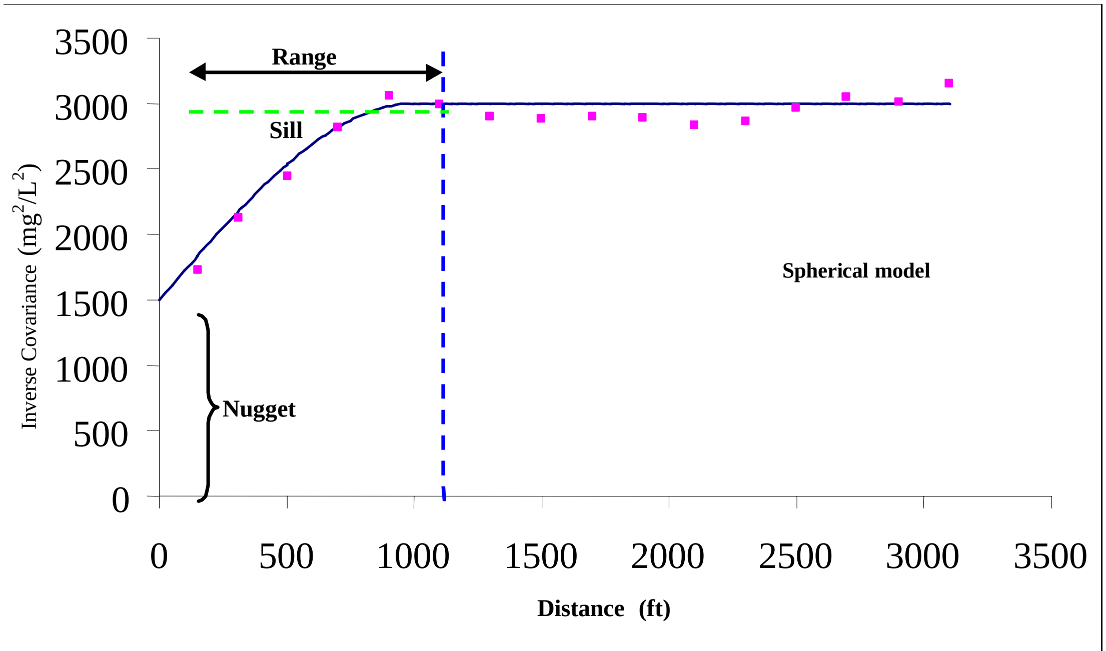
$g(x + h)$ = value of the variable in sample at a distance *h* from sample at location *x*; and

n = number of samples in which the variable has been determined.

Semivariograms (plots of $\gamma(h)$ versus *h*) are a means of depicting graphically the range of distances over which, and the degree to which, sample values at a given point are related to sample values at adjacent, or nearby, points, and conversely, indicate how close together sample points must be for a value determined at one point to be useful in predicting unknown values at other points. For $h = 0$, for example, a sample is being compared with itself, so normally $\gamma(0) = 0$ (the semivariance at a spacing of zero, is zero), except where a so-called nugget effect is present (Figure 6.1), which implies that sample values are highly variable at distances less than the sampling interval. Analytical variability and sampling error can contribute to the nugget. As the distance between samples increases, sample values become less and less closely related, and the semivariance therefore increases, until a “sill” is eventually reached, where $\gamma(h)$ equals the overall variance (*i.e.*, the variance around the average value). The sill is reached at a sample spacing called the “range of influence,” beyond which sample values are not related. Only values between points at spacings less than the range of influence can be predicted; but within that distance, the semivariogram provides the proper weightings, which apply to sample values separated by different distances.

When a semivariogram is calculated for a variable over an area (*e.g.*, concentrations of PCE in the Wash King shallow zone), an irregular spread of points across the semivariogram plot is the usual result (Rock, 1988). One of the most subjective tasks of geostatistical analysis is to identify a continuous, theoretical semivariogram model that most closely follows the real data. Fitting a theoretical model to calculated semivariance points is accomplished by trial-and-error, rather than by a formal statistical procedure (Davis, 1986; Clark, 1987; Rock, 1988). If a "good" model fit results, then $\gamma(h)$ (the semivariance) can be confidently estimated for any value of *h*, and not only at the sampled points.

FIGURE 6.1
IDEALIZED SEMIVARIOGRAM MODEL
LONG-TERM MONITORING NETWORK OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE



6.2 SPATIAL EVALUATION OF THE MONITORING NETWORK AT WASH KING

PCE was used as the indicator chemical for the spatial evaluation of the groundwater monitoring network in the Wash King shallow and deep zones because of its relative prevalence and spatial distribution in the groundwater at Wash King. The kriging evaluation examines a two-dimensional spatial "snapshot" of the data. Two separate kriging analyses were conducted for the Wash King shallow and deep hydrogeologic zones. Typically, only those wells included in the most recent sampling event "snapshot" are included in the kriging evaluation. However, the spatial evaluation has a lower limit of 11 wells; thus, the shallow aquifer does not have enough currently sampled wells to conduct a spatial statistical evaluation. As an alternative, the most recent results (including those prior to 2005) were included for the spatial analysis. The majority of the non-active wells have no detected PCE, and would likely still have no detected PCE had they been measured in 2005. In addition, the changes in concentrations in wells that have been sampled in 2003 and 2005 were minor, and in most cases concentrations decreased. The few wells with detected concentrations in 2003 (see Table 3.3) could potentially have had different measured concentrations in 2005, so the kriging analysis may have been slightly altered. However, although spatial results should be evaluated while considering these assumptions, this evaluation has the advantage of considering the relative spatial importance of all of the area wells. 15 shallow aquifer wells and 24 deep aquifer wells were used in the kriging analyses. Wells MW-304D, MW-305D and MW-102D were not used in the deep well set because they are screened significantly below the other deep wells; MW-304D and MW-305D both have associated “intermediate” wells that would be more appropriate to include, as shown in Figure 2.3.

The commercially available geostatistical software package Geostatistical Analyst™ (an extension to the ArcView® geographic information system [GIS] software package) (Environmental Systems Research Institute, Inc. [ESRI], 2001) was used to develop semivariogram models depicting the spatial variation in the shallow and deep aquifers for PCE in groundwater.

As semivariogram models were calculated for each scenario (Equation 6-1), considerable scatter of the data was apparent during fitting of the models. Several data transformations (including a log transformation) were attempted to obtain a representative semivariogram model. Ultimately, the concentration data were transformed to “rank statistics,” in which, for example, the 24 wells in the deep zone were ranked from 1 (lowest concentration) to 24 (highest concentration) according to their most recent PCE concentrations. Tie values were assigned the median rank of the set of ranked values; for example, if five wells had non-detected concentrations, they would each be ranked “3”, the median of the set of ranks: [1,2,3,4,5]. Transformations of this type can be less sensitive to outliers, skewed distributions, or clustered data than semivariograms based on raw concentration values, and thus may enable recognition and description of the underlying spatial structure of the data in cases where ordinary data are too “noisy.”

The rank statistics were used to develop semivariograms that most accurately modeled the spatial distribution of the data in the two scenarios. The parameters for best-fit semivariograms for the two spatial evaluations are listed in Table 6.1.

TABLE 6.1
BEST-FIT SEMIVARIOGRAM MODEL PARAMETERS
LONG-TERM MONITORING NETWORK OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Parameter	Shallow Zone	Deep Zone
Model	Circular	Circular
Range (ft)	1000	600
Sill	17.5	45
Nugget	0	15

After the semivariogram models were developed, they were used in the kriging system implemented by the Geostatistical Analyst™ software package (ESRI, 2001) to develop two-dimensional kriging realizations (estimates of the spatial distribution of PCE in groundwater at Wash King), and to calculate the associated kriging prediction standard errors. The median kriging standard deviation was obtained from the standard errors calculated using the entire monitoring network for each scenario (*e.g.*, the 24 wells in the deep zone). Next, each of the wells was sequentially removed from the network, and for each resulting well network configuration, a kriging realization was completed using the

