GROUNDWATER FLOW MODEL AND DNAPL EVALUATION SUPPLEMENTAL REPORT

NW NATURAL GASCO SITE

Prepared for
NW Natural

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1 INTRODUCTION

This supplemental report summarizes the work completed and findings of groundwater model and dense non-aqueous phase liquid (DNAPL) evaluations completed as part of source control design at the NW Natural Gasco Site. Chapter four of the *Preliminary Design Report, Groundwater Source Control* (Anchor 2008) identified groundwater flow modeling tasks to be completed, including extraction well design-related issues and the impact of shutdowns and river flow variations. In previous meetings and correspondences, the Oregon Department of Environmental Quality (DEQ) has also requested evaluation of DNAPL mobility as it relates to design of the proposed vertical barrier. This report responds to all of the above technical issues, with the exception of the analysis of the impact of shutdowns. That analysis can more efficiently be addressed after DEQ and NW Natural have conferred on the findings in this report.

NW Natural proposes to meet with DEQ to present the findings of these studies, and this supplemental report is intended to provide DEQ with information to prepare for the meeting. The following sections describe development of reasonable worst case flow conditions, model recalibration, reasonable worst case scenarios, nearshore dredge scenarios, and potential effect on DNAPL.

2 REASONABLE WORST CASE HYDRAULIC GRADIENT DATA ANALYSIS

At DEQ's request a reasonable worst hydraulic gradient case condition was developed by analyzing existing site groundwater level data and comparing the water level data to measured river stage. The greatest difference between water levels at wells and river stage occurred at various times from well to well. However, the greatest difference occurred for 11 wells in the March 27, 2000, monitoring event. Consequently, the water level data from this event were selected as the reasonable worst case condition. More detail on this analysis is presented in Appendix B.

3 MODEL RECALIBRATION

The model was recalibrated to the selected worst case water level data from March 27, 2000. The river boundary condition was changed to the measured stage of 6.82 feet. Model calibration consisted of changing the upland boundary head and the aerial recharge rate to match the March 27, 2000, water level data. The only physical change to the model structure was addition of the MODFLOW Drain Package to represent groundwater seepage to the extraction system in the LNG Basin. This addressed the relatively low water level in MW-10-25, a well completed in the fill near the LNG Basin.

In the model recalibration, the recharge rate changed from the average base case of 0.029 inches per day to 0.054 inches per day. The higher rate yields 1.67 inches of recharge in the March 2000 calibration, which is over 50 percent of the precipitation recorded for March 2000. . This is a relatively high recharge rate and consequently quite conservative with respect to groundwater flow.

The upland boundary head changed in the alluvium from 33 feet in the average base case to 37 feet for the March 2000 calibration. The boundary head did not change in the fill as the calibration to water levels in the fill was accomplished by changing the recharge rate.

Following recalibration, the model was adjusted by extending the deep high hydraulic conductivity zone in the alluvium upland until it intersected bedrock. This same adjustment was done for the average base case to address DEQ's concerns that the model was under-representing groundwater flow from the upland boundary. This upland boundary flow to the alluvium is interpreted as being flow from the underlying basalt west of the Site.

Overall, the calibration to March 2000 worst case conditions with the change in the upland boundary head, recharge rate, and adjustment of the deep alluvium hydraulic conductivity zone increases the overall groundwater flow in the model by 30 percent from the average base case condition. This higher groundwater flow rate represents a transient condition that may only last for a few weeks during winter conditions. For instance, the gradients recorded in March 2000 were not observed in other February or March monitoring events. Therefore, using the model calibrated to the March 2000 data in a steady-state analysis of groundwater containment is a very conservative approach.

4 REASONABLE WORST CASE SCENARIOS

The recalibrated reasonable worst case MODFLOW model was used to simulate five source control scenarios. In all scenarios with the vertical barrier, it is constructed to a bottom elevation of -60 feet along the reach of shoreline recommended in the preliminary design report. The source control scenarios simulated are:

1. Base case with no vertical barrier or pumping.
2. Vertical barrier with no pumping.
3. Barrier with pumping from shallow extraction wells.
4. Barrier with pumping from intermediate depth extraction wells completed near the bottom of the barrier.
5. Barrier with combination of shallow and intermediate depth extraction wells.

The map on Figure 1 shows the locations of subsurface profiles A-A′ and B-B′. Results from all of the model runs are shown along profile A-A′ (Appendix A, Figures A-1 through A-7). Profile A-A′ extends from the river edge across the location of proposed Extraction Well PW-1 and extends approximately 700 feet upland of the shoreline. Results from one model run are also shown along profile B-B′, to assess gradients between extraction wells (Appendix A, Figure A-8).

The first two source control scenarios were analyzed for hydraulic gradients under ambient conditions and with the wall in the absence of pumping, such as in a situation where pumps were turned off. The groundwater gradients near the river and extending upland beyond the proposed location of the wall for these two scenarios are shown on the subsurface profiles in Figures 2 and 3. Figures 2 and 3 display the horizontal and vertical groundwater hydraulic gradients that are predicted when wells are not pumping, both with and without a vertical barrier.

Source control scenarios 3 through 5 were analyzed for the effect on hydraulic gradients and to estimate the pump rate necessary to capture upland groundwater. These scenarios evaluate the different groundwater gradients that result from shallow extraction wells, intermediate depth wells, and paired wells. A summary of the horizontal and vertical hydraulic gradients in the vicinity of and landward from the wall are presented on the subsurface profile in Figure 4. Subsurface profiles showing the detailed distributions of hydraulic gradients that underlie the data on Figure 4 are provided in Appendix A. Combined pumping rates for all ten extraction well locations predicted to attain capture of groundwater from the Site are presented in the following table.

Model Scenario **Current Bathymetry**	**Estimated Pump Rate (gpm)**
Shallow wells	290
Intermediate Wells	250
Combined shallow and intermediate wells	252[1]

1) Pump rate evenly divided between shallow and intermediate wells

5 NEARSHORE DREDGE SCENARIOS

At DEQ's request, the reasonable worst case flow model was modified to represent an additional worst case possibility in which sediment offshore from the Site is dredged to a depth of 20 feet below existing mudline with no backfill material to fill the dredge prism. The assumption was made that the 20-foot dredge segment would extend along the entire alignment of the extraction wells (approximately 2,300 feet) and approximately 300 feet offshore.

The same five scenarios discussed above were analyzed under this condition. A summary of gradients is presented on the subsurface profile in Figure 5. Detailed gradient distributions for these scenarios are presented on the subsurface profiles in Appendix A. Combined pumping rates for all 10 extraction well locations predicted to attain capture of groundwater from the Site are presented in the following table.

Model Scenario Dredge Bathymetry	Estimated Pump Rate (gpm)
Shallow wells	320
Intermediate Wells	260
Combined shallow and intermediate wells	260[1]

1) Pump rate evenly divided between shallow and intermediate wells

6 POTENTIAL EFFECT ON DNAPL

One of the objectives for this evaluation is to determine if there is a potential for upward vertical migration of free-phase DNAPL product into the riverbed sediments and/or surface water as a result of the implementation of the proposed corrective measures at the Gasco Site. Specifically, DEQ asked if the installation of the proposed vertical barrier and associated pumping of groundwater extraction wells on the landward side of the barrier could induce DNAPL migration beneath the wall that could subsequently discharge into the Willamette River.

Fundamentally, the flow of DNAPL is not coincident with groundwater flow in magnitude or direction in saturated environments because of density/specific gravity differences between the two media. The three driving forces that act concurrently on subsurface DNAPL include the gravity gradient (weight of the fluids), the capillary pressure gradient (surface tension of the fluids), and the hydraulic gradient (Cohen and Mercer 1993). It is normally assumed that upward vertical hydraulic gradients associated with groundwater flow can prevent or slow the downward movement of DNAPL. For example, shallow recovery wells and drains can be used to create or increase vertical (upward) hydraulic gradients, particularly across an aquitard that separates two aquifers, and this mechanism has been considered to contain sinking DNAPL at several sites. However, reversing DNAPL flow for recovery is very difficult because of capillary effects between the fluid and surrounding aquifer matrix materials.

The equations used to evaluate the effect of hydraulic gradient and head differences required to prevent DNAPL from sinking vertically downward are given by Cohen and Mercer (1993):

$$i_h = (\rho_n - \rho_w)/ \rho_w \quad \text{(equation 1.1)}$$

and,

$$\delta h = z_n(\rho_n - \rho_w)/ \rho_w \quad \text{(equation 1.2)}$$

where:

i_h = hydraulic gradient

ρ_n = specific gravity of DNAPL

ρ_w = specific gravity of water

δh = hydraulic head difference

z_n = thickness of DNAPL body

These density driven forces would have to be overcome for upward vertical migration to occur before capillary forces could exert an additional significant effect on vertical migration tendencies. Therefore, as a first approximation, Equation 1.1 may be used to address the question of whether an upward groundwater hydraulic gradient may reverse the downward vertical migration of DNAPL at the site such that the DNAPL might be drawn to a recovery well or discharge to a surface water body.

Table 1 provides a summary of DNAPL properties at the Site (HAI 2007). This table shows that the specific gravity of DNAPL at the Gasco Site varies between 1.05 and 1.1. Solving equation 1.1 above, the upward vertical hydraulic gradient that is required to overcome or prevent the downward migration of DNAPL due to gravitational forces is between 0.05 and 0.10.

The vertical hydraulic gradients described in Sections 4 and 5 were examined at the bottom of the proposed vertical barrier to assess if upward hydraulic gradients could potentially overcome gravitational forces associated with the downward migration of DNAPL. Two areas were examined for each of the five Reasonable Worst Case scenarios outlined for the groundwater model above under existing and dredged conditions. The two areas that were evaluated are:

- The area on the landward side and adjacent to the proposed barrier—approximately at Stations 1200 to 1350 in the model grid
- The area on the river side and adjacent to the proposed barrier—approximately at Stations 1000 to 1150 in the model grid

The evaluations were performed on gradients predicted at the bottom of the proposed wall (the -60 foot elevation), and are centered on cross section A-A′. Subsurface profile B-B′ was offset from the pumping wells to evaluate how the magnitudes of predicted gradients change with distance away from the proposed pumping wells. In cases where the model well screen was located at the -60 foot level (combined and intermediate scenarios), the gradient from the -70 foot level was substituted at Station 1200.

The following conclusions can be derived from the above analysis:

- None of the modeled conditions have upward hydraulic gradients that could draw DNAPL upward towards the river on the river side of the barrier wall. The vertical gradients in this area are near zero, and mobile DNAPL in the area would tend to migrate in a downward direction since gravitational forces greatly exceed the hydraulic gradient (Figure 6).
- Based on differences between hydraulic and gravitational gradients, there is a potential that downward migration of DNAPL in the immediate vicinity of the pumping wells could be retarded or contained (Figure 7). This effect decreases rapidly moving away from extraction wells. Capillary effects may prevent the complete reversal of downward DNAPL migration in these areas, and heterogeneities in the aquifer matrix would play an important role in determining the magnitude of these effects.

7 SUMMARY OF MODEL FINDINGS

1. The groundwater elevation data for March 27, 2000, represents a reasonable worst case condition for future modeling and design purposes.
2. Overall, the calibration to March 2000 worst case conditions with the change in the upland boundary head, recharge rate, and adjustment of the deep alluvium hydraulic conductivity zone increases the overall groundwater flow in the model by 30 percent from the average base case condition for the period the worst case condition is in effect.
3. Modeled source control scenarios of shallow, intermediate, and paired extraction wells show that the use of shallow extraction wells requires the highest pump rate to achieve capture.
4. The intermediate extraction well scenario results in the highest upward vertical gradients on the landward side of the vertical barrier, but these gradients decrease more rapidly with distance from the pumping well than in the shallow extraction well scenario.
5. Model runs of the dredge bathymetry showed somewhat higher pumping rates to attain capture than the current bathymetry. However, modeling the dredge bathymetry in addition to the March 2000 reasonable worst case flow condition is believed to be overly conservative because the 20-foot dredge depth will likely be restored with engineered fill or filled in by natural river sedimentation processes. With the addition of post-dredge engineered fill or natural river sedimentation the resulting bathymetry will be close enough to current bathymetry to make the modeled groundwater flows essentially the same. Therefore, the March 2000 reasonable worst case model described in Section 4 is recommended as the worst case scenario to be considered in future design evaluations.
6. None of the modeled scenarios have upward hydraulic gradients that could draw DNAPL upward towards the river on the river side of the barrier wall. Based on differences between hydraulic and gravitational gradients, there is a potential that downward migration of DNAPL in the immediate vicinity of the pumping wells could be retarded or contained.
7. The modeling results demonstrate that the DEQ-proposed vertical barrier depth of -60 feet elevation has a large factor of safety to prevent DNAPL migration from the area upland of the vertical barrier into the river channel.

