

Site Completion Case Study Frontier Hard Chrome



EPA

United States
Environmental Protection
Agency

Thanks to:
Bernie Zavala
U.S. EPA, Region 10

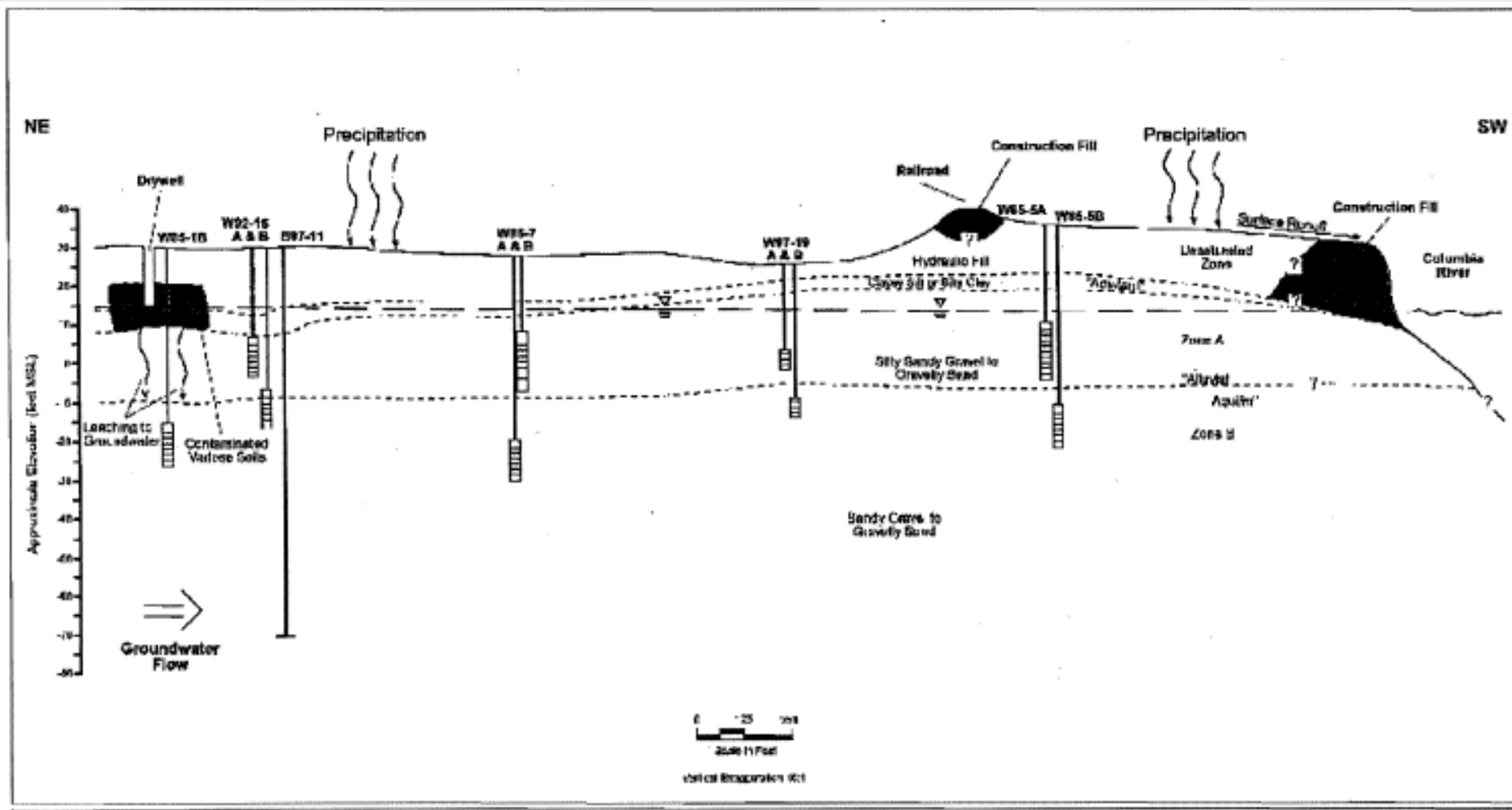
Overview of this Presentation

- ◆ Description of the site (CSM) and data results from additional investigations
- ◆ The remedial technologies & implementation of the remedy
- ◆ Groundwater monitoring program
- ◆ Evaluation of the groundwater data by the U.S. EPA's Groundwater Statistics tool
- ◆ Results and recommendations