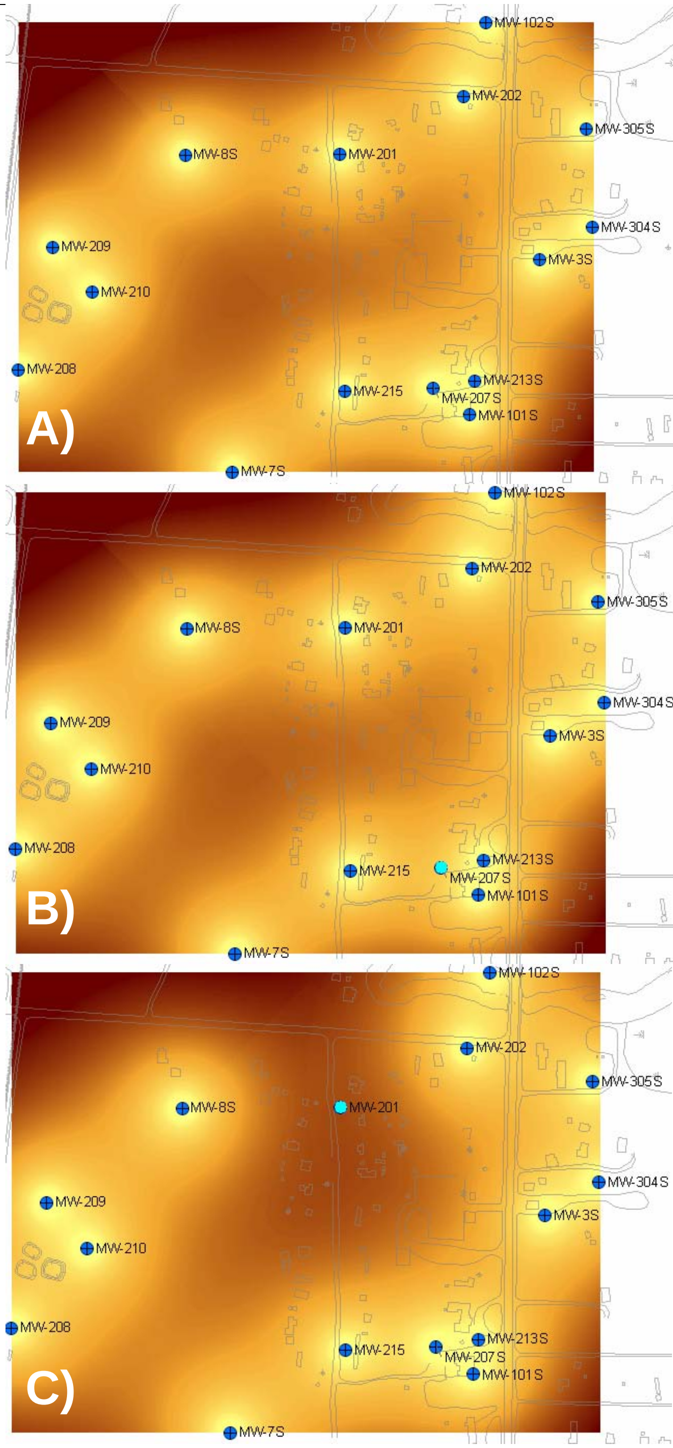
COC concentration rankings from the remaining wells. The "missing-well" monitoring network realizations were used to calculate prediction standard errors, and the median kriging standard deviations were obtained for each "missing-well" realization and compared with the median kriging standard deviation for the "base-case" realization (obtained using the complete monitoring network), as a means of evaluating the amount of information loss (as indicated by increases in kriging error) resulting from the use of fewer monitoring points.

Figure 6.2 illustrates an example of the spatial-evaluation procedure by showing kriging prediction standard-error maps for three kriging realizations for the 15 shallow zone wells. Each map shows the predicted standard error associated with a given group of wells based on the semivariogram parameters discussed above. Lighter colors represent areas with lower spatial uncertainty, and darker colors represent areas with higher uncertainty; regions in the vicinity of wells (*i.e.*, data points) have the lowest associated uncertainty. Map A on Figure 6.2 shows the predicted standard error map for the "base-case" realization in which all 15 wells are included. Map B shows the realization in which well MW-207S was removed from the monitoring network, and Map C shows the realization in which MW-201 was removed. Figure 6.2 shows that when a well is removed from the network, the predicted standard error in the vicinity of the missing well increases (as indicated by a darkening of the shading in the vicinity of that well). If a "removed" (missing) well is in an area with several other wells (*e.g.*, well MW-207S; Map B on Figure 6.2), the predicted standard error may not increase as much as if a well (*e.g.*, MW-201; Map C) is removed from an area with fewer surrounding wells.

Based on the kriging evaluation, each well received a relative value of spatial information "test statistic" calculated from the ratio of the median "missing well" error to median "basecase" error. If removal of a particular well from the monitoring network caused very little change in the resulting median kriging standard deviation, the test statistic equals one, and that well was regarded as contributing only a limited amount of information to the LTM program. Likewise, if removal of a well from the monitoring network produced larger increases in the kriging standard deviation (typically more than 1 percent), this was regarded as an indication that the well contributes a relatively greater amount of information and is relatively more important to the monitoring network. At the conclusion of the kriging realizations, each well was ranked from 1 (providing the least information) to the number of wells included in the zone analysis (providing the most information), based on the amount of information (as measured by changes in median kriging standard deviation) the well contributed toward describing the spatial distribution of PCE, as shown in Tables 6.2 and 6.3. Wells providing the least amount of information represent possible candidates for exclusion from the monitoring network at Wash King.

6.3 SPATIAL STATISTICAL EVALUATION RESULTS

Figures 6.3 and 6.4 and Tables 6.2 and 6.3 present the test statistics and associated rankings of the evaluated subsets of monitoring locations for PCE in the shallow and deep zones, respectively. The wells are ranked from least to most spatially relevant based on the relative value of the associated recent COC information provided by each well, as calculated based on the kriging realizations. Examination of these results indicate that



A) Basecase (All wells)

B) Missing well MW-207S: relative small change in spatial uncertainty

C) Missing well MW-201: relative large change in spatial uncertainty

Legend

Well missing from kriging realization

Predicted Standard Error Map

Less spatial uncertainty

Greater spatial uncertainty

FIGURE 6.2

IMPACT OF MISSING WELLS ON PREDICTED STANDARD ERROR

LONG TERM MONITORING OPTIMIZATION
BUNKER HILL MINING AND METALLURGICAL COMPLEX
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

TABLE 6.2

RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF PCE IN THE SHALLOW ZONE

LONG-TERM MONITORING OPTIMIZATION

WASH KING LAUNDRY SUPERFUND SITE

Well Name [a/]	Kriging Metric	Kriging Ranking [b/]	Exclude	Retain
MW-304S	1.0025	1	X	
MW-207S	1.0050	2	X	
MW-213S	1.0072	3	X	
MW-208	1.0073	4	X	
MW-101S	1.0122	5	--[c/]	--
MW-102S	1.0160	6	--	--
MW-209	1.0193	7	--	--
MW-305S	1.0210	8	--	--
MW-210	1.0252	9	--	--
MW-7S	1.0303	10	--	--
MW-202	1.0336	11	--	--
MW-215	1.0436	12		X
MW-8S	1.0580	13		X
MW-201	1.0702	14		X
MW-3S	1.1400	15		X

[a/] Well set includes 15 "shallow zone" wells designated in Table 2.1.
[b/] 1= least relative amount of information; 15= most relative amount of information.
[c/] Well in the “intermediate” range; received no recommendation for excludsion or retention. (see Section 6.2).

TABLE 6.3

RESULTS OF GEOSTATISTICAL EVALUATION RANKING OF WELLS BY RELATIVE VALUE OF PCE IN THE LOWER ZONE

LONG-TERM MONITORING OPTIMIZATION

WASH KING LAUNDRY SUPERFUND SITE

Well Name [a/]	Kriging Metric	Kriging Ranking [b/]	Exclude	Retain
MW-301D	0.9998	1	X	
MW-301S	0.9998	2	X	
MW-206D	0.9999	3	X	
MW-206S	1.0000	4	X	
MW-303	1.0001	5	X	
MW-212S	1.0003	6	X	
MW-205D	1.0005	8[c/]	X	
MW-212D	1.0005	8	X	
MW-302	1.0005	8	X	
MW-101D	1.0011	10	--[d/]	--
MW-205S	1.0013	11	--	--
MW-204S	1.0016	12	--	--
MW-204D	1.0022	13	--	--
MW-213D	1.0024	14	--	--
MW-104	1.0032	15	--	--
MW-304I	1.0035	16	--	--
MW-4	1.0041	17	--	--
MW-3D	1.0062	18		X
MW-207D	1.0089	19		X
MW-105	1.0123	20		X
MW-2D	1.0139	21		X
MW-8D	1.0159	22		X
MW-103	1.0195	23		X
MW-305I	1.0312	24		X

[a/] Well set includes "deep zone" wells designated in Table 2.1, excluding MW-304D, MW-305D, and MW-102D.
[b/] 1= least relative amount of information; 24= most relative amount of information.
[c/] Tie values receive the median ranking of the set.
[d/] Well in the “intermediate” range; received no recommendation for excludsion or retention.
(see Section 6.2).