8 REFERENCES

Anchor Environmental, LLC 2008. *Preliminary Design Report, Groundwater Source Control, NW Natural GASCO Site*. Prepared for NW Natural. Portland, Oregon.

Cohen, R.M. and Mercer, J.W. 1993. *DNAPL Site Evaluation*. Office Research and Development, U.S. EPA.

HAHN and Associates, Inc. 2007. *Remedial Investigation Report, NW Natural Gasco Facility*. Prepared for NW Natural. Portland, Oregon.

TABLE

TABLE 1
Summary of DNAPL Testing Results: Physical and Chemical

Parameter	Unit of Measure	Gasco Property Wells					Siltronic Property Wells	
		Surficial Fill Unit			Alluvial Unit		Surficial Fill Unit	Alluvial Unit
		Well MW-6-32	**Well MW-10-25**	**Well MW-11-32**	**Well MW-16-45**	**Well PW-01-80**	**Well WS-10-27**	**Well WS-11-125**
		Screen: 22-32 feet bgs	Screen: 15-25 feet bgs	Screen: 22-32 feet bgs	Screen: 30-45 feet bgs	Screen: 40-80 feet bgs	Screen:`11-26 feet bgs	Screen: 110-125 feet bgs
		Sample No.2708-981214-MW6-32-01	Sample No. 2708-981214-MW10-25-02	Sample No. 2708-981214-MW11-32-03	Sample No. 2708-041011MW-16-45-0il	Sample No. 2708-070221-PW01-Oil	Sample No. WS10070104	Sample No. WS11-125-N
Total Metals [1]	mg/kg (ppm)							
Arsenic		2.75	3.85	-	-	-	-	-
Barium		ND>0.500	0.700	-	-	-	-	-
Cadmium		ND>0.500	ND>0.500	-	-	-	-	-
Chromium		0.700	0.850	-	-	-	-	-
Lead		ND>10	ND>10	-	-	-	-	-
Mercury		0.059	ND>0.0500	-	-	-	-	-
Selenium		0.550	ND>0.500	-	-	-	-	-
Silver		ND>0.500	ND>0.500	-	-	-	-	-
Aromatic Hydrocarbons [2]	mg/kg (ppm)							
Benzene		589	14,400	2,740	ND>10.0	1,000	874	271
cis-1,2-DCE		-	-	-	ND>10	ND>764	ND>20	188
Ethylbenzene		2,220	5,320	1,760	34.4	2,228	807	925
Isopropylbenzene		-	-	-	ND>20	ND>1,590	69	ND>50
n-Propylbenzene		-	-	-	ND>10	ND>794	33	ND>50
1,2,4-Trimethylbenzene		-	-	-	54.9	976	394	434
1,3,5-Trimethylbenzene		-	-	-	16.2	ND>794	147	121
Naphthalene		-	-	-	1,720	75,400	39,500	114,000
Toluene		ND>5.00	21,900	2,950	17.8	ND>794	43	194
Trichloroethene		-	-	-	ND>10	ND>794	ND>20	59.6
Xylene		1,240	19,500	4,400	66.1	ND>1,590	664	720
PAHs [3]	mg/kg (ppm)							
Total PAHs		214,900	189,700	164,470	32,787	46,910		
Total Carcinogenic PAHs		9,300	19,490	16,210	2,647	ND		
Petroleum Hydrocarbon ID [4]	None							
Gasoline-Range (mg/kg)		Detected [12]	Detected [12]	Detected [12]	Not Detected	22,900	-	14.9
Diesel-Range (mg/kg)		Detected [12]	Detected [12]	Detected [12]	Detected [12]	545,000 [12]	-	347
Heavy Oil-Range (mg/kg)		Detected [12]	Detected [12]	Detected [12]	Detected [12]	175,000 [12]	-	73.1
Reactive Cyanide [5]	mg/kg (ppm)	ND>0.200	ND>0.200	-	-	-	- -	- -
Reactive Sulfide [6]	mg/kg (ppm)	434	ND>50.0	-	-	-	- -	- -
Specific Gravity [7]	gm/cc	1.05	1.05	1.09	1.084 @ 70F; 1.079 @100F; 1.080 @130F	1.1006 @ 70F; 1.0955 @10 1.0920 @130F	-	1.1
Viscosity [8]	cSt	7.2 @ 50C (122F)	14.7 @ 50C (122F)	45.7 @ 50C (122F)	105 @ 70F; 40.1@100F; 18.7@130F	65.6 @ 70F; 24.1@100F; 13.3 @130F	-	-
Ignitability [9]	degrees F	No Flash to 150 degrees F	94.0 degrees F	-	No Flash to 150 degrees F	No Flash to 150 degrees F	-	-
Heating Value [10]	BTU/lb	9,230	12,230	12,280	-	-	-	-
pH [11]	pH unit	6.26	4.30	-	8.28	7.10	-	7.01
Interfacial / Surface Tension [13]	dynes/centimeter							
Water with Air		-	-	-	66.7 @ 70F	66.9 @ 75F	-	-
DNAPL with Air		-	-	-	34.9 @ 70F	36.2 @ 75F	-	-
DNAPL with Water		-	-	-	14.2 @ 70F	15.8 @ 75F	-	-

NOTE:

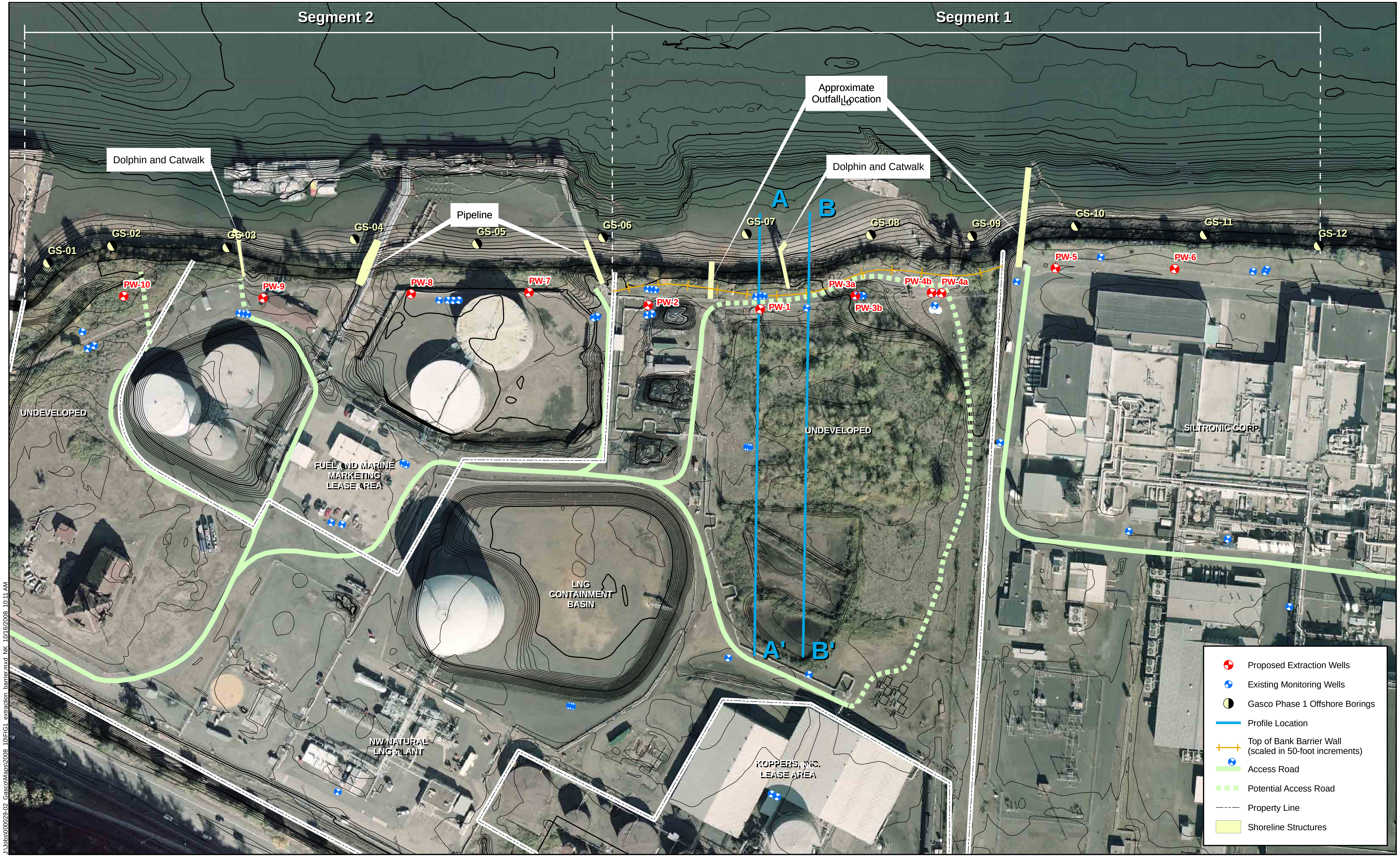
1 = EPA Method 6010/6020/7471
2 = EPA Method 8020A or EPA 8260B
3 = EPA Method 8270 SIM or 8270C
4 = EPA Method 8015M or NW-TPH Methodology or EPA 8015
5 = EPA Method 9010A
6 = EPA Method 9030
7 = SM 2710F

8 = ASTM Method D-445
9 = EPA Method 1010
10 = ASTM Method D2015
11 = EPA Method 150.1/9040A
12 = Laboratory reports that detected hydrocarbons have pattern and range consistent with creosotes
13 = DuNuoy Method - ASTM D971
J = Estimated concentration, results are between the Method Detection Limit (MDL) and the Method Reporting Limit (MRL).

bgs=below ground surface
cc=cubic centimeter
cSt = centistokes
BTU = british thermal unit
DNAPL = dense non-aqueous phase liquids
EPA = U. S. Environmental Protection Agency
gm = gram
lb = pound
mg/kg = milligrams/kilogram

ND = not detected above detection limit indicated
ppm = parts per million

FIGURES



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0 150
Scale in Feet
1 inch equals 150 feet