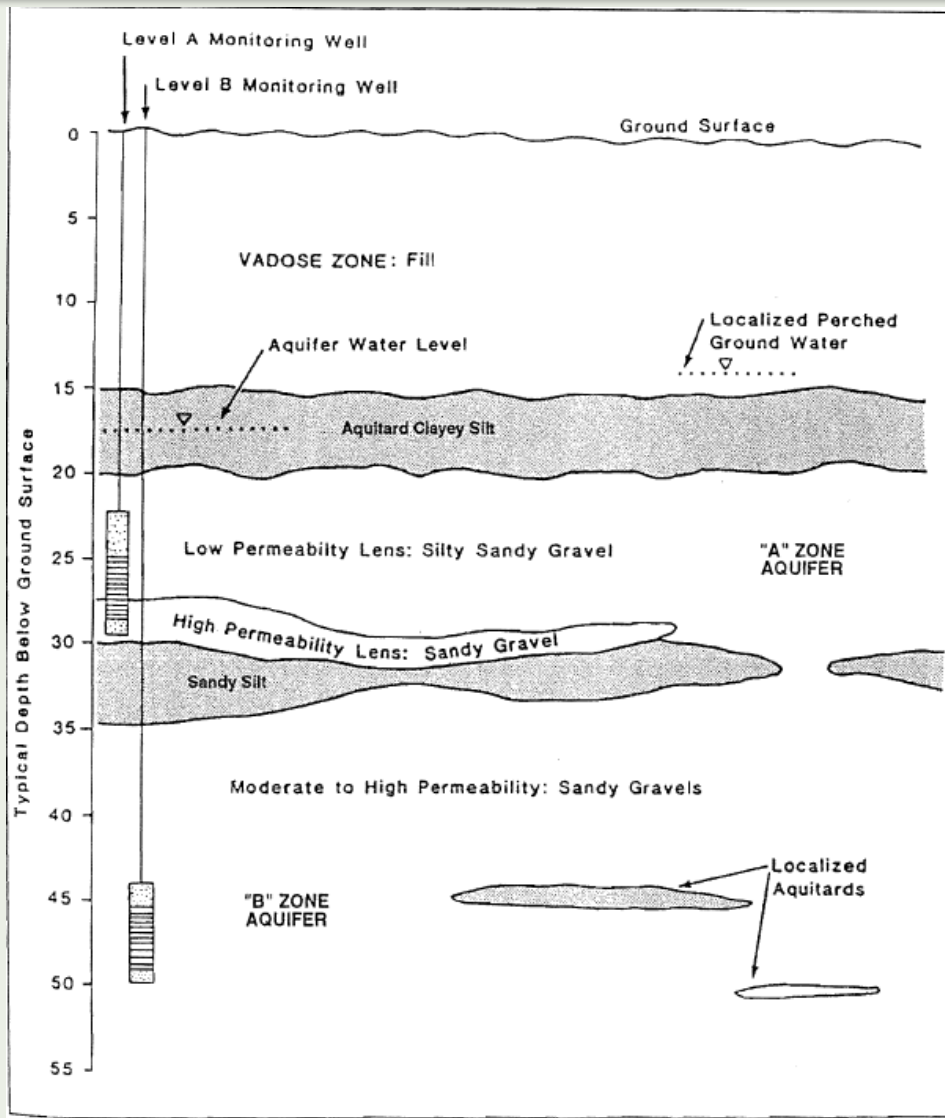
Frontier Hard Chrome Superfund Site



Conceptual Site Model

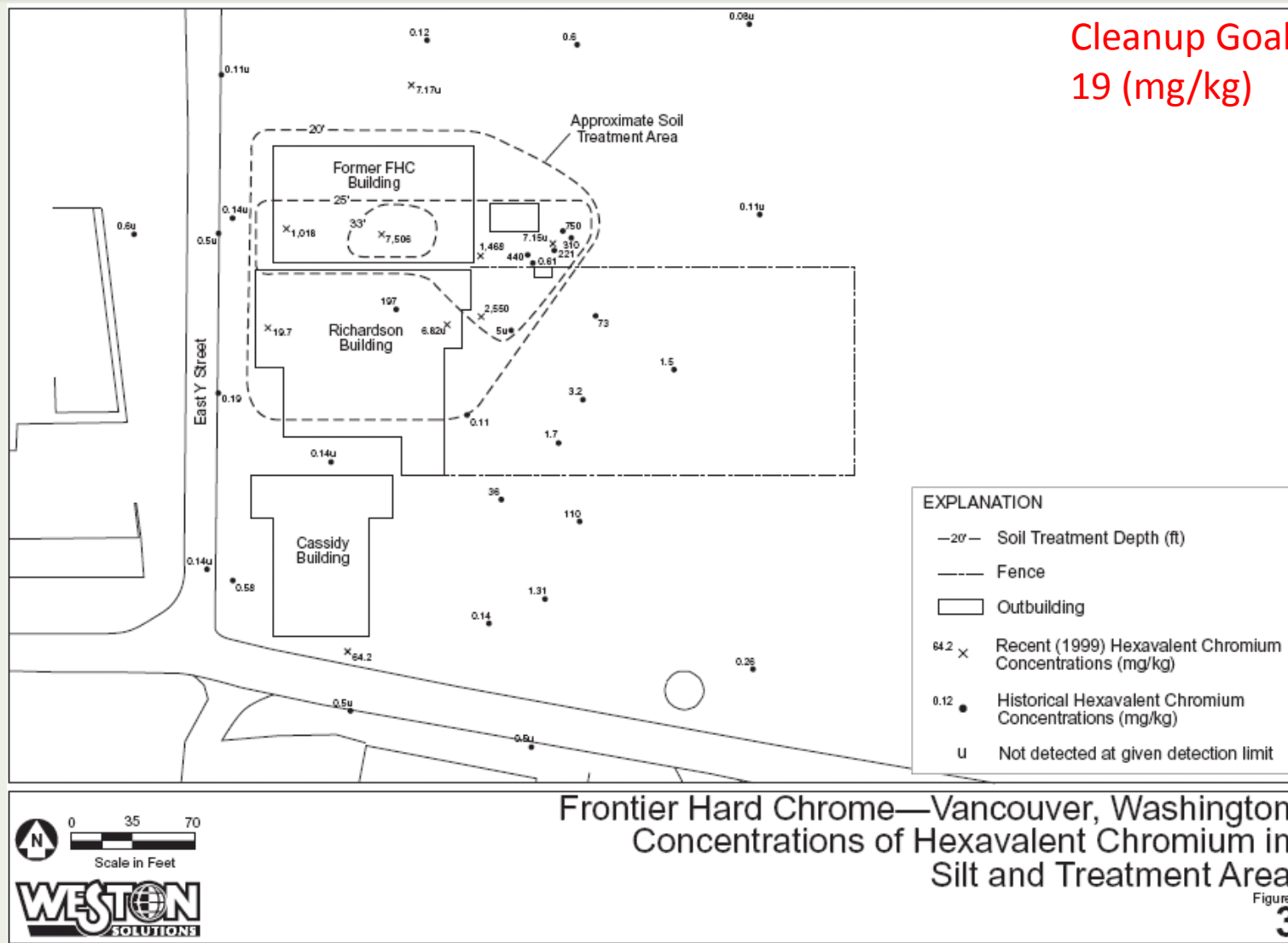


Generalized Hydrogeological Model



Data Results from the Additional Investigation Soil (mg/kg)