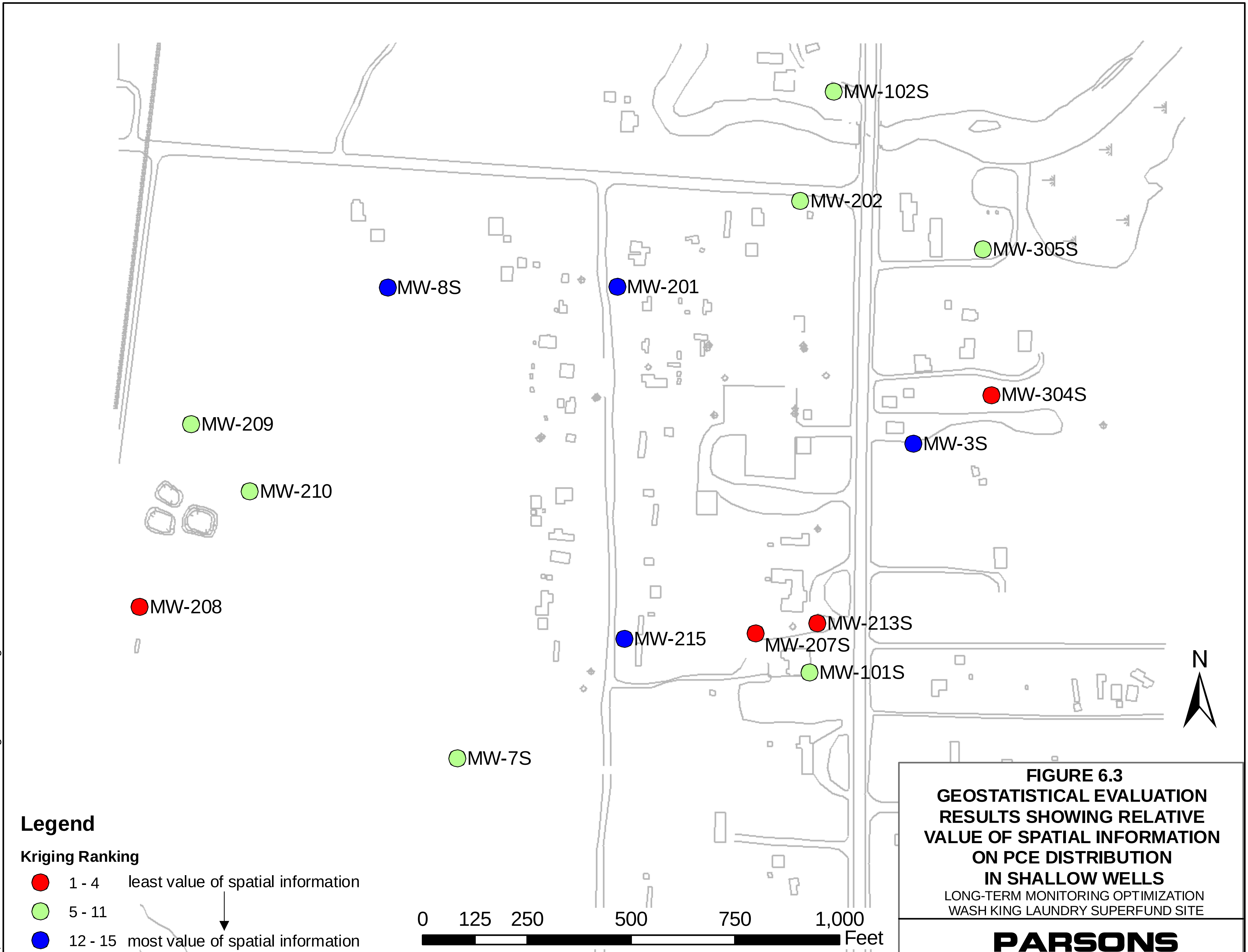


FIGURE 6.3
GEOSTATISTICAL EVALUATION RESULTS SHOWING RELATIVE VALUE OF SPATIAL INFORMATION ON PCE DISTRIBUTION IN SHALLOW WELLS
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

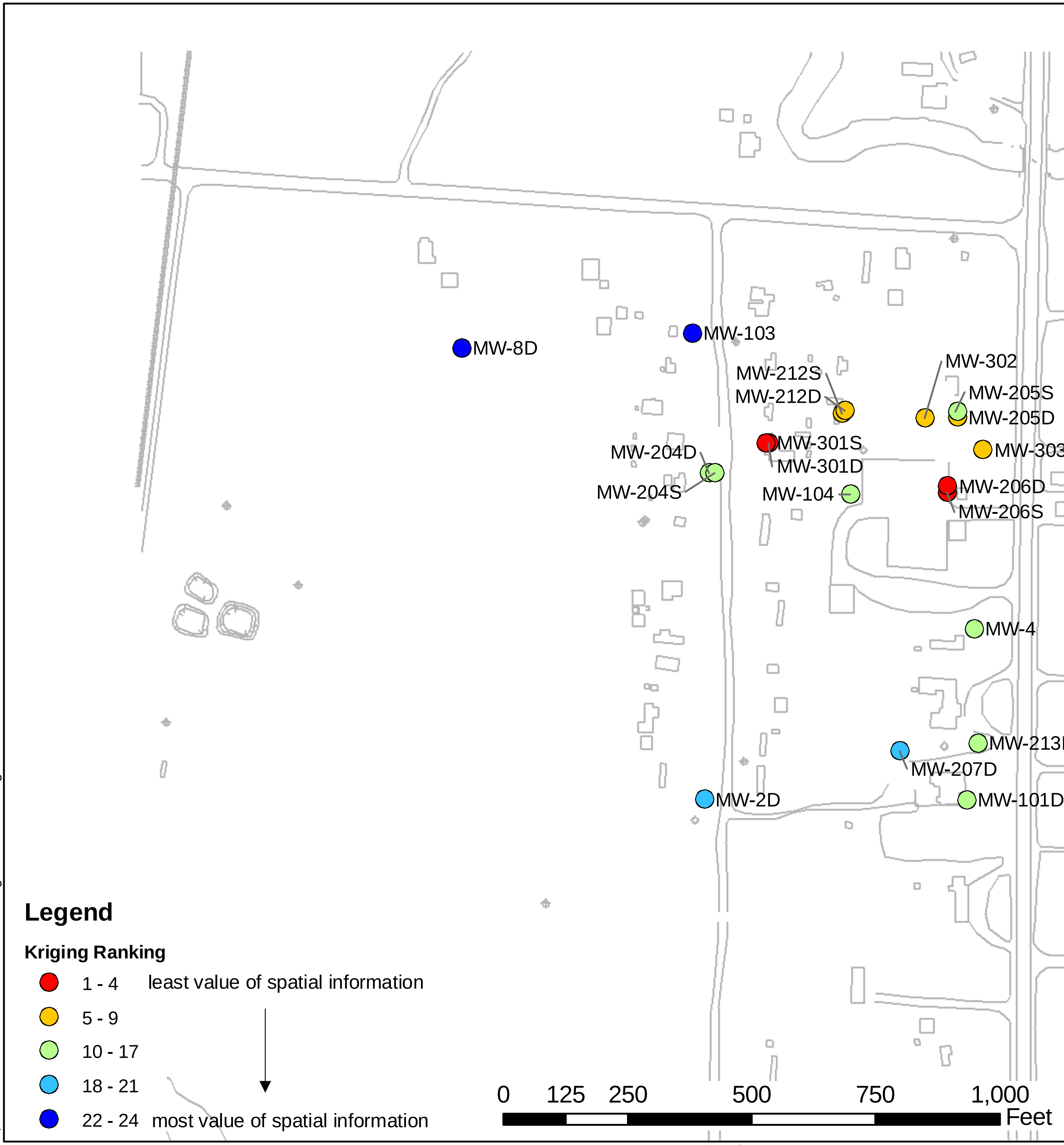


FIGURE 6.4
GEOSTATISTICAL EVALUATION RESULTS SHOWING RELATIVE VALUE OF SPATIAL INFORMATION ON PCE DISTRIBUTION IN DEEP WELLS

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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monitoring wells in close proximity to several other monitoring wells (*e.g.*, red color coding on Figures 6.3 and 6.4) generally provide relatively lesser amounts of information than do wells at greater distances from other wells or wells located in areas having limited numbers of monitoring points (*e.g.*, blue color coding on Figures 6.3 and 6.4). This is intuitively obvious, but the analysis allows the most valuable and least valuable wells to be identified quantitatively. For example, Table 6.3 identifies the wells ranked 8 and below that provide the relative least amount of information, and the wells ranked at or above 18 that provide the greatest amount of relative information regarding the occurrence and distribution of PCE in groundwater among those wells in the lower zone. The lowest-ranked wells are potential candidates for exclusion from the Wash King groundwater monitoring program, and the highest-ranked wells are candidates for retention in the monitoring program; intermediate-ranked wells receive no recommendation for removal or retention in the monitoring program based on the spatial analysis. The recommendations provided in Tables 6.2 and 6.3 are based on the evaluation of ***spatial statistical results only***, and must be used in conjunction with the results of the qualitative and temporal evaluations to generate final recommendations regarding retention of monitoring points in the LTM program, and the frequency of monitoring at particular locations in Wash King. Also note that due to the limitations of the data (e.g., 2005 results are not available for all wells) the qualitative and temporal results are given more weight in the combined analysis.

SECTION 7

SUMMARY OF LONG-TERM MONITORING OPTIMIZATION EVALUATION

Forty-nine groundwater monitoring and extraction wells at Wash King were evaluated qualitatively using hydrogeologic, hydrologic, and contaminant information, and quantitatively using temporal and spatial statistical techniques. As each tier of the evaluation was performed, monitoring points that provide relatively greater amounts of information regarding the occurrence and distribution of COCs in groundwater were identified, and were distinguished from those monitoring points that provide relatively lesser amounts of information. In this section, the results of the evaluations are combined to generate a refined monitoring program that potentially could provide information sufficient to address the primary objectives of monitoring, at reduced cost. Monitoring points not retained in the refined monitoring network could be removed from the monitoring program with relatively little loss of information. It should be noted that development of an optimized long-term monitoring program for the site would benefit from a better understanding of the hydraulic effects of the current pump-and-treat system. In addition, further evaluation of how the persistence of the VOC plume could be reduced (e.g., via additional source removal efforts) should be considered.