Figure 1
Cross Section Location Map
Gasco/Siltronic
Portland, Oregon

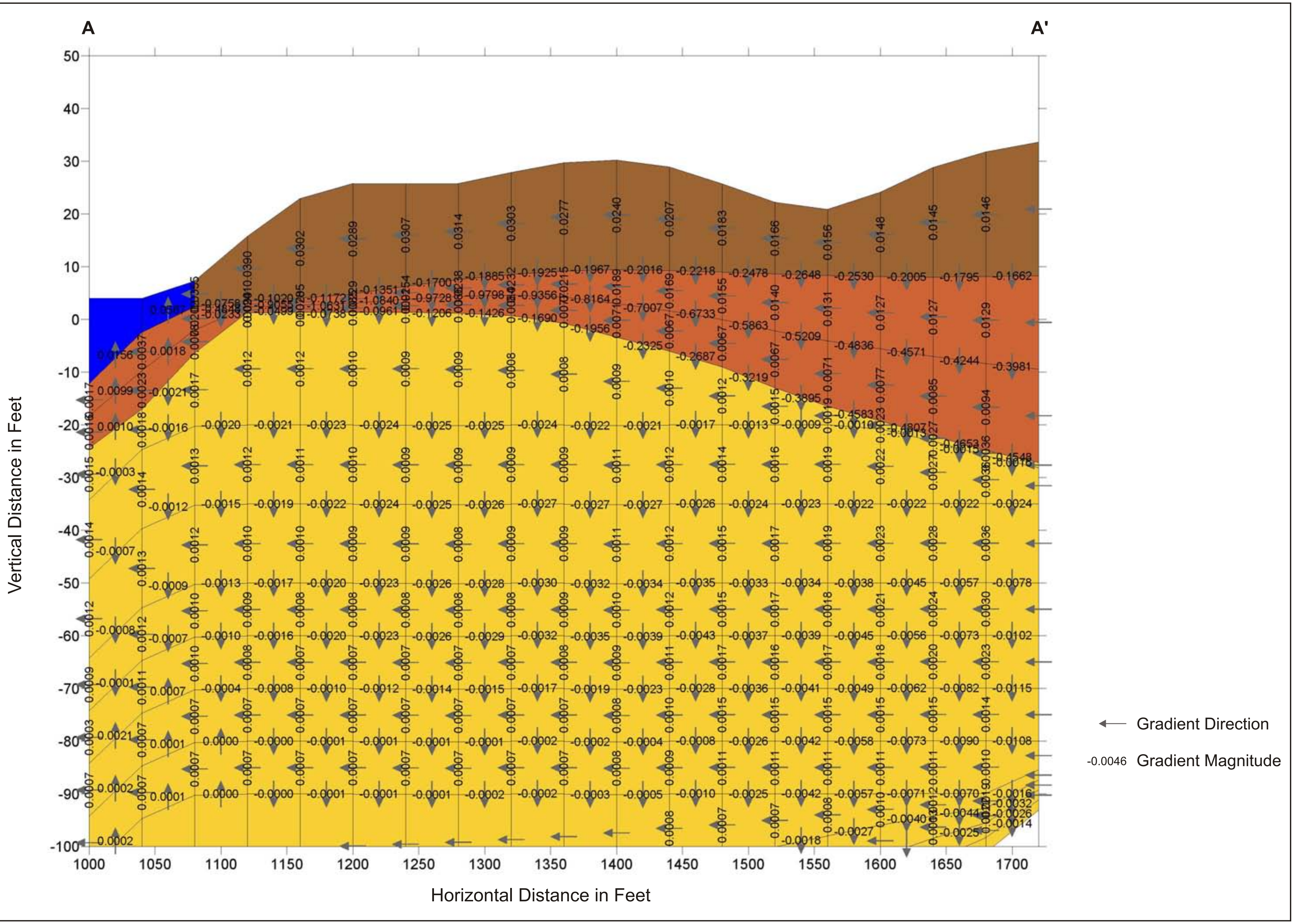

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Figure 2

Reasonable Worst Case Gradient Profile A-A' - Ambient without Vertical Barrier
NW Natural "Gasco" Site

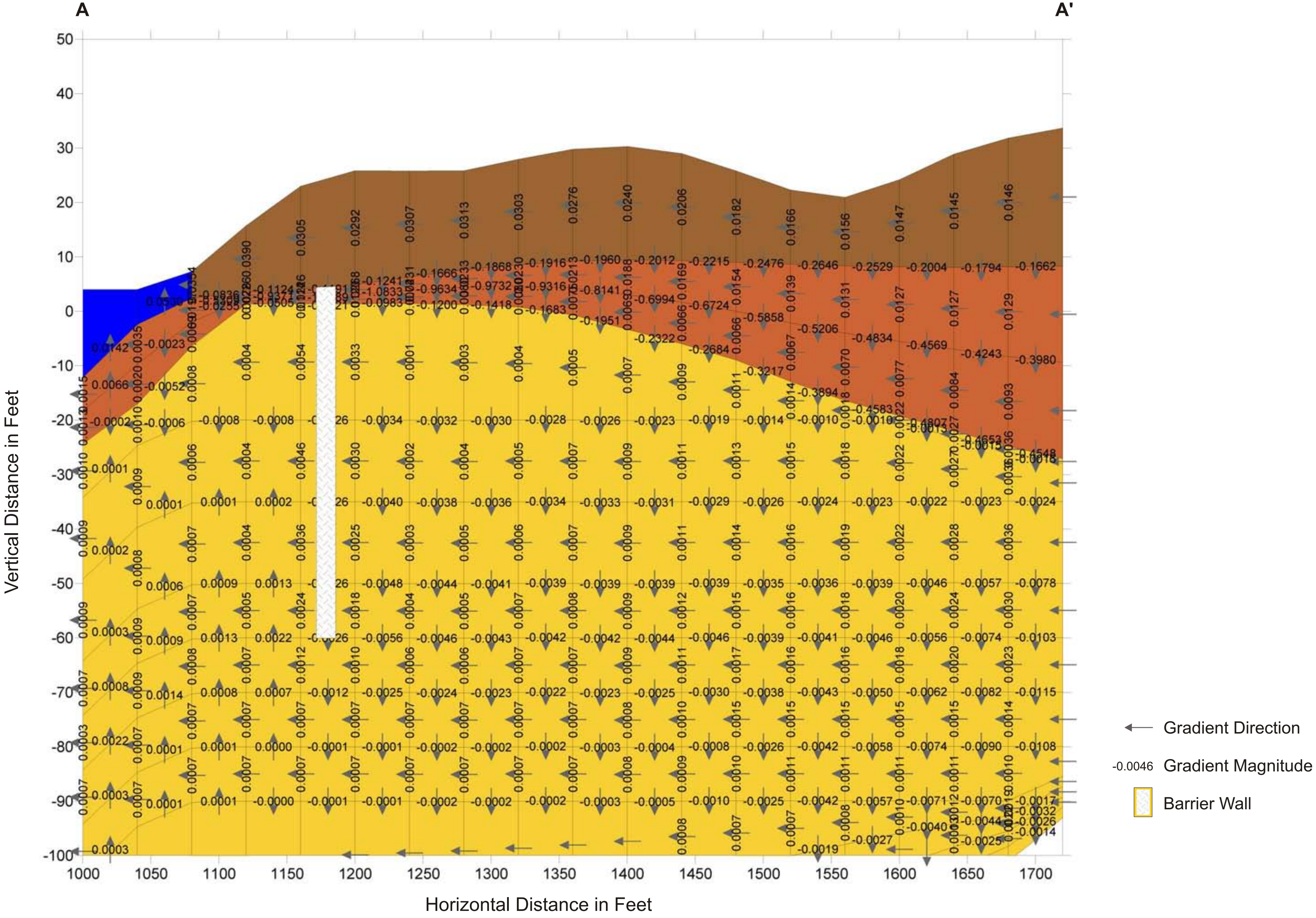
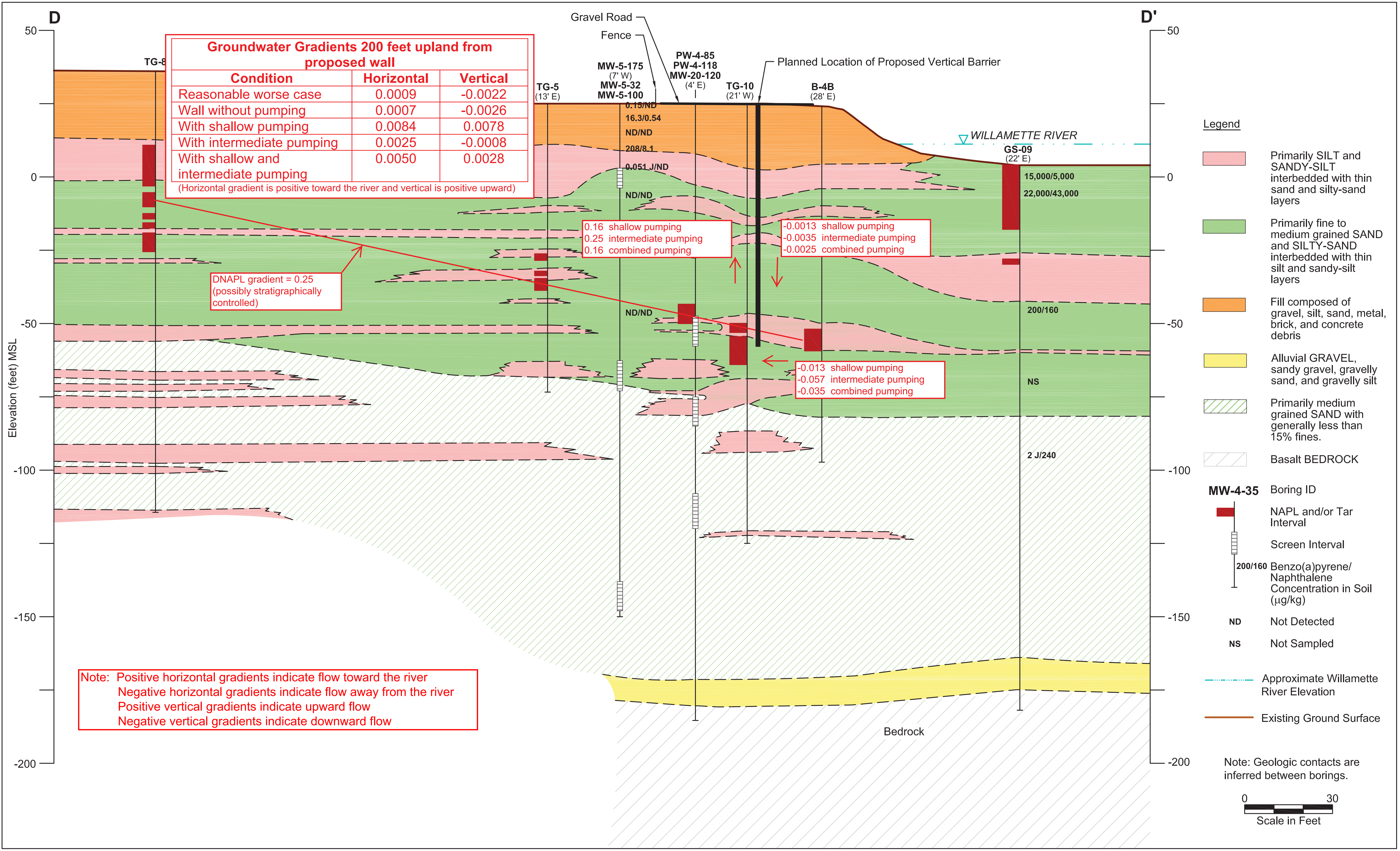


Figure 3
Reasonable Worst Case Gradient Profile A-A' - Ambient with Vertical Barrier
NW Natural "Gasco" Site



Groundwater Gradients 200 feet upland from proposed wall

Condition	Horizontal	Vertical
Reasonable worse case	0.0009	-0.0022
Wall without pumping	0.0007	-0.0026
With shallow pumping	0.0084	0.0078
With intermediate pumping	0.0025	-0.0008
With shallow and intermediate pumping	0.0050	0.0028

(Horizontal gradient is positive toward the river and vertical is positive upward)

DNAPL gradient = 0.25 (possibly stratigraphically controlled)

0.16 shallow pumping
0.25 intermediate pumping
0.16 combined pumping

-0.0013 shallow pumping
-0.0035 intermediate pumping
-0.0025 combined pumping

-0.013 shallow pumping
-0.057 intermediate pumping
-0.035 combined pumping

Note: Positive horizontal gradients indicate flow toward the river
Negative horizontal gradients indicate flow away from the river
Positive vertical gradients indicate upward flow
Negative vertical gradients indicate downward flow

Note: Geologic contacts are inferred between borings.