Cleanup Goal
19 (mg/kg)



Direct push survey

Direct push survey sampling for Cr(VI) in groundwater & downhole electromagnetic borehole flowmeter testing results

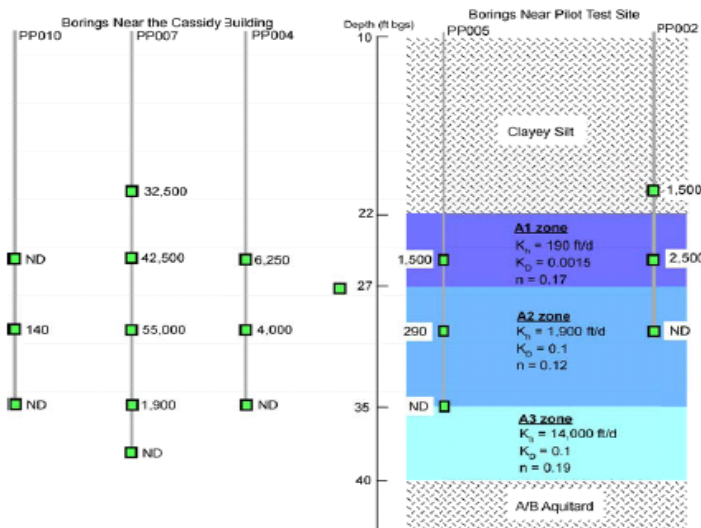
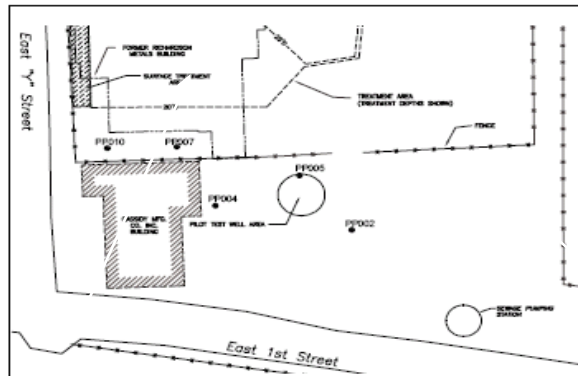