7.1 GROUNDWATER MONITORING NETWORK SUMMARY

The results of the qualitative, temporal, and spatial evaluations for the groundwater monitoring and extraction wells are summarized in Table 7.1, along with the final recommendations for sampling point retention or exclusion and sampling frequency. These final recommendations are also shown on Figures 7.1 and 7.2. The results of the evaluations were combined and summarized in accordance with the decision logic shown on Figure 7.3 and described below.

1. Each well retained in the monitoring network on the basis of the qualitative hydrogeologic evaluation was recommended to be retained in the refined monitoring program.

2. Those wells recommended for exclusion from the monitoring program on the basis of all three evaluations, or on the basis of the qualitative and temporal evaluations (with no recommendation resulting from the spatial evaluation) were recommended for removal from the monitoring program.

3. If a well was recommended for removal based on the qualitative evaluation and recommended for retention based on the temporal or spatial evaluation, the final recommendation was based on a case-by-case review of well information.

TABLE 7.1
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE WASH KING GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

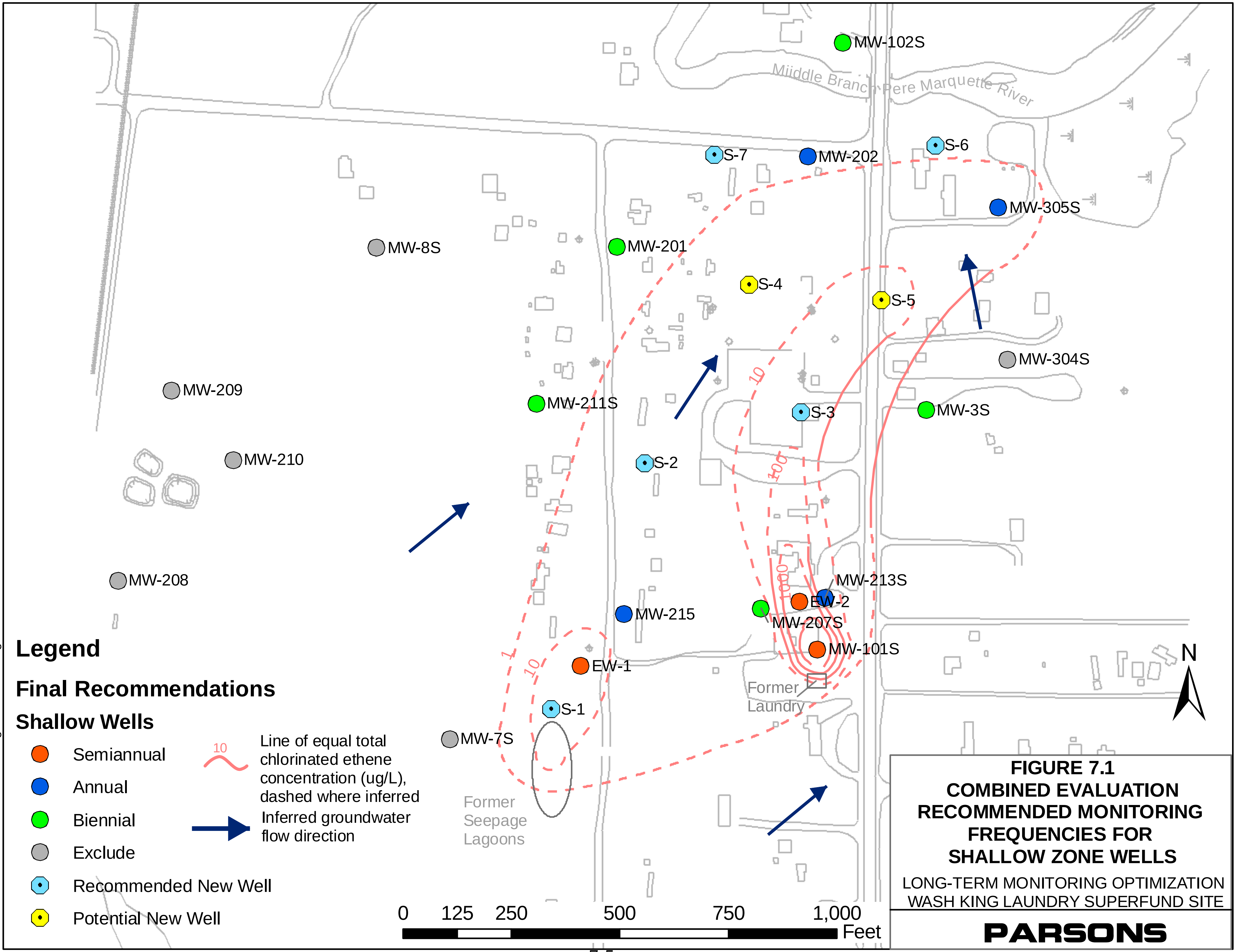
Well Name	Zone	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
EW-1	Extraction	Quarterly		X	Semiannual	X		Not Analyzed			X	Semiannual	Temporal statistics confirm qualitative evaluation.
EW-2	Extraction	Quarterly		X	Semiannual		X	Not Analyzed			X	Semiannual	Qualitative overrides statistical evaluation. (See Table 4.3)
EW-4	Extraction	Quarterly		X	Semiannual	X		Not Analyzed			X	Semiannual	Temporal statistics confirm qualitative evaluation.
EW-5	Extraction	Quarterly		X	Semiannual		X	Not Analyzed			X	Semiannual	Qualitative overrides statistical evaluation. (See Table 4.3)
EW-6	Extraction	Quarterly		X	Semiannual	X		Not Analyzed			X	Semiannual	Temporal statistics confirm qualitative evaluation.
MW-101D	Deep	Semi-annual		X	Annual	X		No Recommendation			X	Annual	Statistics confirm qualitative evaluation.
MW-101S	Shallow	Semi-annual		X	Annual		X	No Recommendation			X	Semiannual	Frequency modified based on temporal statistics.
MW-205D	Deep	Semi-annual		X	Annual	X		X			X	Annual	Temporal statistics confirm qualitative evaluation.
MW-205S	Deep	Semi-annual		X	Annual		X	No Recommendation			X	Annual	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-207D	Deep	Semi-annual		X	Biennial	X			X		X	Biennial	Statistics confirm qualitiative evaluation.
MW-207S	Shallow	Semi-annual		X	Biennial	X		X			X	Biennial	Statistics confirm qualitiative evaluation.
MW-208	Shallow	Semi-annual	X		Exclude	X		X		X		Exclude	Statistics confirm qualitiative evaluation.
MW-209	Shallow	Semi-annual	X		Exclude	X		No Recommendation		X		Exclude	Temporal statistics confirm qualitiative evaluation.
MW-210	Shallow	Semi-annual	X		Exclude	X		No Recommendation		X		Exclude	Temporal statistics confirm qualitiative evaluation.
MW-212D	Deep	Semi-annual		X	Annual	X		X			X	Annual	Temporal statistics confirm qualitiative evaluation.
MW-212S	Deep	Semi-annual		X	Annual	X		X			X	Annual	Temporal statistics confirm qualitiative evaluation.
MW-213D	Deep	Semi-annual		X	Annual		X	No Recommendation			X	Semiannual	Frequency modified based on temporal statistics.
MW-213S	Shallow	Semi-annual		X	Annual	X		X			X	Annual	Statistics confirm qualitiative evaluation.
MW-301D	Deep	Semi-annual	X		Exclude	X		X		X		Exclude	Statistics confirm qualitiative evaluation.
MW-301S	Deep	Semi-annual	X		Exclude	X		X		X		Exclude	Statistics confirm qualitiative evaluation.
MW-302	Deep	Semi-annual	X		Exclude	X		X		X		Exclude	Statistics confirm qualitative evaluation.
MW-303	Deep	Semi-annual		X	Semiannual		X	X			X	Semiannual	Temporal statistics confirm qualitative evaluation; conditional retention as described in Table 4.3
MW-304D	Deep	Semi-annual	X		Exclude	X		Not Analyzed		X		Exclude	Temporal statistics confirm qualitiative evaluation.
MW-304I	Deep	Semi-annual	X		Exclude	X		No Recommendation		X		Exclude	Temporal statistics confirm qualitiative evaluation.
MW-304S	Shallow	Semi-annual	X		Exclude	X		X		X		Exclude	Statistics confirm qualitiative evaluation.
MW-305D	Deep	Semi-annual		X	Annual		X	Not Analyzed			X	Annual	Temporal statistics confirm qualitiative evaluation.
MW-305I	Deep	Semi-annual		X	Annual		X		X		X	Annual	Temporal statistics confirm qualitiative evaluation.
MW-305S	Shallow	Semi-annual		X	Annual	X		No Recommendation			X	Annual	Statistics confirm qualitative evaluation.
MW-3D	Deep	Semi-annual		X	Biennial	X			X		X	Biennial	Statistics confirm qualitative evaluation.
MW-3S	Shallow	Semi-annual		X	Biennial	X			X		X	Biennial	Statistics confirm qualitative evaluation.
Wells Not Currently Sampled													
MW-103	Deep	Not Sampled		X	Biennial	Not Analyzed			X		X	Biennial	Spatial statistics confirm qualitative evaluation.