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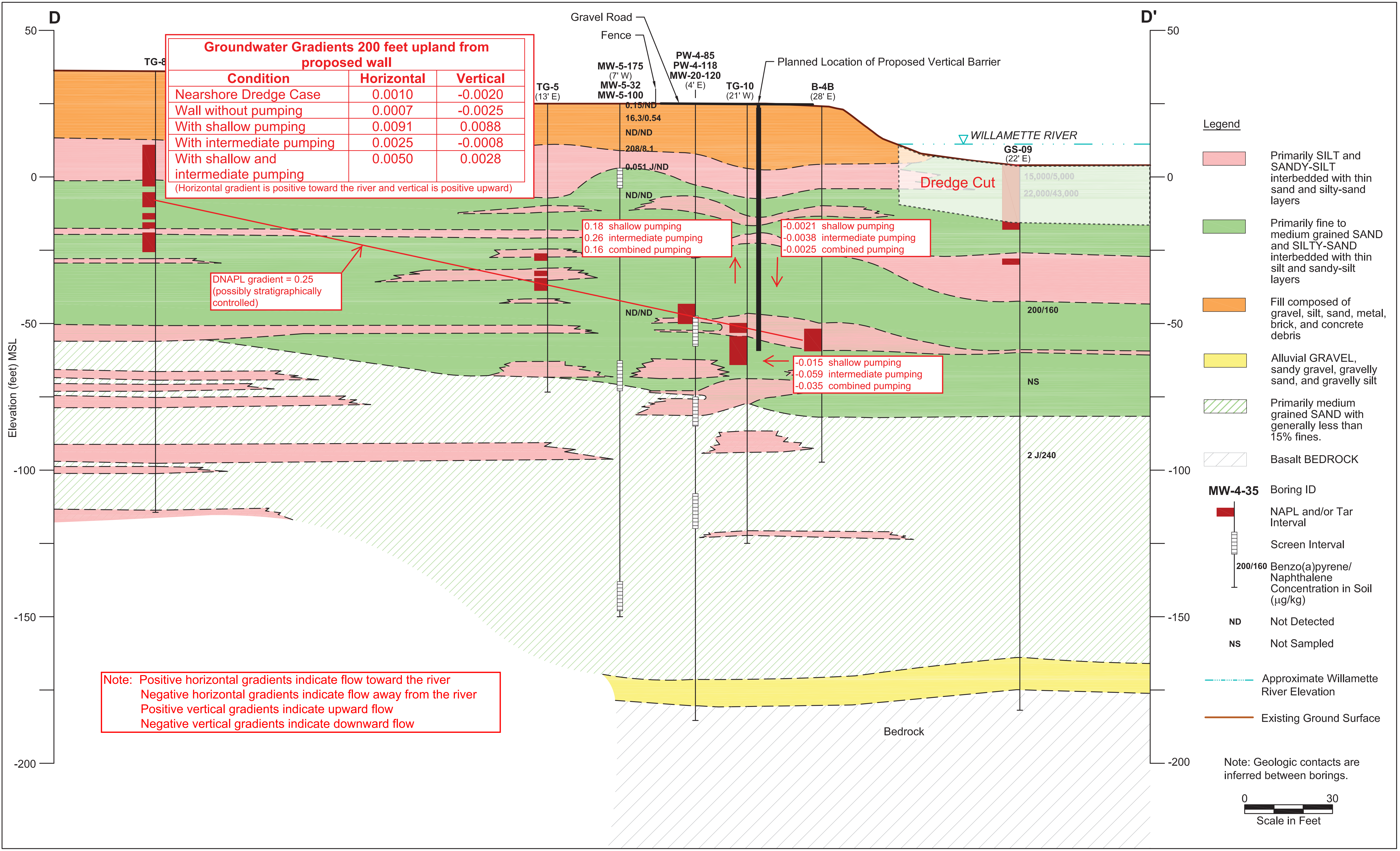
Figure 4
Geologic Profile with Gradient Summary, Current Bathymetry Case



Groundwater Gradients 200 feet upland from proposed wall

Condition	Horizontal	Vertical
Nearshore Dredge Case	0.0010	-0.0020
Wall without pumping	0.0007	-0.0025
With shallow pumping	0.0091	0.0088
With intermediate pumping	0.0025	-0.0008
With shallow and intermediate pumping	0.0050	0.0028

(Horizontal gradient is positive toward the river and vertical is positive upward)

DNAPL gradient = 0.25
(possibly stratigraphically controlled)

0.18 shallow pumping
0.26 intermediate pumping
0.16 combined pumping

-0.0021 shallow pumping
-0.0038 intermediate pumping
-0.0025 combined pumping

-0.015 shallow pumping
-0.059 intermediate pumping
-0.035 combined pumping

Note: Positive horizontal gradients indicate flow toward the river
Negative horizontal gradients indicate flow away from the river
Positive vertical gradients indicate upward flow
Negative vertical gradients indicate downward flow

Note: Geologic contacts are inferred between borings.

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Figure 5
Geologic Profile with Gradient Summary, Nearshore Dredge Bathymetry Case

FIGURE 6
-60 foot Level Vertical Hydraulic Gradients Riverside of Proposed Barrier Wall

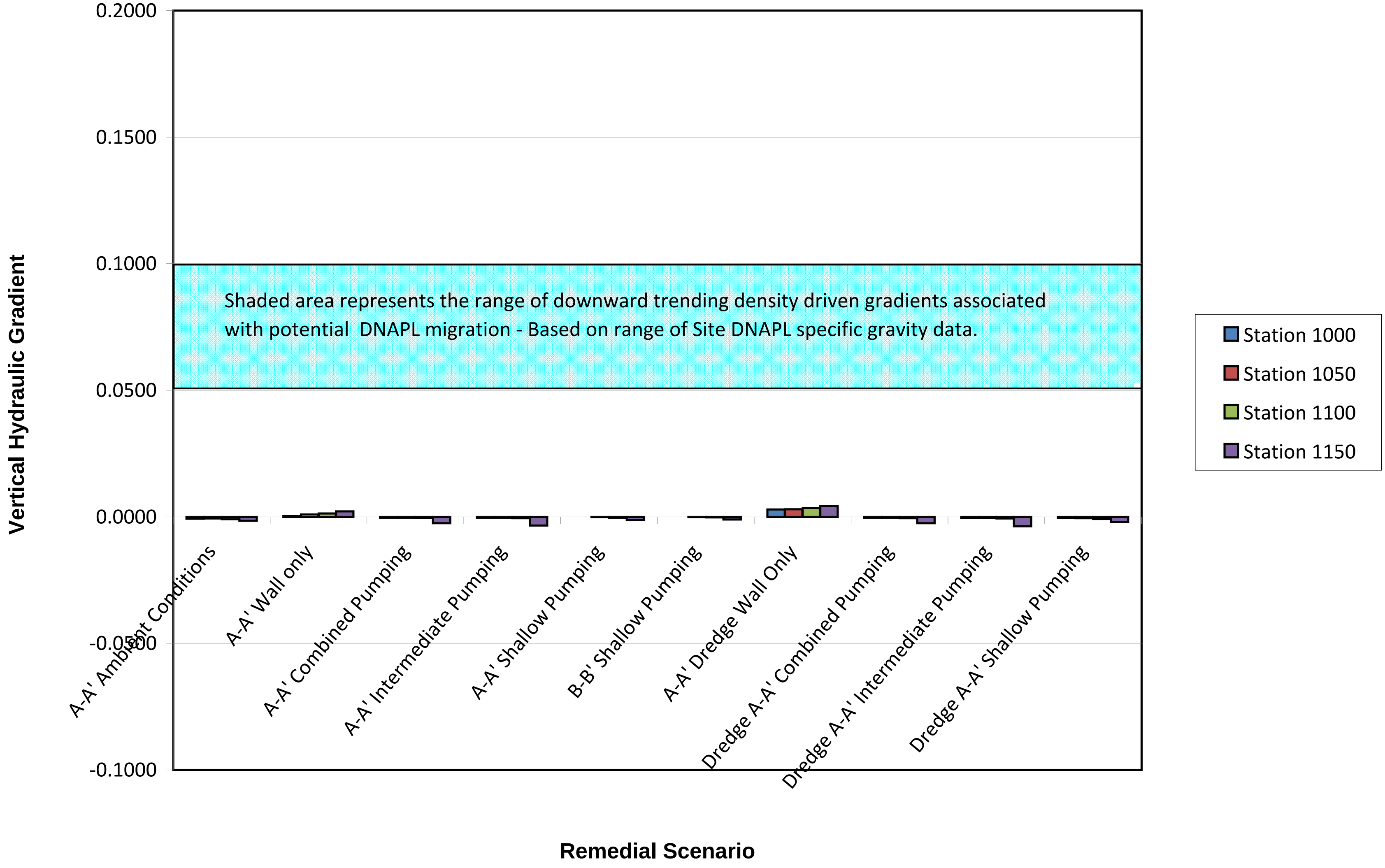

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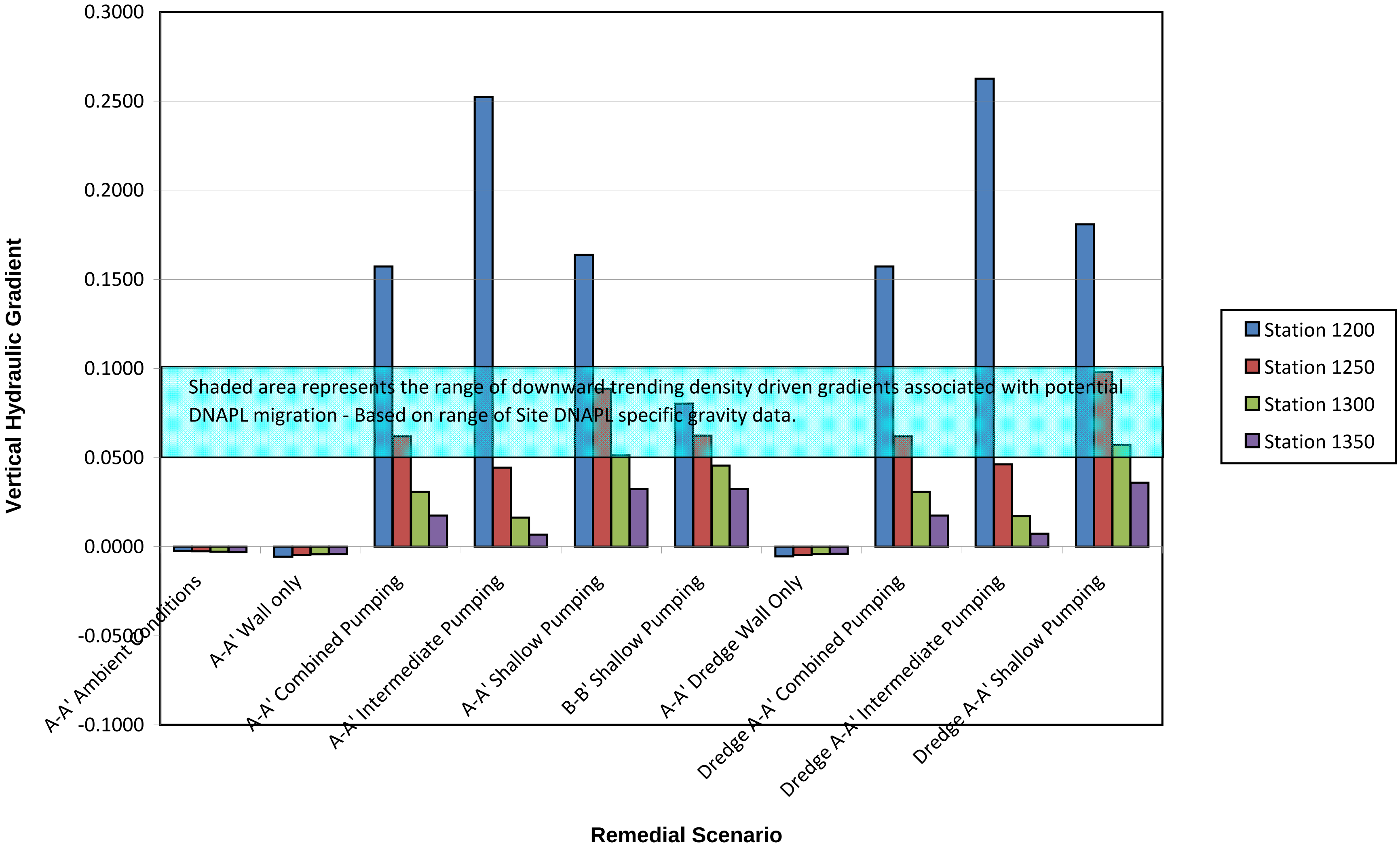
FIGURE 7

-60 foot Level Vertical Hydraulic Gradients Landward of Proposed Barrier Wall



Shaded area represents the range of downward trending density driven gradients associated with potential DNAPL migration - Based on range of Site DNAPL specific gravity data.