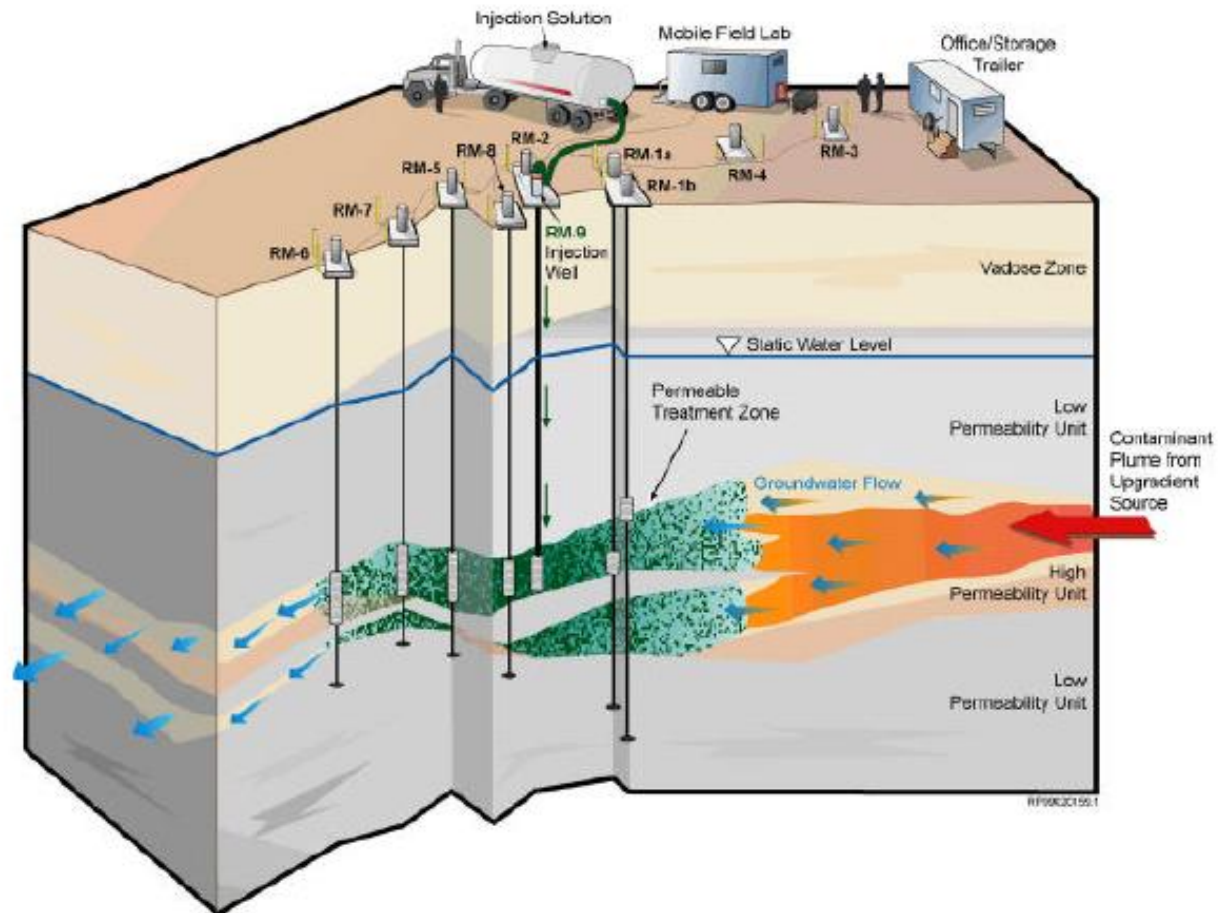
Figure 2.3. Geoprobe Sampling Locations and Aqueous Cr(VI) Concentrations (µg/L) Measured During the Initial Vertical Profile Sampling at the Site (EPA)

Taken from Battelle, (1/2004) In Situ Redox Manipulation Permeable Reactive Barrier Emplacement: Final Report, Frontier Hard Chrome

The Remedial Technologies

- ◆ In Situ Redox Manipulation Permeable Reactive Barrier
- ◆ Treatment of the source area soil & groundwater in situ using augers to mix a reducing agent “EcoBond”

Schematic to illustrating the concept of the ISRM Wall



Taken from Battelle (1/2004), In Situ Redox Manipulation Permeable Reactive Barrier Emplacement: Final Report, Frontier Hard Chrome