TABLE 7.1
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE WASH KING GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Zone	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
MW-104	Deep	Not Sampled		X	Annual	Not Analyzed		No Recommendation			X	Annual	No statistical recommendations for well; final recommendations based on qualitative analysis.
MW-105	Deep	Not Sampled	X		Exclude	Not Analyzed			X	X		Exclude	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-201	Shallow	Not Sampled		X	Biennial	Not Analyzed			X		X	Biennial	Spatial statistics confirm qualitative evaluation; conditional frequency as described in Table 4.3.
MW-202	Shallow	Not Sampled		X	Annual		X	No Recommendation			X	Annual	Statistics confirm qualitative evaluation.
MW-204D	Deep	Not Sampled		X	Biennial	X		No Recommendation			X	Biennial	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-204S	Deep	Not Sampled		X	Biennial	X		No Recommendation			X	Biennial	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-206D	Deep	Not Sampled		X	Annual	Not Analyzed		X			X	Annual	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-206S	Deep	Not Sampled		X	Annual			X			X	Annual	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-211D	Deep	Not Sampled	X		Exclude	Not Analyzed		Not Analyzed		X		Exclude	No statistical recommendations for well; final recommendations based on qualitative analysis.
MW-211S	Shallow	Not Sampled		X	Biennial	Not Analyzed		Not Analyzed			X	Biennial	No statistical recommendations for well; final recommendations based on qualitative analysis.
MW-215	Shallow	Not Sampled		X	Annual	X			X		X	Annual	Spatial statistics confirm qualitative evaluation.
MW-2D	Deep	Not Sampled		X	Annual	Not Analyzed			X		X	Annual	Spatial statistics confirm qualitative evaluation.
MW-4	Deep	Not Sampled		X	Annual	Not Analyzed		No Recommendation			X	Annual	No statistical recommendations for well; final recommendations based on qualitative analysis.
MW-8D	Deep	Not Sampled	X		Exclude	Not Analyzed			X	X		Exclude	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-8S	Shallow	Not Sampled	X		Exclude	Not Analyzed			X	X		Exclude	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-7S	Shallow	Not Sampled	X		Exclude	Not Analyzed		No Recommendation		X		Exclude	Qualitative overrides statistical evaluation. (See Table 4.3)
MW-102D	Deep	Not Sampled		X	Biennial		X	Not Analyzed			X	Biennial	Temporal statistics confirm qualitiative evaluation.
MW-102S	Shallow	Not Sampled		X	Biennial		X	No Recommendation			X	Biennial	Temporal statistics confirm qualitiative evaluation.
Recommended New Wells													
S-1	Shallow			X	Annual						X	Annual	Better define plume and track remedial progress over time.
S-2	Shallow			X	Annual						X	Annual	Better define plume and track remedial progress over time.
S-3	Shallow			X	Annual						X	Annual	Better define plume and track remedial progress over time.
S-4	Shallow			X	Potential (Annual)						X	Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from S-2 and S-3.
S-5	Shallow			X	Potential (Annual)						X	Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from S-2 and S-3.
S-6	Shallow			X	Annual						X	Annual	Better define plume and track remedial progress over time.
S-7	Shallow			X	Annual						X	Annual	Better define plume and track remedial progress over time.
D-1	Deep			X	Annual						X	Annual	Better define plume and track remedial progress over time.
D-2	Deep			X	Annual						X	Annual	Better define plume and track remedial progress over time.

TABLE 7.1
SUMMARY OF LONG TERM MONITORING OPTIMIZATION EVALUATION OF THE WASH KING GROUNDWATER MONITORING PROGRAM
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Name	Zone	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
			Exclude	Retain	Recommended Monitoring Frequency	Exclude/ Reduce	Retain	Exclude	Retain	Exclude	Retain	Recommended Monitoring Frequency	
D-3	Deep			X	Potential (Annual)							Potential (Annual)	Better define plume and track remedial progress over time; conditional on results from D-2.
D-4	Deep			X	Annual						X	Annual	Better define plume and track remedial progress over time.
D-5	Deep			X	Annual						X	Annual	Better define plume and track remedial progress over time.
D-6	Deep			X	Annual						X	Annual	Better define plume and track remedial progress over time.



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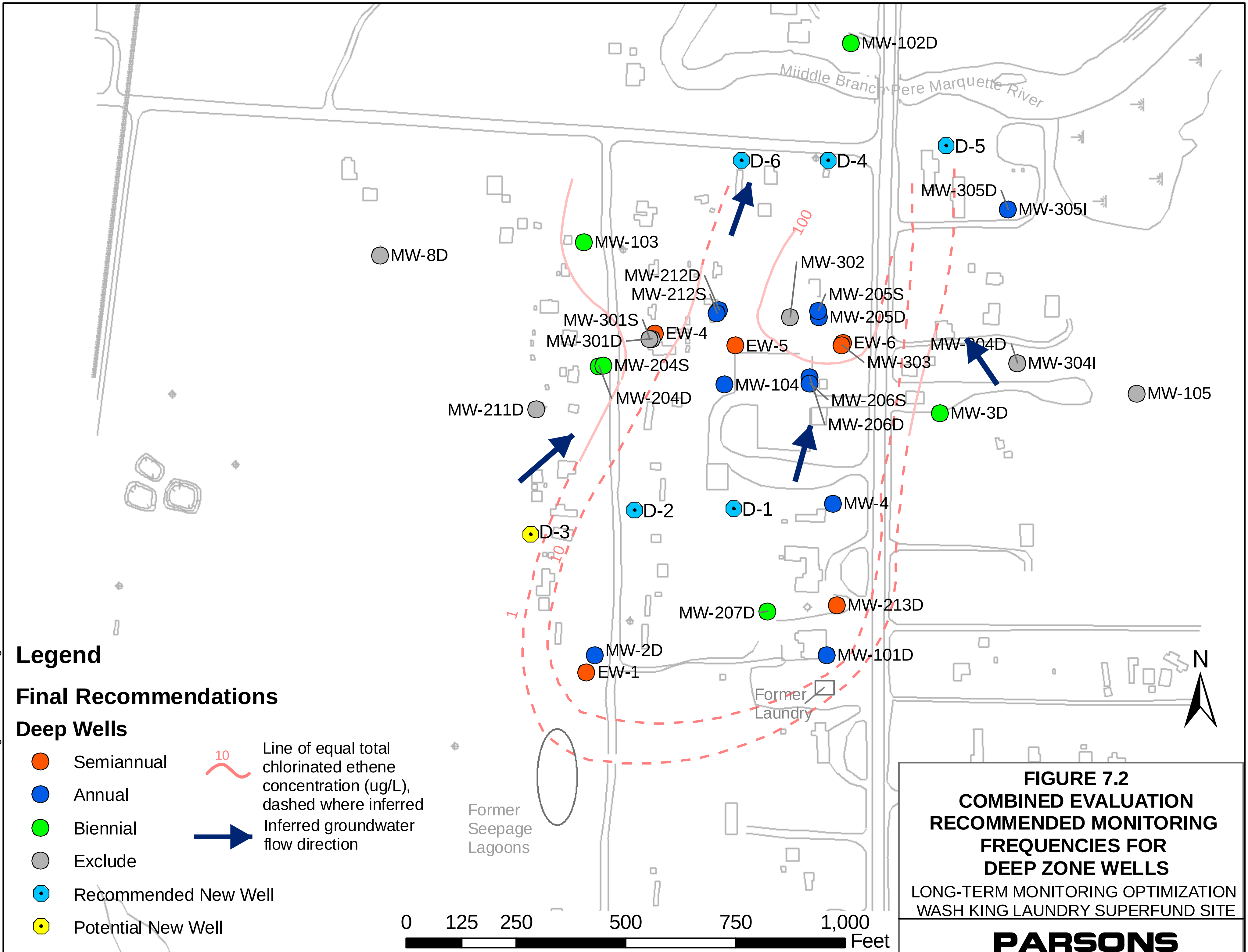