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APPENDIX A

GRADIENT PROFILES A-1 THROUGH A-8

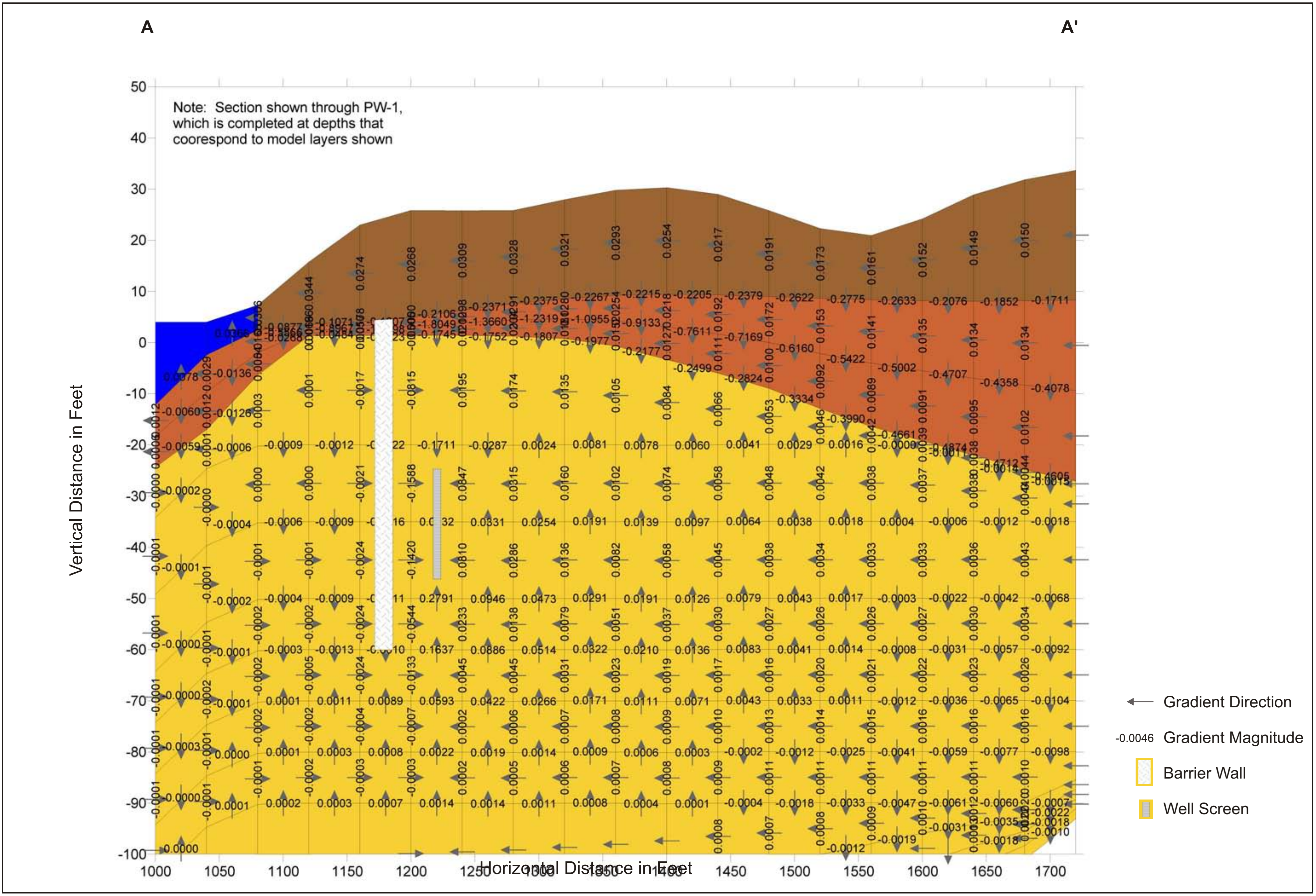

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Figure A-1
Gradient Profile A-A', Current Bathymetry, Shallow Well
NW Natural "Gasco" Site

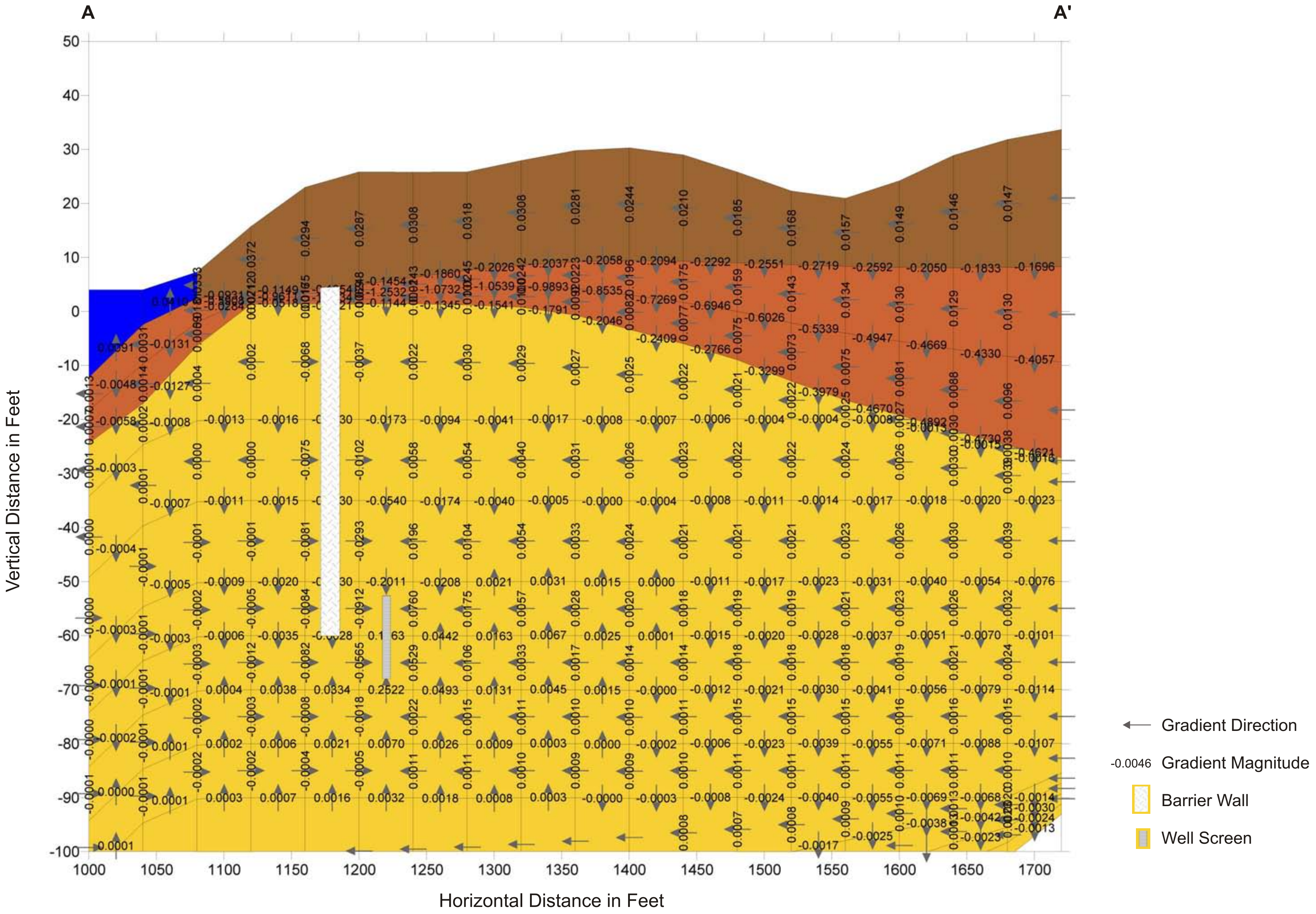

Figure A-2
Gradient Profile A-A', Current Bathymetry, Intermediate Well
NW Natural "Gasco" Site