Final Location of the Reactive Barrier

Injection
and
Monitoring
Wells

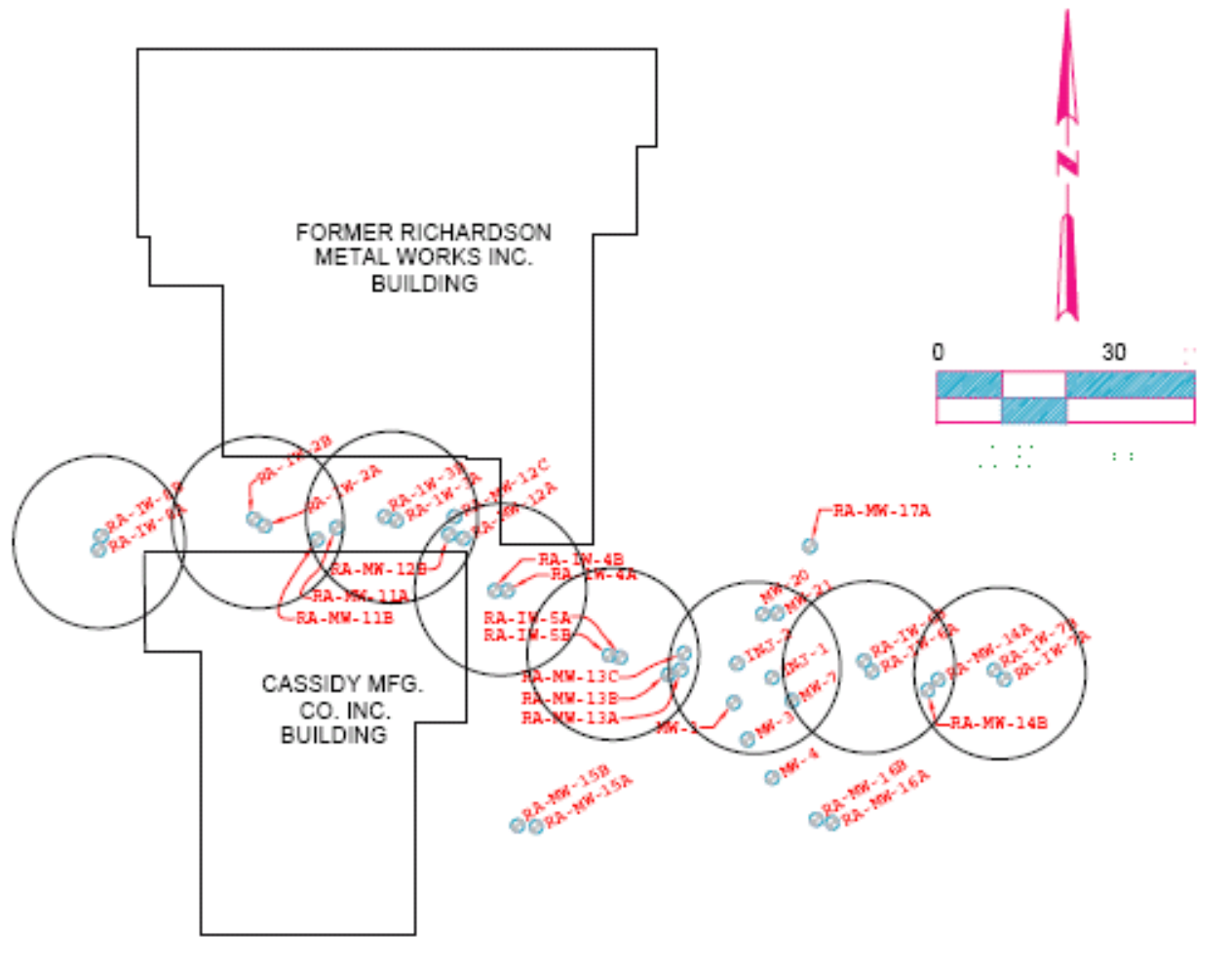


Figure 3.8. Well Location Map

Implementation of the ISRM Wall



Treatment of the Source Area Soil & Groundwater In Situ Using Augers to Mix the Reducing Agent “EcoBond”