FIGURE 7.2
COMBINED EVALUATION RECOMMENDED MONITORING FREQUENCIES FOR DEEP ZONE WELLS

LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

PARSONS

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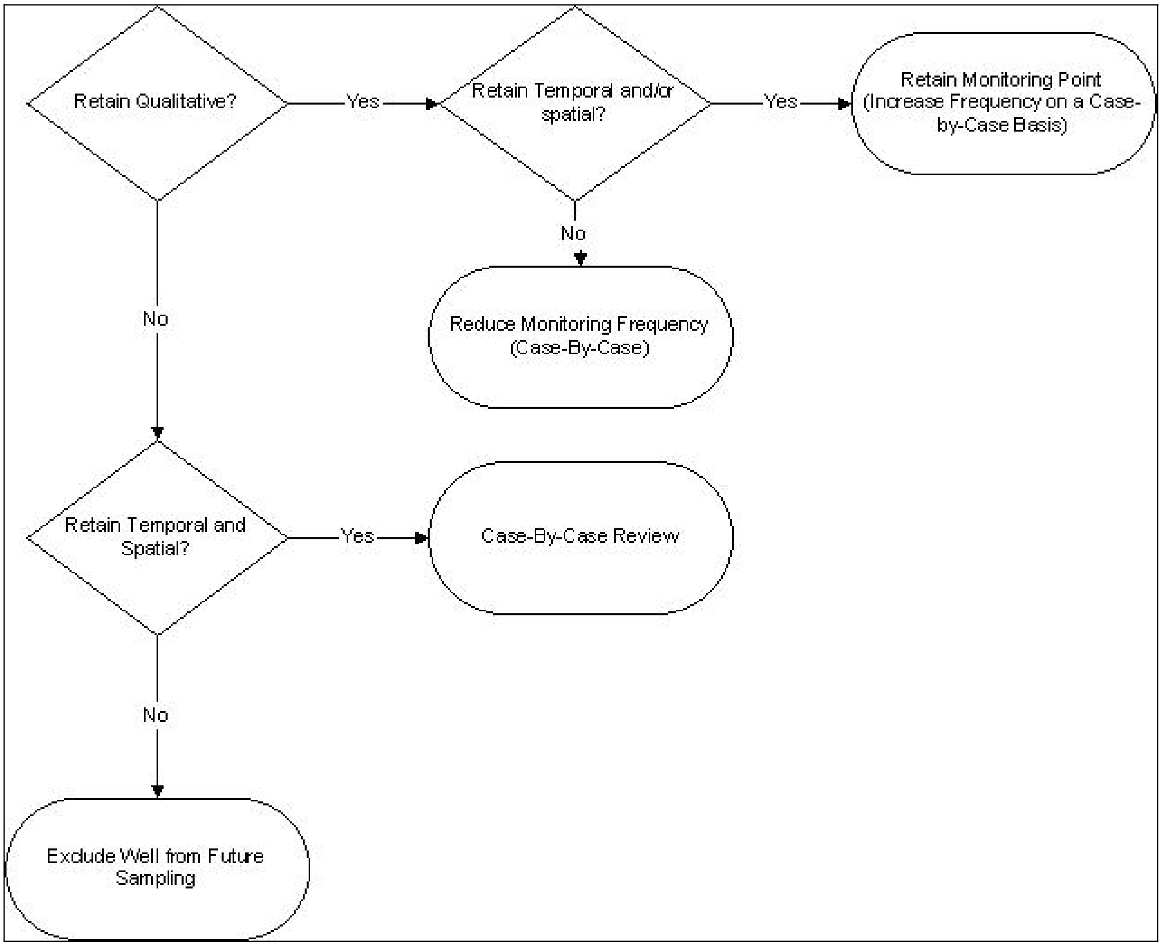
FIGURE 7.3
COMBINED EVALUTION SUMMARY DECISION LOGIC
LONG-TERM MONITORING NETWORK OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE



4. If a well was recommended for retention based on the qualitative evaluation and recommended for removal based on the temporal and spatial evaluation, the well was recommended to be retained, but the possibility of reducing the sampling frequency was evaluated based on a case-by-case review of well information.

It should be noted, as stated in number four above, that the final recommended monitoring frequencies that resulted from the combined analysis are not, in all cases, the same as those recommended as a result of the qualitative evaluation. The justifications for the final recommendations are provided in the "Rationale" column in Table 7.1, and fall into the following general categories:

- *Temporal and/or spatial statistical results confirm the sampling frequency recommendations from the qualitative evaluation.* For example, well MW-301S is recommended for exclusion from the network or for sampling frequency reduction by both the temporal and spatial statistical results; thus, the statistics confirm the qualitative recommendation to exclude the well. Similarly, well MW-207S is recommended for exclusion or reduction by the temporal and spatial statistical results; thus the statistics confirm the relatively low (biennial) sampling frequency recommended by the qualitative evaluation. Likewise, well MW-303 is recommended for retention based on the temporal statistical evaluation, which confirms maintaining the relatively higher (semiannual) sampling frequency recommendation stemming from the qualitative evaluation.

- *Increase monitoring frequency based on statistics.* For example, well MW-101S is recommended for annual sampling based on the qualitative evaluation, but for semiannual sampling based on the summary evaluation due to the increasing TCE trends identified in the temporal evaluation.

- *Qualitative factor overrides statistics recommendations.* For example, although well MW-205S is recommended for exclusion or reduction based on the limited value of its temporal trend information, the qualitative evaluation noted that the concentrations are decreasing post December 2002, and thus override the high variation no trend results driving the temporal evaluation recommendations that considered a longer time period. Additionally, although wells MW-8D and MW-8S are recommended for retention based on the spatial evaluation, they are ultimately recommended for exclusion from the monitoring program because the qualitative evaluation points out that these wells are outside of the area of interest of the plume.

Table 7.2 presents a summary of the revised monitoring network as compared to the basecase network (number shown in parentheses). For the Wash King groundwater monitoring wells, the LTMO results indicate that a refined monitoring program consisting of 35 existing wells sampled less frequently (11 wells sampled biennially, 16 sampled annually, and 8 sampled semiannually) and 10 primary and 2 optional new wells (sampled annually) would be adequate to address the two primary objectives of monitoring listed in Section 1. This refined network (including the two optional new wells) would result in an average of 49.5 well-sampling events per year, compared to 50 per year under the current quarterly (EW) and semi-annual (MW) monitoring program. A well-sampling event is defined as a single sampling of a single well. Implementing these recommendations for optimizing the LTM monitoring program at Wash King would increase the number of wells sampled from 30 to 47 (including the two optional new wells), but entail essentially the same number of groundwater well-sampling events per year**.** The costs of the basecase and refined monitoring programs would likely be similar given the similar number of well-sampling events per year.

TABLE 7.2
SUMMARY OF REVISED AND BASECASE MONITORING PROGRAMS
LONG-TERM MONITORING OPTIMIZATION
WASH KING LAUNDRY SUPERFUND SITE

Well Type	Monitoring Frequency[a/]					Total Sampling Points
	Exclude	Biennial	Annual	Semiannual	Quarterly	
Monitoring	14 (17)	11 (0)	28 [b/] (0)	3 (25)	0 (0)	42 (25)
Extraction	0 (0)	0 (0)	0 (0)	5 (0)	0 (5)	5 (5)
Total Wells	**14 (17)**	**11 (0)**	**28 (0)**	**8 (25)**	**0 (5)**	**47 (30)**

[a/] Basecase sampling frequency corresponding to Table 2.1 shown in parentheses.

[b/] Number includes 10 primary and 2 optional new wells.

SECTION 8

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APPENDIX A

COMMENTS AND RESPONSES ON DRAFT REPORT

HTRW Center of Expertise Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation, Parsons, 12/05

Reviewer: Dave Becker, Geologist

Item No.	Page	Section	Comment	Response
1		General.	This is another excellent report. I have only a few comments. I defer to the Wash King project team for a detailed review of the changes to the program. a) One addition that would assist in evaluating the results would be a piezometric surface map. For this site, a map such as this would help evaluate the recommended changes, especially near the river. b) This site would seem to be a good candidate for a remediation system evaluation to assess the efficiency of the extraction system. I concur with the suggestions from Parsons regarding the need for EW-4.	a) two piezometric surface maps will be added to the report—one each for the shallow and deep zones. See also Michigan DEQ comment #4 (below). *b)* Agree
2	4-6	Table 4.3.	a) The location of shallow well MW-202 near the river at the downgradient end of the plume would seem to justify annual sampling, rather than biennial. b) New wells S-4 and S-5 could be made contingent on the results from S-2 and S-3. If S-2 and S-3 appear to bound the higher concentration portion of the plumes from the laundry and the basins, then S-4 and S-5 may not be quite so necessary. c) I would suggest you recommend annual sampling of the new wells for some period of time (say three to four years) after which the monitoring frequency would be re-evaluated (along with the rest of the network).	a) Agree--MW-202 will be recommended for annual sampling in the final report given the location of this well on the upgradient side of the river. b) Agree; text to this effect will be added to Section 4.3.1. c) Agree; the last sentence of Section 4.3.1 will be expanded to include this recommendation.
3	p. 4-10	Sec. 4.2.1. first line on page	Suggest you replace “aerially” with “spatially.”	Change will be made.
4	4-17	Sec. 4.3.1.	I am not sure you can say that the shallow zone between EW-2 and the river is not impacted by the extraction system without a more detailed assessment of the capture zones of the deeper extraction wells. There may be adequate capture for all zones.	The words “is likely not impacted by the GWE system” will be replaced by “may not be impacted by the GWE system, depending on the capture zones of the deeper extraction wells.”
5	6-1	Sec. 6.	You may want to reference the USACE Engineer Technical Letter 1110-1-175, Application of Geostatistics to Hazardous, Toxic, and Radioactive Waste Projects. See http://www.usace.army.mil/inet/usace-docs/.	Reference reviewed and added to report.
6	6-4	Sec. 6.2.	I agree with the way the wells that have not been sampled since 2003 were handled. I would suggest you boost the confidence in this approach by noting that the changes in concentrations in wells that have been sampled in 2003 and 2005 were minor, and in most cases, went down.	Suggested comment added to the text.