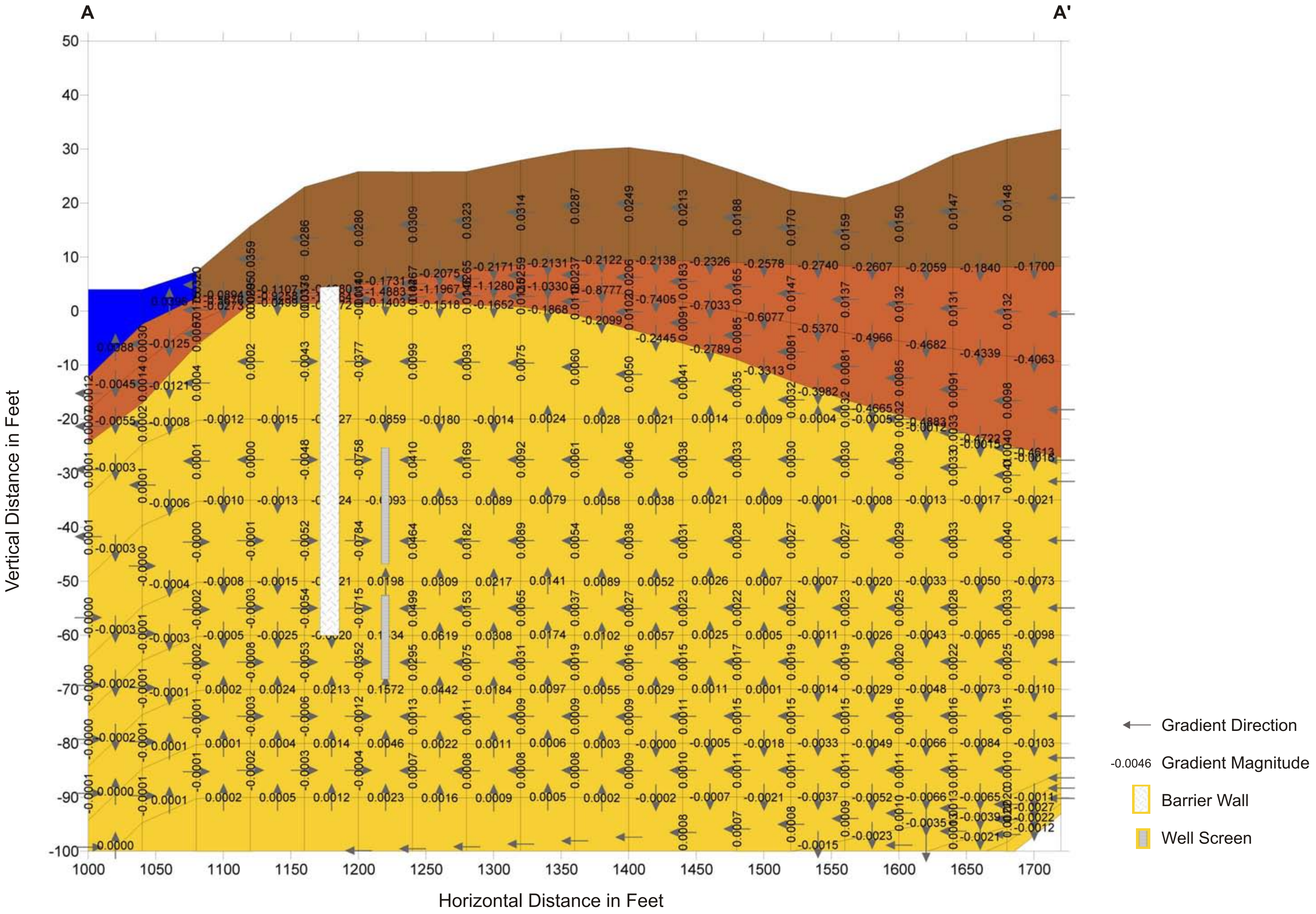

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Figure A-3

Gradient Profile A-A', Current Bathymetry, Shallow and Intermediate Wells

NW Natural "Gasco" Site

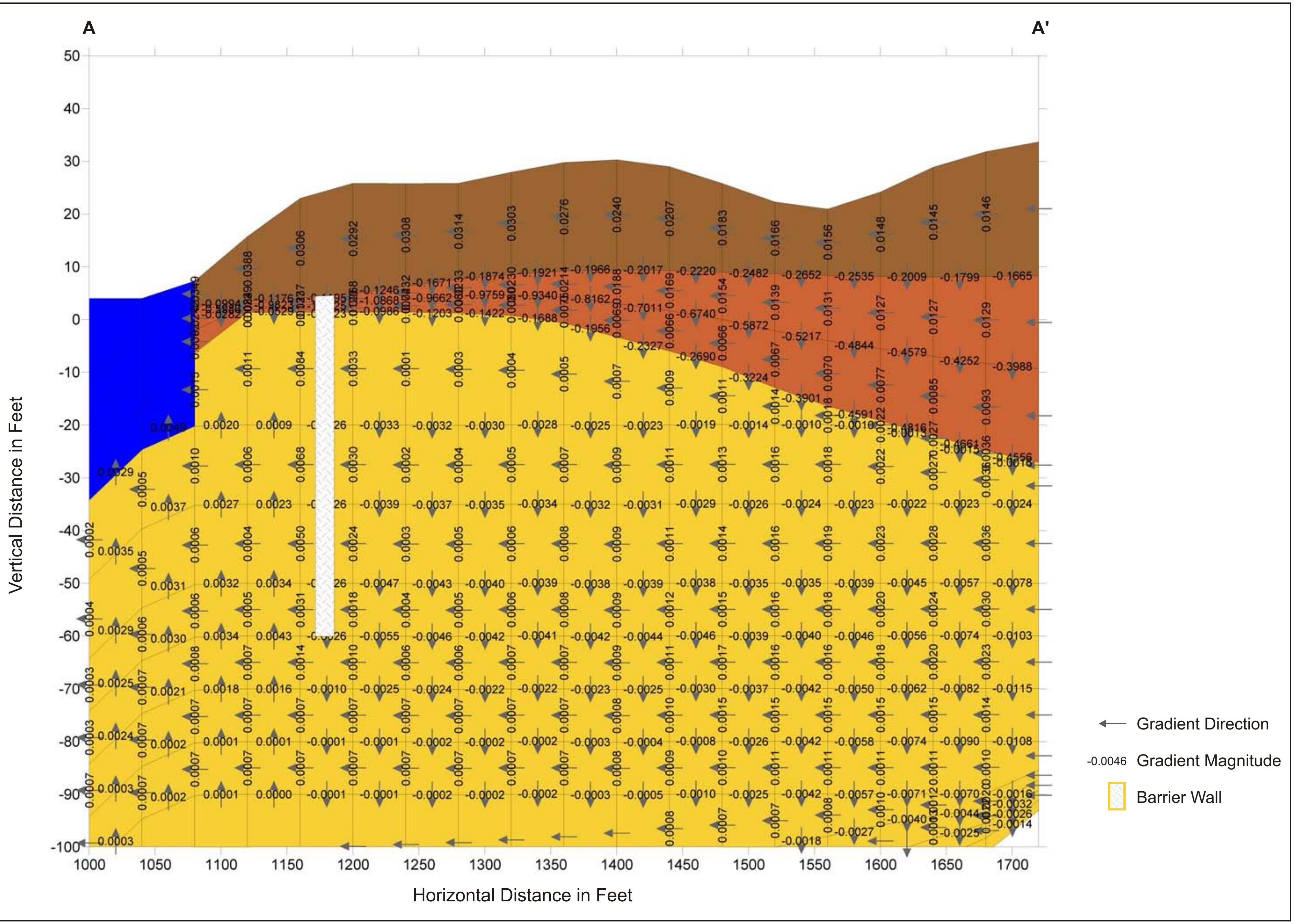

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Figure A-4

Gradient Profile A-A', Dredge Bathymetry, Vertical Barrier, No Pumping
NW Natural "Gasco" Site

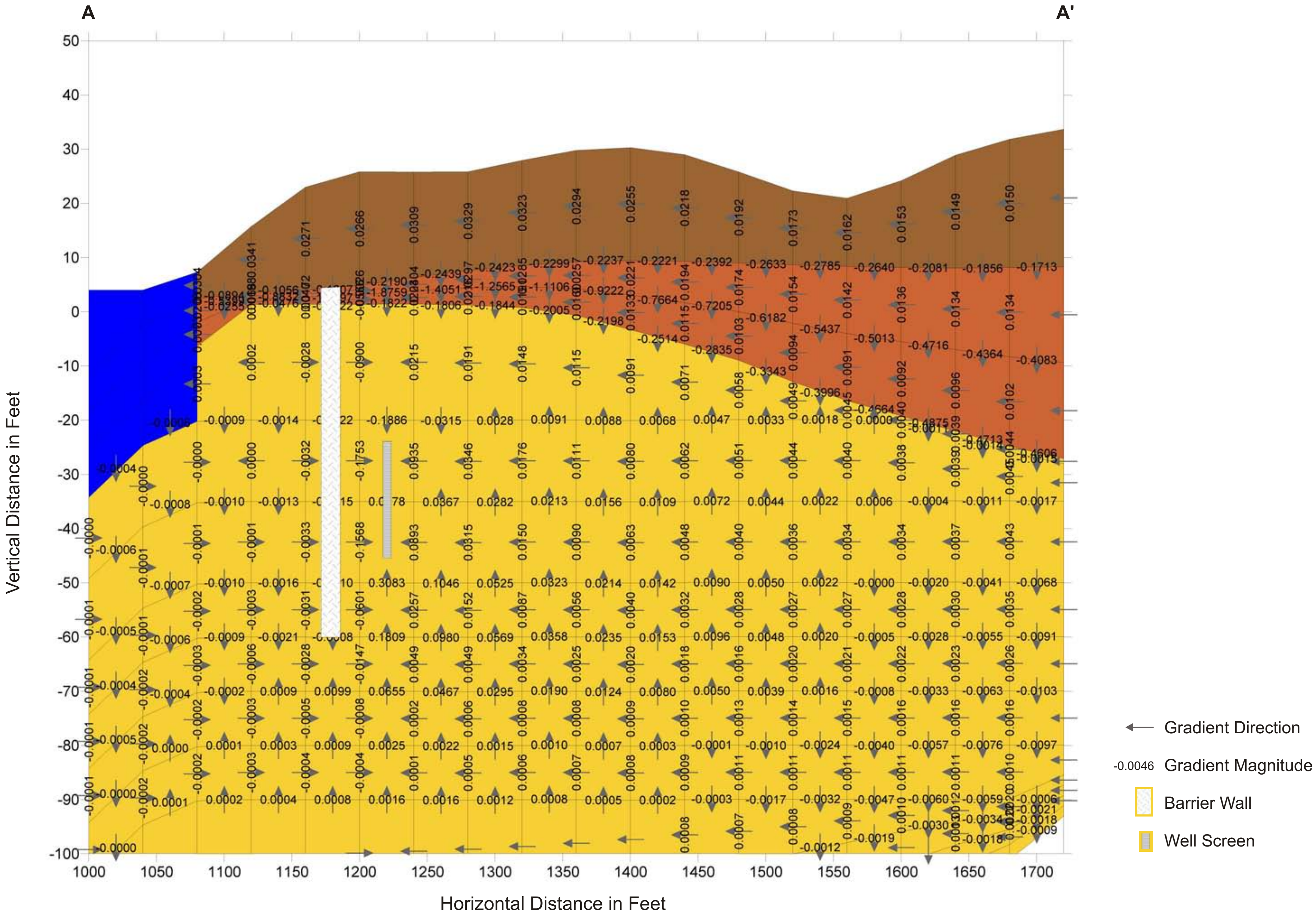

Figure A-5

Gradient Profile A-A', Dredge Bathymetry, Vertical Barrier, Shallow Well
NW Natural "Gasco" Site

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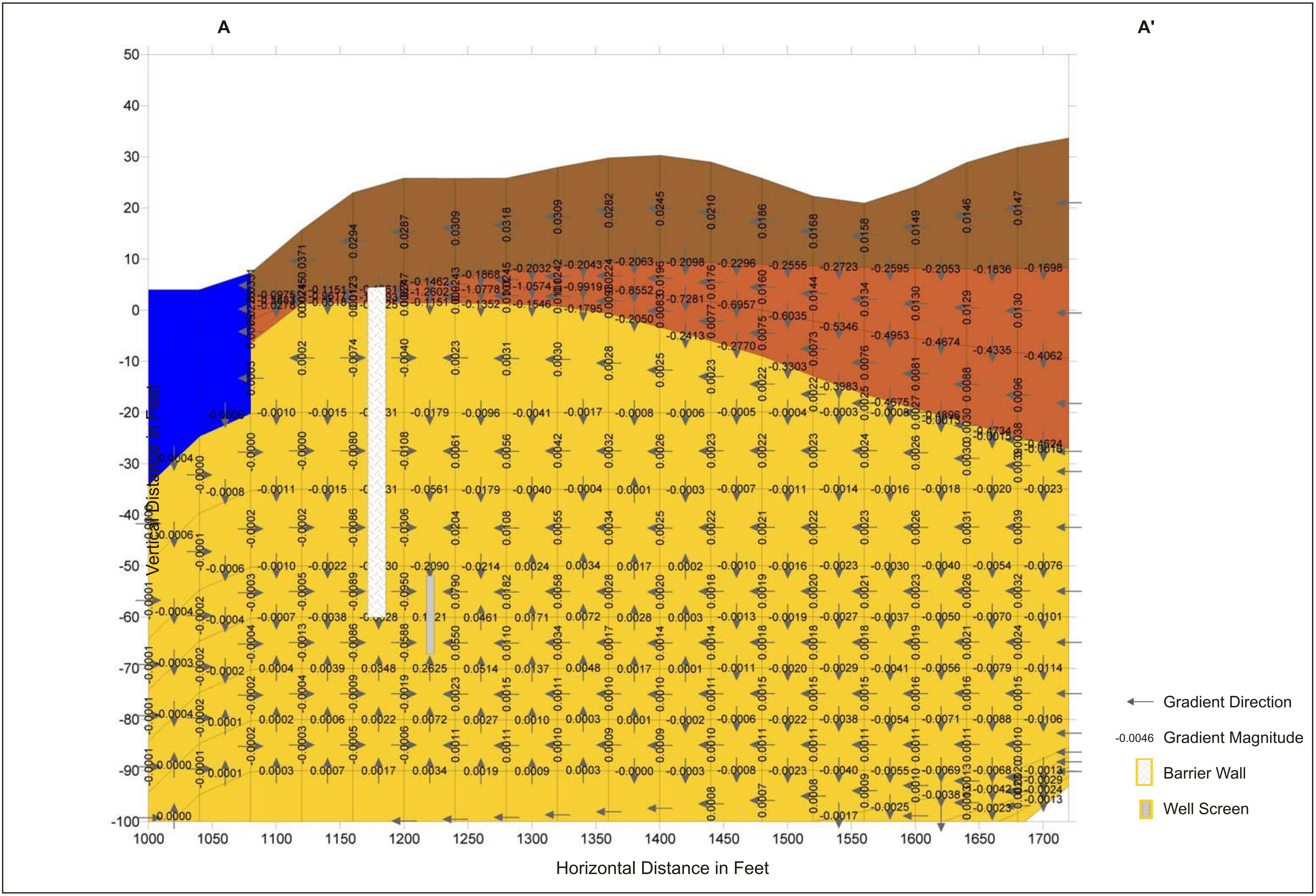

Figure A-6
Gradient Profile A-A', Dredge Bathymetry, Vertical Barrier, Intermediate Well
NW Natural "Gasco" Site