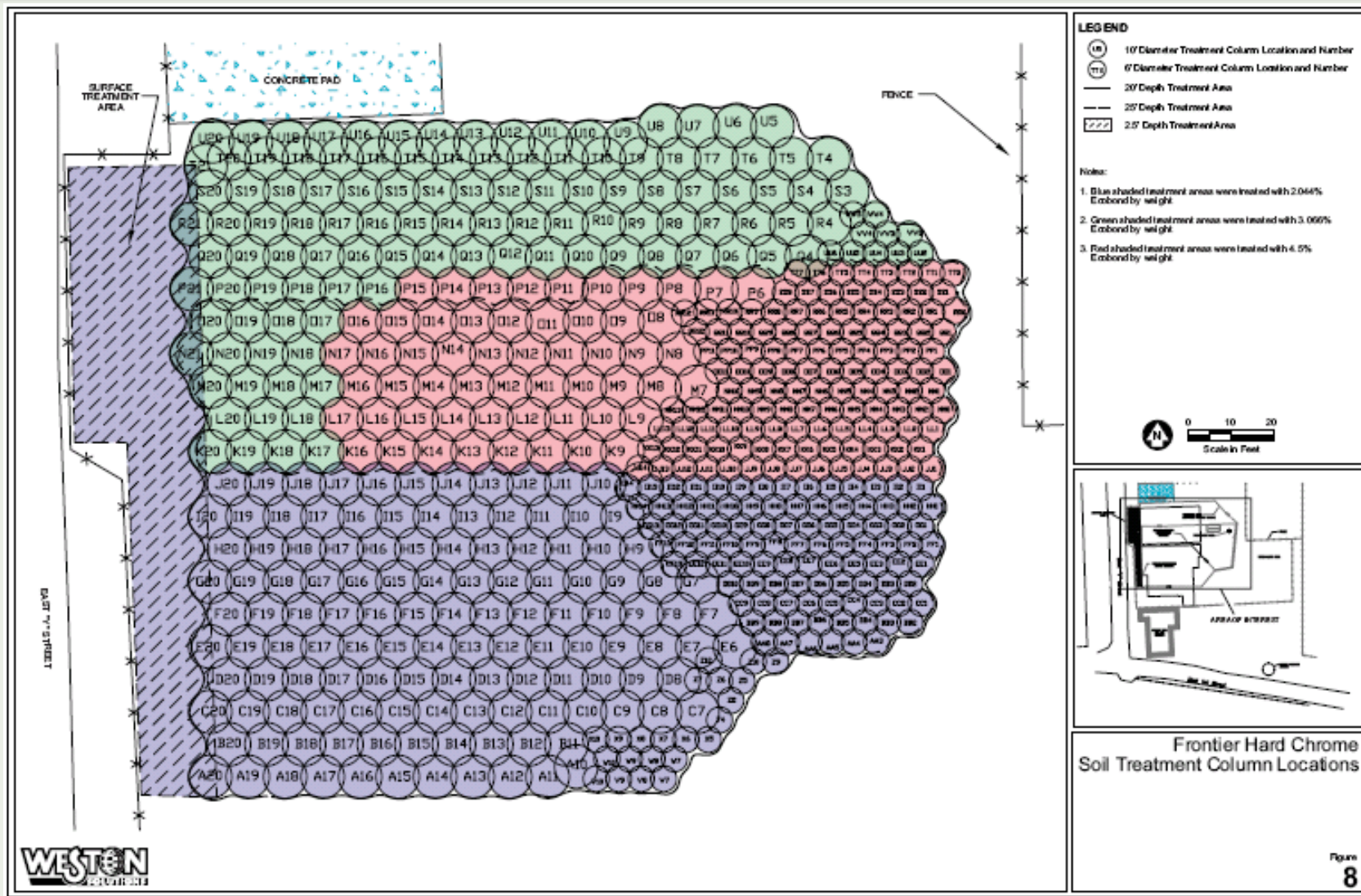
Two different auger size diameters, 10 and 6 feet with injection ports along the stem of the auger.
Treatment depths 2.5 to 25 feet BGS