United States Environmental Protection Agency Region V Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation, Parsons, 12/05
(Continued)

Item No.	Page	Section	Comment	Response
7	7-5	Fig. 7.2.	The only other recommendation that I may differ with you on is the need for continued sampling of MW-303. I would suggest the information from MW-303 is duplicative of EW-6. They are similarly screened. I would find the EW-6 results more indicative of the actual conditions over a broader swath of the aquifer in this area due to the fact that it is extracting water.	As indicated in Table 4.3, MW-303 was only retained due to the abrupt increase in the TCE concentration that occurred in August 05. Removal of this well from the LTM program was recommended if future monitoring indicates a return to previous conditions. The most recent sampling result available for EW-6 is June 05; this sample did not reflect an increase in TCE concentrations. If future sampling of EW-6 indicates that this well is adequately mirroring TCE concentrations in MW-303, then removal of MW-303 from the LTM program is recommended. Otherwise, MW-303 should be retained. Tables 4.3 and 7.1 will be revised to include this recommendation.

United States Environmental Protection Agency Region V Review Comments on the Draft Long-Term Monitoring Network Optimization Evaluation, Parsons, 12/05

Reviewer: Dr. Luanne Vanderpool, Geologist, Advanced Analysis & Decision Support Section

Item No.	Page	Section	Comment	Response
1		Section 2.2.3, Hydrogeology	Inclusion of a potentiometric map (or maps for both the deep and shallow portions) would be helpful to illustrate variation in gradients as wells as flow directions in general.	Maps will be added—see responses to Dave Becker comment #1 (above) and Michigan DEQ comment #4 (below).
2	page 2-5	Section 2.2.3, Hydrogeology	Mention is made of calculating the vertical gradient at well pair MW-211S/D. Where is this well pai?. There is no MW-211 in Table 2.1 nor in Figure 2.1 nor Figure 3.1.	According to survey coordinates obtained from the Michigan DEQ, this well pair is (or was?) located approximately 110 feet north and 700 feet east of MW-210. The wells are shown on June 2001 potentiometric surface maps created by Malcolm Pirnie and provided to Parsons. However, there are no groundwater analytical data associated with this well pair, and we are not sure of the current status of this well pair. If the wells are no longer existing, their locations will be described in the text in Section 2.2.3. If the wells are still present, they will instead be added to site maps in the LTMO report.
3	Page 4-12	Section 4.2.2	The first sentence of the last paragraph on page 4-12 states that future sampling of nine existing wells is recommended on an annual basis. Yet on the following page three of these wells are listed with a recommendation of biennial.	The text on page 4-12 will be changed to read “annual to biennial basis”.
4	Page 4-13	Section 4.2.2	The first sentence of the first paragraph lists three wells. The second sentence refers to “these two wells”. Should it be “three” wells?	Yes, “two” will be changed to “three”.
			The first sentence of the second paragraph refers to “five of the remaining seven shallow wells”. Should this be five of six wells?	Yes, “seven” will be changed to “six”.
5	Page 4-14	Section 4.2.3	The last paragraph mentions well pair MW-206S/MW-206D as having elevated concentrations of COCs. Is this correct or should the reference be to well pair MW-206S/MW-206D which are closer to MW302 and contain much higher levels of COCs?	Reference to well pair MW-206S/MW-206D will be changed to MW-205S/MW-205D.
6	Page 4-15	Section 4.2.3	The first sentence of the first full paragraph refers to 20 existing deep zone wells, while the second sentence begins “Eleven of these 19 wells”. Should the reference in the second sentence be 20 rather than 19?	Yes, “19” will be changed to “20”.

Item No.	Page	Section	Comment	Response
7		Section 4.3, Data Gaps	I concur with the data gaps identified and the recommendations for the new wells. I am distressed by the apparent loss of locations for vertical profiling VOC data (the GP-series). Depending on the location and results where the vertical profiling was done, this data might be able to show some of the proposed wells unnecessary.	We agree that it would be useful to locate the vertical profiling data prior to finalizing recommendations for new wells.
8	Page 4-16	Section 4.3.1	Figure 2.3 is referenced here. Figure 2.3 shows concentrations in the deep zone. The correct figure is Figure 2.2.	Figure number will be changed to 2.2.
9		Section 4.3.1 and Table 4.3	Is recommended well S-7 proposed with an annual sampling frequency as shown in this table or is it a potential well as shown on Figure 4.1? There is an S-8 in table 4.3; it does not appear on Figure 4.1 and text talks about up to seven new shallow zone monitoring wells. Is there really an S-8?	S-7 is a potential well as shown on Figure 4.1. S-8 should be deleted. Table 4.3 will be corrected.
10	page 5-8	Section 5.2	According to the report the algorithm for calculating Mann-Kendall assigned a value of ND to non-detects rather than assuming and assigning a numerical value. While the Mann-Kendal does not require a quantitative value, it does require a qualitative ranking. How were the NDs used? Were all detection limits consistent within an individual trend analysis? If detection limits differed, how was this handled? Were there any detections (usually qualified with a "j") below the detection limit? How were these handled; were they deemed higher than a ND? In other words, would a value detected at less than the detection limit be treated as greater than the detection limit in this algorithm?	The "ND" trend assignment was designated only to those results in which *all* measured values were assigned the "ND" qualifier. A value of 0 was assigned to all ND measurements to avoid the incidence of spurious trends for instances in which the reporting limit changes. Text will be added to the report to clarify this point. J values are included in the trend analysis as regular data points, but an additional "<PQL" trend is assigned to those wells in which all results are either ND or Trace (between the RL and MDL) values to flag those results as likely not having a significant trend. However, the Wash King database had no "J" flag values.
11	page 5-8	Section 5.2, and Table 5.1	This is an admittedly picky comment. There is considerable information in this table, however, it is not the easiest table to understand. The intensity of some of the colors (blue and green particularly) obscures the printing (even if the words are made redundant by the colors). The bolded boundaries are not as intuitively obvious as one would like. Once I finally identified the bolded cells, they seemed obvious thereafter, but on several separate occasions I studied the table without discerning the differences.	The table was modified to change the blue and green colors to a lighter shade that will not obscure the printing, and the bolded boundaries were modified to orange, as well as italicizing the trend results to (hopefully) make the table easier to interpret.
12		Section 6	I am not quite sure how the geostatistical analysis would best handle this issue, but	You are correct in pointing out that the

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			the analysis presented certainly doesn't seem complete. The missing well analysis appears to have been done on a single well at a time basis; but not on a multiple well basis (looking at the simultaneous removal of two or more wells). Using the example in Figure 6.2 B, indeed MW-207S is fairly redundant with MW-213S (and both are ranked high for exclusion in Table 6.2). MW101S is also relatively redundant with MW-207S and MW-213S (and it ranks slightly lower with no recommendation either to exclude or retain in Table 6.2). Yet if a new base case were defined with MW-207S and MW-213S removed and this compared to the scenario with all three wells removed, I suspect there would be considerable more of an impact on the predicted standard error map.	analysis considers well value on a well-by-well basis. However, the value of the 3-tiered analysis is that the spatial evaluation is combined with both a qualitative and temporal evaluation so that the relative value of each well is considered from multiple aspects. So, for example, the spatial analysis would identify a pair of redundant wells, and recommend them both for exclusion but the qualitative evaluation would determine which of the wells (if either) should be retained. In fact, it could potentially be undesirable to re-analyze the spatial contribution on a multiple-well basis—for example, the 2 "lowest" spatial value wells could be retained based on their temporal or qualitative information, so any spatial analysis completed without these wells would be of limited value to the combined analysis. Additional text was added to Section 6.3 to clarify this point.

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13		Section 7, Summary of Long-Term Monitoring Optimization Evaluation	While overall I agree with the final recommendations of this analysis, there is one aspect with which I disagree. The issue relates to wells that I would categorize as boundary wells, wells that assist with the definition of lateral boundaries of the plume. This includes MW-3S, MW-201, MW-204S, MW-204D, and MW-3D (and MW-202 although it may be lateral or may be downgradient). Some of these wells were not sampled since 2003 which may have created an illusion that they have been deemed unimportant to the agency. The analysis categorizes these wells (in Table 5.1) as non-detect cross gradient (except MW-202 which is classified as downgradient sentry). This is true; but blurs the distinction between those wells which define the lateral extent of the plume and other more distant clean cross gradient wells (e.g. MW210). The report recommends a sampling frequency of biennial for these boundary wells. While a frequency of semiannual is probably unnecessary, I strongly recommend an annual sampling frequency, not a biennial. Similar to the bias towards downgradient sentry wells in Figure 5.4 (Temporal Trend Decision Rationale Flowchart) there should be a bias towards lateral boundary wells. During the qualitative analysis, Table 4.1 indicates a bias towards sampling boundary wells, however the qualitative analysis recommends only biennial sampling due to "the apparently stable to diminishing extent of the plume footprint over the last several years". I have insufficient confidence in the plume's "apparently stable" behavior without more on-going annual sampling to confirm this. I suggest that these wells (MW-3S, MW-201, MW-202, MW-204S, MW-204D, and MW-3D) be sampled on an annual basis for the next five years. At that time there would be sufficient data to better document plume stability (or shrinkage) and another reduction in sampling frequency might be appropriate. If some of the proposed new wells (e.g. S-2 and S-4 were added to the monitoring program, they might be able to serve as boundary wells and replace MW-201 and MW-202.	The optimal sampling frequency for the listed wells is, to some degree, subjective. Given 1) the age of the plume (presumably generated in the 1970s), 2) the fact that two of the six listed wells (MW-3S/3D) were sampled 14 times from 1997 to 2005, 3) another two of the six listed wells (MW-204S/204D) were sampled six times from 2000-2003, and 4) the groundwater extraction system continues to operate, it seems reasonable to assume that significant cross-gradient expansion of the plume will not occur within a 2-year time frame unless the extraction system operation ceases or is altered. The recommended biennial sampling frequency for these wells will be made contingent on the results of the next sampling event to ensure that the frequency decision is based on recent data (this contingency was already recommended for MW-202). In addition, a recommendation will be added to increase the sampling frequency if significant changes to the hydraulic regime occur (i.e., changes to existing extraction system or initiation of nearby offsite groundwater extraction). However, per Dave Becker comment # 2a (above), MW-202 will be recommended for annual sampling. The text, tables, and figures will be revised accordingly.