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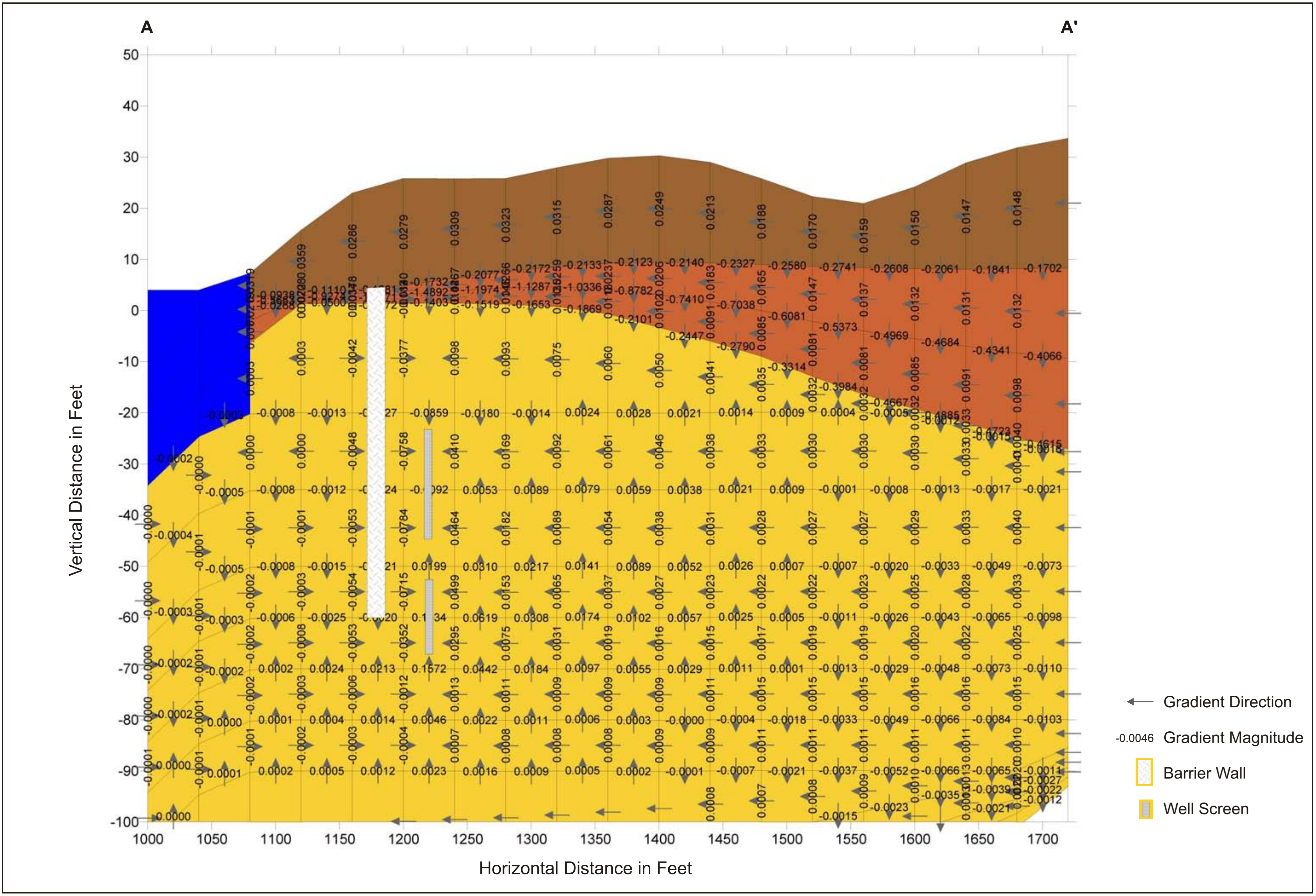

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Figure A-7

Gradient Profile A-A', Dredge Bathymetry, Vertical Barrier, Shallow and Intermediate Wells
NW Natural "Gasco" Site

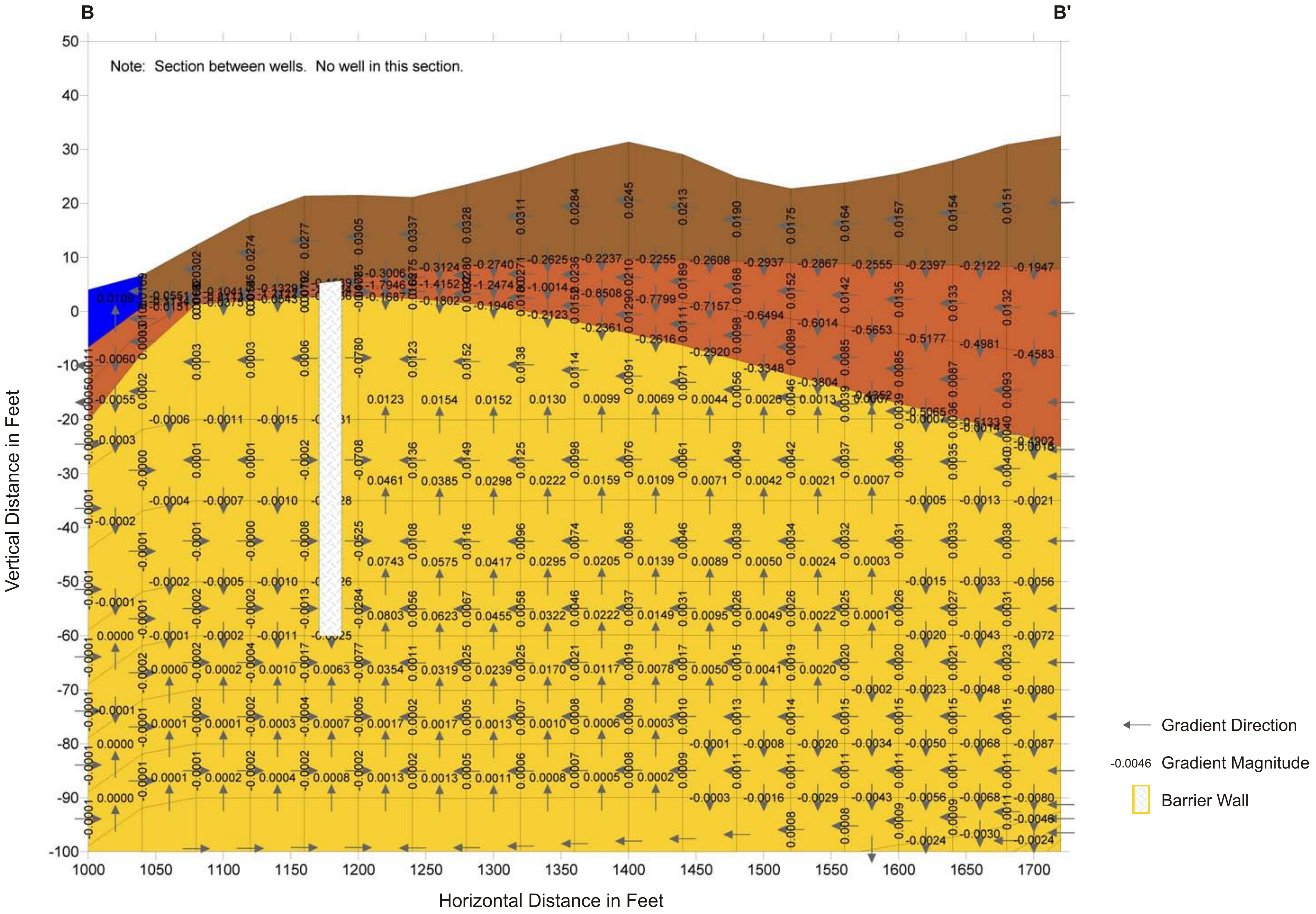

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Figure A-8
Gradient B-B', Current Bathymetry, Veritical Barrier, Shallow Well
NW Natural "Gasco" Site

APPENDIX B

SSPA MEMO ON REASONABLE WORST CASE SCENARIO

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Memorandum

Date: October 15, 2008

From: Michael J. Riley

To: John Edwards, Anchor Environmental

Subject: NW Gasco: Groundwater Modeling, Proposed Reasonable Worst-Case Scenario

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The groundwater model analysis for the Gasco shoreline wells was conducted for average water level data and river stage data presented in the site Draft Remedial Investigation Report (RI), June 30, 2006. Average water level data from 8 fill wells and 16 alluvium wells and from on-site river stage measurements were compiled for model calibration. The model was then used to evaluate groundwater extraction rates from shoreline wells to contain site groundwater.

The Oregon Department of Environmental Quality (DEQ) has requested that the groundwater model analysis be conducted for a reasonable worst-case condition rather than just of average conditions to evaluate higher groundwater extraction rates that may be necessary to contain groundwater under higher groundwater flow conditions. The following is an analysis of site groundwater and river stage data and recommendation on conditions to use for a reasonable worst-case evaluation.

Data Analysis

The difference between water level data and river stage data for fill and alluvium wells are presented in Table 1. The highlighted cells in the table indicate when the highest difference between groundwater level and river stage occur for each well.

For fill wells, the highest water level difference occurred at the March 2000 monitoring event at 5 of the 8 wells. The highest occurred at two wells during the September 2005 event and the highest occurred in November 1998 at one well. The highest water level differences exceeded the average values used in the model by approximately 2.5 to 4.5 feet.

For alluvium wells, the highest water level occurrence varied over more dates than for the fill wells. Of the 16 alluvium wells, three wells had the highest difference from the river in August 1999 while December 2004 was the highest in three other wells. Two wells had the highest difference in September 1996. Isolated maximum differences occurred in October 2001 and December 2003 at one well each. The most frequent maximum difference occurred in March 2000 when the maximum difference occurred at six wells.

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The alluvium wells showed a marked difference from well to well depending on proximity to the shoreline. For wells close to the shoreline (MW-2-61, MW-3-56, MW-4-35, MW-4-57, MW-4-101, MW-5-32, MW-5-100, MW-5-175, MW-8-56, and MW-13-61), the maximum water level difference between groundwater and the river varied less than 2 feet with the exception of MW-4-35. In addition, these wells showed negative differences indicating that the river stage was above the water level in the well.

Wells located farther from the shoreline (MW-9-29, MW-10-61, MW-12-36, MW-14-110, MW-15-50, and MW-15-66), showed much higher maximum differences ranging from 7 to 25 feet. In addition, these wells do not show negative values in the difference between water levels and river stage. In all of these wells, even the minimum difference is well above river stage.

Water level differences were compared to monthly precipitation data to aid in understanding differences between river stage and water levels. There was no correlation between precipitation and occurrence of highest water level differences. For instance, November 1998, had 11 inches of rainfall, but only one well showed a maximum water level difference that month. By contrast, 5 fill wells and 6 alluvium wells showed the highest water level data in March 2000, when only 3.2 inches of rainfall occurred. It is likely that the November 1998 rainfall partially went to moisture deficit since previous months were quite dry. However, the winter of 2000 was not particularly wet with 13.4 inches of rainfall from January through March. From 1996 to 2005, the rainfall that occurred in the three months prior to February or March monitoring events was higher in 6 of those years than in 2000. From this, there is no obvious correlation between precipitation and the highest difference between water level data and river stage.

Recommendation

A reasonable worst-case scenario can be based on the March 2000 water level and river stage data. The lack of correlation between precipitation and highest water level differences indicates that there is no value in searching precipitation data for extreme events. The likely reason for the lack of correlation is that higher precipitation generates higher runoff with little change in infiltration, especially if the soil is already saturated.

Water levels in nearshore alluvium wells are strongly correlated with river stage showing limited range between minimum and maximum water level differences. Nearshore wells in both the fill and alluvium often show negative differences between water levels and river stage, which suggests that the difference may be affected by the timing of data collection with respect to tidal fluctuations. Consequently, the differences may not be meaningful with respect to groundwater flow rates over periods of longer than a few hours.

Based on the above, it is recommended that the reasonable worst-case scenario for evaluation of capture at nearshore wells be based on water level data at upland wells and river stage data from the March 27, 2000 monitoring event. The groundwater flow model would be re-calibrated to water level data at fill wells MW-8-29, MW-10-25, MW-11-32, and MW-13-30 and alluvium wells MW-9-29, MW-10-61, MW-12-36, MW-14-110, MW-15-50, and MW-15-66. The recalibration will likely include changes to both the recharge rate and the upland boundary head.

The reasonable worst-case re-calibration would be used to simulate the hypothetical intermediate and shallow well extraction systems. The pump rates developed for the reasonable worst-case scenarios will be compared to the simulations under average conditions as a means of evaluating possible seasonal fluctuations in pump rates to achieve capture.