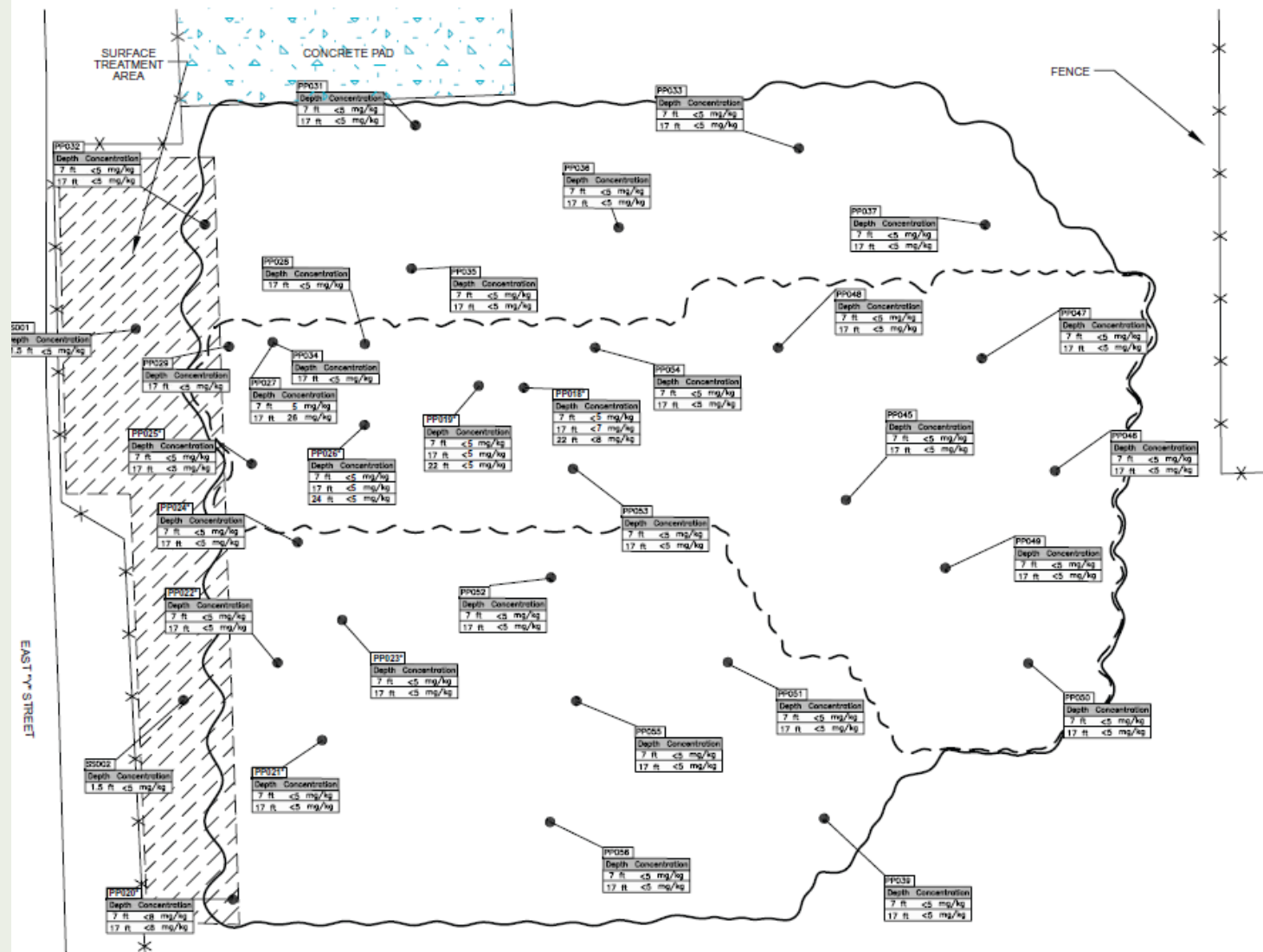
Treatment of the Source Area Soil & Groundwater In Situ Using Augers to Mix the Reducing Agent “EcoBond”



Treatment of the Source Area Soil & Groundwater In Situ Using Augers to Mix the Reducing Agent "EcoBond"



Confirmation Soil Sample Results Hexavalent Chromium (7 & 17 feet BGS)

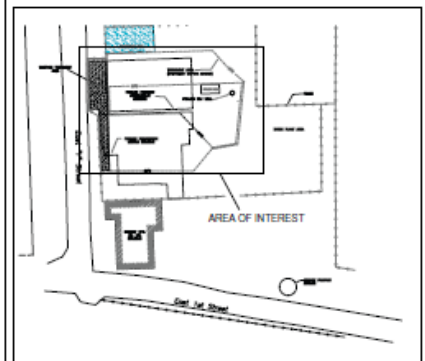


LEGEND

- PP018 ● Push-Probe Location and Number
- SS001 ● Grab Soil Sample Location and Number
- 20' Depth Treatment Area
- - - 25' Depth Treatment Area
- ▨ 2.5' Depth Treatment Area
- <5 mg/kg Hexavalent Chromium Not Detected Above Given Detection Limit
- * Denotes Optimization Testing Sample