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Reviewer: Keith M. Krawczyk, Project Manager, Specialized Sampling Unit, Superfund Section, Remediation and Redevelopment Division

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1			Staff of the Michigan Department of Environmental Quality (MDEQ) has completed a review of the Draft Long-Term Monitoring Network Optimization Evaluation Report (Report) for the Wash King Laundry Superfund Site (Site). I have also reviewed and concur with and/or understand the comments submitted by Dr. Luanne Vanderpool and Mr. Russ Hart of the United States Environmental Protection Agency (U.S. EPA). The optimization evaluation has provided a valuable analysis that will be used in preparation for the upcoming Five-Year Review, including what constitutes necessary groundwater monitoring and an efficient sampling plan for long-term monitoring purposes. The Report provides a means to consider the existing and future data collection that can be used to evaluate the effectiveness of the current groundwater treatment system. However, due to acknowledged data gap realities that exist at this Site, the Report cannot arrive at the definitive suggestions that currently exist without caveat. As such, the MDEQ's comments on the Report will be more general in nature, attempting to best describe the limitations of conducting a long-term monitoring optimization review at this time.	Comment noted.
2			Analytical results of groundwater samples collected from monitor wells that are down-gradient of the extraction system indicate elevated levels of contamination. This suggests that the groundwater extraction system may not be fully capturing the contaminant plume. A three- dimensional capture zone analysis should be completed to determine the radius of influence of the groundwater extraction system and areas of potential contaminant transport breakthrough. This evaluation could be accomplished most efficiently by installing a series of piezometers using direct push technology. Isopotentiometric measurements in those piezometers and monitor wells can then be used to develop a better understanding of the hydraulic regime during the operation of the groundwater treatment system to evaluate if the existing extraction system has an adequate radius of influence. The Report should acknowledge that this would be a necessary step in advance of developing a long-term monitoring program.	Performing a remedial process optimization (RPO) evaluation of the pump-and-treat system would be appropriate to better understand the effectiveness of the system (given that it has now been operating for approximately 5-6 years) and whether any modifications to the system are in order to better meet remedial goals. The RPO evaluation also should examine 'big picture' issues such as whether the current remedial goals and objectives are appropriate and realistic, and whether the current pump-and-treat system (or a modified version) is still the optimal approach for meeting them. The results of this type of evaluation could

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				then be factored into the long-term monitoring plan. This type of evaluation is beyond the scope of the current study. The following text will be added to the end of the first paragraph of Section 7: "*It should be noted that development of an optimized long-term monitoring program for the site would benefit from a better understanding of the hydraulic effects of the current pump-and-treat system.*"
3			The Report acknowledges analytical data that shows a significant source area of perchloroethylene (PCE) near the Wash King building. Although the extraction well (EW-2) near this location is removing dissolved PCE from the shallow aquifer zone, PCE is not strongly adsorbed to activated carbon, and consequently, activated carbon is not the optimal medium for removing such high concentrations of this contaminant. The review conducted for this Report actually shows that the remedial timeframe and associated remedial costs for this Site may be exponentially reduced by instead utilizing an *in situ* chemical oxidation (ISCO) technology such as ozone sparging. Direct push techniques can be used to quickly delineate the area of residual solvent and point to where an appropriate ISCO technology should be implemented that will destroy the source material. It is very possible that if an ISCO approach is implemented, cleanup criteria could be met in years, reducing the expected timeframe by decades. The MDEQ suggests that the Report indicate that this review points to the need to consider other remedial options, in addition to the recommendations for monitoring upgrades that it already provides.	The scope of the current effort was focused on optimizing the existing long-term monitoring system. This effort was not meant to address the larger issue of remedial process optimization. However, we agree that additional source removal efforts, if well-planned and well-executed, could potentially reduce the time required to meet remedial goals substantially. The following text will be added to the end of the first paragraph of Section 7 after the new sentence listed in the response to the comment #2 (above): "*In addition, further evaluation of how the persistence of the VOC plume could be reduced (e.g., via additional source removal efforts) should be considered.*"
4			It is recognized in the Report that the value of the analytical data available from the existing monitoring network is somewhat limited. The monitoring wells that are considered, or which are applicable for defining the plume boundaries, may be debatable (as evidence, see Figures 4.1 and 4.2). However, the lack of consistent monitoring and characterization in the shallow and deeper portions of the aquifer across the Site is not debatable. The MDEQ concurs with the cited data gaps and the proposed additional monitor wells to help resolve those issues. In addition to the wells that are proposed in the Report, it is suggested	We agree with installing a well cluster between the "305" wells and MW-202 and replacing destroyed well MW-202. The need for a well cluster west of MW-202 will be evaluated once potentiometric maps for the site are created (see Dave Becker comment #1 and Dr. Luanne Vanderpool comment #1 (above). The

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			that a few other wells are necessary to define the down-gradient extent of the groundwater contaminant plume that is beyond the groundwater extraction wells. A well cluster should be installed between the "305" wells and MW-202; currently, only a shallow well (S-6) is proposed at that location. A well cluster is also needed west of the MW-202 location; there is no monitoring in that area of the Site. It should be noted that monitor well MW-202 has reportedly been destroyed and should be replaced with a new shallow well that is screened at a more appropriate interval in the aquifer. It is hoped the proposed monitor wells would define the down-gradient extent of impact and mitigate current data requirements.	report will be modified accordingly to include these new recommendations. Recent water level elevation data sets provided to Parsons do not contain data for all site wells (e.g., data for shallow wells MW-8S and MW-202 are not included). It would be helpful to prepare potentiometric surface maps using water level data for all site wells in order to make them as accurate and useful as possible.
5			Because the aquifer is monitored and characterized inconsistently across the Site and because it can be argued that data from some wells are not representative, it seems that it is inappropriate to interpolate between points, as is done in Section 6 of the Report. As such, the MDEQ has reservations about using or commenting on the spatial statistical evaluation. This evaluation might be more useful once a dataset is obtained from the proposed long-term monitoring network. If this discussion is to remain in the Report, acknowledgment of this concern should be included so as to appropriately place this use of statistics into perspective.	Agreed that the spatial analysis has limitations based on the limitations on the data and the well zone classifications and would be a good idea to re-conduct after more data is obtained. However, data from 2003 was included only after review to ensure that it was in-line with 2005 results, and the spatial evaluation results are used only as one of three-tiers of the lines of evidence. More value was given to both the qualitative and temporal results in the combined evaluation. Text will be added to clarify the above comments in the report.
6			Lastly, these remaining comments seek to point out what appear to be inherent deficiencies in trying to conduct this optimization review. There is no evaluation in this Report of the soil vapor extraction system. A review of this nature would seem to be a vital component to be considered as part of any holistic remedy for the Site. It would also seem that doing a review of this nature would require ascertaining whether all the necessary contaminants of concern are being analyzed for, including whether any degradation contaminants may have resulted given the age of this Site. The Report and the U.S. EPA's comments recognize that there are data gaps. To that end, it seems premature to make final decisions at this time regarding which wells should be	Evaluation of the SVE system was not in the scope of the current effort, which was focused solely on the groundwater monitoring program. Available data indicate that chlorinated ethenes are the contaminants of concern (COCs) in site groundwater; therefore, all necessary COCs are being targeted for analysis. Text will be added to the report

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			sampled and at what frequency, even though the analysis in the Report seems reasonable. It can be expected that new and current data will make the timing of determining which locations provide "optimal" data or conversely, "somewhat marginal" or "redundant" data, more appropriate after the proposed work, rather than now. Therefore, it is suggested that the final conclusion of this Report state that an optimal long-term groundwater monitoring network and sampling frequency be established after the data gaps have been addressed, rather than prior to this being accomplished.	addressing the site-specific analytical program. Text will be added to Section 7 indicating that additional remedial process optimization evaluations would be useful, as indicated in the responses to comments 2 and 3 (above). However, we believe that the optimization recommendations made in this report could be implemented now, rather than waiting for data gaps to be addressed. The LTM plan should be dynamic and should be periodically re-evaluated as new information is obtained. Money saved by implementing the recommended changes to the current sampling program could be better spent filling data gaps and performing a holistic remedial process optimization evaluation to ensure that the cleanup effort is optimized.
7			The MDEQ did find some minor corrections that could be made to make this Report more accurate, but given the overall concerns of how to frame what can be achieved in conducting an optimization review at this time, time was not spent listing out those minor corrections. Please contact me if you would like to discuss those minor edits or if you need to discuss the items addressed in this letter in greater detail.	Comment noted; we will contact you to discuss the minor edits.