Table 1. Difference between water level and river stage based on data presented in the Draft Remedial Investigation Report

(Highlighted values are dates of maximum difference between water levels and river at each well)

	Nearshore Fill						Upland Fill		Nearshore Alluvium										Upland Alluvium					
Date	**MW-1-22**	**MW-2-32**	**MW-3-26**	**MW-6-32**	**MW-8-29**	**MW-13-30**	**MW-10-25**	**MW-11-32**	**MW-2-61**	**MW-3-56**	**MW-4-35**	**MW-4-57**	**MW-4-101**	**MW-5-32**	**MW-5-100**	**MW-5-175**	**MW-8-56**	**MW-13-61**	**MW-9-29**	**MW-10-61**	**MW-12-36**	**MW-14-110**	**MW-15-50**	**MW-15-66**
05-Dec-95	1.70	0.33	-0.37	-0.10	0.44		5.34	6.80		-0.62	-0.48	-0.76		-0.53			-0.38		12.55	7.01	10.42			
05-Jan-96	7.85	1.99	2.21	8.24	7.65		11.59	13.77		-0.21	-0.36	-0.28		-0.17			-0.04		17.89	10.58	15.44			
12-Feb-96	0.58	-0.58	-0.84	-0.47	-4.33		1.68	3.01		-0.99	-0.98	-1.00		-1.01			-0.86		7.90	3.98	6.99			
18-Mar-96	7.90	2.02	1.83	9.00	9.46		12.86	14.56		0.00	-0.11	-0.09		0.05			0.18		17.11	10.45	15.27			
16-Apr-96	6.57	1.10	1.45	7.56	8.98		12.06	13.74		0.07	-0.25	-0.07		-0.06			0.16		16.19	9.73	14.47			
10-May-96	9.37	3.36	3.50	10.58	11.69		14.61	16.36		0.43	0.33	0.30		0.42			0.57		19.08	11.80	16.82			
17-Jun-96	5.14	1.33	0.98	6.38	7.36		9.98	11.76		0.13	0.20	0.07		0.14			0.25		16.89	9.64	12.98			
21-Aug-96	11.61	6.03	5.24	12.71	13.28		16.01	18.36		0.45	1.14	0.39		0.74			0.57		22.55	13.27	17.53			
17-Sep-96	11.89	6.60	7.70	12.77	13.16		16.62	18.57		0.25	1.59	0.20		0.76			0.70		24.33	14.23	18.03			
30-Sep-96	12.18	6.82	5.39	13.03	13.50		16.93	18.73		1.63	1.68	1.52		1.75			1.28		23.55	14.09	18.32			
15-Nov-96	11.17	5.24	6.15	11.31	11.26		15.60	16.99		0.39	0.49	0.33		0.79			0.56		23.84	13.75	17.64			
24-Feb-97	8.74	2.15	1.90	9.08	7.06		10.77	13.61		-0.01	0.12	-0.09		0.06			0.20		19.70	11.40	15.38			
10-Jun-97	2.03	0.40	0.48	1.87	0.70		3.38	6.06		0.04	0.01	0.14		0.03			0.05		12.98	7.30	10.37			
26-Aug-97	11.47	4.86	3.60	9.08	10.88		14.22	16.19		0.07	0.08	0.79		0.30			0.10		18.04	11.27	16.66			
25-Nov-97	11.61	4.24	6.14	10.50	9.52		14.14	15.79		0.71	0.68	1.01		0.88			0.56		21.08	12.72	18.18			
16-Feb-98	11.94	4.12	5.25	11.01	8.83	9.92	13.41	16.16		0.31	1.08	0.22		0.53			0.42	0.59	22.11	13.23	18.76			
01-Jun-98	2.71	-0.06	-0.05	2.21	1.49	1.62	7.04	7.99		0.01	0.09	-0.02		-0.05			-0.05	0.12	12.85	7.42	11.31			
25-Aug-98	10.73	5.32	4.03	11.38	11.80	10.90	18.50	17.70		-0.12	0.82	-0.23		0.29			0.27	0.16	18.58	11.74	17.32			
16-Nov-98	10.53	4.07	6.11	11.48	12.10	11.28	19.12	18.14	0.25	0.70	1.42	0.63	0.27	1.04	0.32	0.34	1.20	0.87	19.75	12.72	17.97	6.77		
15-Feb-99	12.60	5.26	5.66	12.98	11.25	11.64	16.63	18.18	0.29	0.69	0.42	0.64	0.43	0.90	0.41	0.47	0.98	0.98	22.36	13.81	19.00	6.88		
11-May-99	9.52	3.36	4.44	11.19	11.62	9.92	12.49	16.66	0.51	0.72	0.71	0.63	0.51	0.86	0.53	0.60	0.91	0.96	18.24	11.48	16.67	5.88		
20-Aug-99	11.06	5.98	5.87	9.39	13.12	11.36	17.90	17.82	1.14	1.44	2.24	1.40	1.17	1.78	1.19	1.25	1.77	1.65	19.29	12.55	17.97	7.16	13.78	13.67
25-Oct-99	10.64	4.10	4.08	10.88	12.63	10.71	17.19	17.16	0.01	0.39	0.89	0.41	0.29	0.64	0.32	0.45	0.72	0.52	18.16	11.55	16.55	6.10	12.60	12.45
27-Mar-00	15.05	7.55	8.05	14.64	12.84	13.59	14.70	18.67	0.65	0.98	2.03	0.91	0.63	1.65	0.66	0.73	1.23	1.25	24.58	15.19	20.22	7.48	15.10	14.56
15-Jun-00	8.07	2.86	3.68	9.04	9.14	8.62	14.06	14.61	-0.09	0.09	-0.30	-0.03	-0.16	0.01	-0.18	-0.09	0.29	0.26	17.08	10.36	15.16	4.97	11.41	10.68
04-Oct-00	10.48	5.10	5.87		12.66	11.42	19.01	18.12	-0.63	-0.47	0.40	-0.54	-0.68	-0.22	-0.69	-0.62	-0.45	-0.32	17.86	10.90	15.72	4.98	12.04	11.28
20-Dec-00	9.65	4.61	7.49		12.73	11.04	19.08	18.18	0.16	0.06	1.29	0.14	0.48	0.38	0.56	0.76	-0.11	-0.04	18.31	12.01	16.40	4.24	12.60	11.86
27-Mar-01	11.42	6.10	6.83		13.48	11.63	19.06	18.34	-0.06	0.30	1.11	0.20	-0.16	0.75	-0.16	-0.11	0.64	0.50	19.32	12.06	17.31	5.75	13.15	12.41
28-Jun-01	11.62	5.86	4.86		12.84	11.69	16.84	18.03	0.72	0.85	1.92	0.90	1.00	1.13	0.97	1.11	0.98	0.95	19.23	11.30	17.52	6.42	13.54	12.84
08-Oct-01	11.54	4.33	4.69		13.13	11.48	16.97	17.32	0.59	1.00	1.52	0.88	1.67	1.19	0.74	0.77	1.05	1.03	18.18	11.47	16.27	5.93	12.59	11.90
12-Dec-01	10.34	4.10	5.94		9.83	9.29	15.04	14.71	0.19	0.58	2.74	0.52	0.22	1.14	0.22	0.30	1.02	0.76	20.26	12.65	17.34	6.07	13.24	12.52
02-Apr-02	11.25	5.47	4.98		10.33	10.99	13.93	16.71	0.11	0.22	-0.36	0.17	0.25	0.60	0.23	0.33	0.00	0.41	21.14	12.35	17.69	5.30	12.89	12.12
10-Jul-02	8.61	3.72	3.73		9.70	8.81	14.06	15.43	0.14	0.42	0.46	0.35	0.27	0.59	0.25	0.31	0.44	0.51	17.08	10.45	15.75	5.16	11.10	11.88
23-Sep-02	11.71	4.91	4.78		13.08	11.63			0.37	0.82	1.69	0.66	0.32	1.09	0.30	0.36	1.18	1.03	18.78	11.90	16.67	6.26	13.03	12.35
17-Dec-02	5.59	0.23	4.04		7.48	6.02	13.20	11.27	-0.02	-0.80	1.11	-0.71	-0.52	-0.91	-0.53	-0.62	-1.85	-0.79	14.90	8.71	12.82	3.48	9.95	9.38
17-Mar-03	10.52	4.42	4.99		9.07	9.61	13.49	15.56	0.16	0.39	0.83	0.29	0.12	0.68	0.11	0.19	0.29	0.53	21.45	12.95	11.89	5.86	13.14	12.42
02-Jun-03	6.91	1.77	1.19		6.27	6.48	9.95	12.12	0.11	0.21	0.05	0.11	0.19	0.12	0.14	0.23	0.16	0.31	15.53	9.27	13.80	4.27	10.22	9.67
29-Sep-03	10.63	3.70	3.81		11.99	10.61	17.45	16.12	0.18	1.04	0.63	1.00	1.20	1.13	1.09	1.17	0.64	1.25	17.32	10.88	15.40	5.56	12.08	11.42
29-Dec-03	9.92	3.12	6.39		9.70	8.83	14.41	15.18	0.38	0.80	3.59	0.76	0.62	1.20	0.61	0.67	0.70	0.91	20.96	12.67	17.78	5.76	13.25	12.52
29-Mar-04	11.81	5.60	6.05		11.20	11.32			-0.50	-0.37	0.55	-0.42	-0.50	0.27	-0.49	-0.41	-0.39	-0.28	20.94	12.51	18.32	5.39	13.54	12.70
11-Aug-04	10.81	4.34	3.83		12.08	10.79	17.05	17.12	-0.07	-0.73	0.57	-0.66	-0.79	-0.20	-0.60	-0.43	-0.38	-0.69	18.08	14.16	16.30	4.80	12.66	11.69
20-Dec-04	9.51	3.03	4.88		10.50	9.41	14.96	15.84	1.43	1.24	1.82	1.19	1.21	1.70	1.25	1.36	0.99	1.30	21.07	13.04	17.35	6.17	13.37	12.27
28-Mar-05	9.00	2.50	5.47		8.90	8.15	13.28	14.15	0.76	0.56	1.81	0.55	0.57	0.65	0.55	1.23	0.59	0.78	20.84	12.09	16.42	5.33	12.34	11.67
20-Jun-05	11.43	5.92	5.20		11.55	10.43	15.66	17.25	0.18	0.58	1.34	0.56	0.32	0.94	0.28	0.35	1.08	0.73	21.59	13.48	18.37	6.58	14.07	12.91
16-Sep-05	13.36	5.90	6.04		14.31	13.17	18.37	19.15	0.41	1.04	2.38	0.80	0.29	1.49	0.35	0.39	1.69	1.31	21.39	13.80	18.47	7.25	14.63	13.81
07-Dec-05	10.81	4.52	5.87		10.56	9.79	15.52	16.43	-0.34	-0.19	0.85	-0.30	-0.51	0.53	-0.40	-0.32	-0.03	0.07	21.58	12.94	17.38	5.44	13.19	12.33
Minimum	0.58	-0.58	-0.84	-0.47	0.44	1.62	1.68	3.01	-0.63	-0.99	-0.98	-1.00	-0.79	-1.01	-0.69	-0.62	-1.85	-0.79	7.90	3.98	6.99	3.48	9.95	9.38
Maximum	15.05	7.55	8.05	14.64	14.31	13.59	19.12	19.15	1.43	1.63	3.59	1.52	1.67	1.78	1.25	1.36	1.77	1.65	24.58	15.19	20.22	7.48	15.10	14.56
Calibration Targets	10.51	4.37	5.17	11.99	11.22	10.35	15.85	16.57	0.25	0.45	1.20	0.39	0.31	0.75	0.29	0.38	0.55	0.60	19.47	12.12	16.73	5.76	12.59	11.94
Difference from Calibration Targets	4.54	3.18	2.88	2.65	3.09	3.24	3.27	2.58	1.18	1.18	2.39	1.13	1.36	1.03	0.96	0.98	1.22	1.05	5.11	3.07	3.49	1.72	2.51	2.62