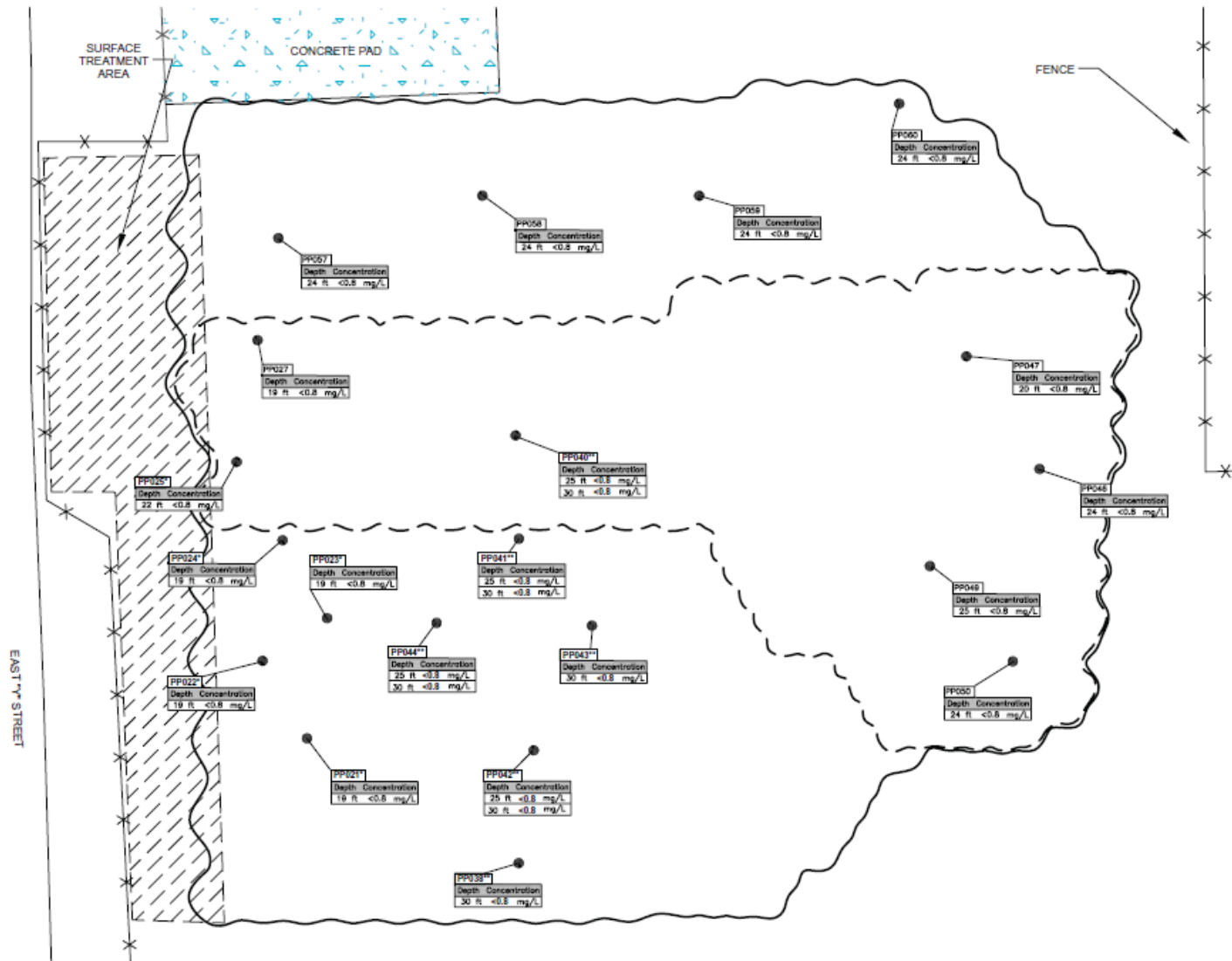
Notes:
Samples were collected between 6/26/03 and 8/28/03.

0 10 20
Scale In Feet



Frontier Hard Chrome Treated Area Confirmation Soil Samples Hexavalent Chromium Results

Confirmation Groundwater Sample Results Hexavalent Chromium (down to 30 feet BGS)



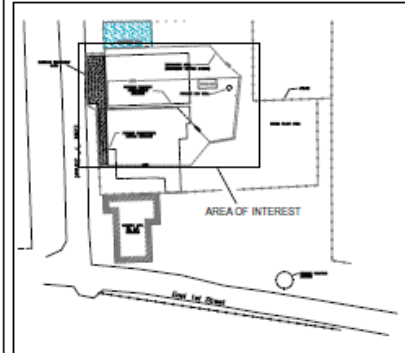
Legend:

- Push-Probe Location and Number
- 20' Depth Treatment Area
- - - 25' Depth Treatment Area
- ▨ 2.5' Depth Treatment Area
- $<0.8\text{ mg/L}</math> Hexavalent Chromium Not Detected Above Given Detection Limit$
- * Denotes Optimization Testing Sample
- ** Denotes sample taken prior to treatment. Low concentrations likely due to prior treatment of surrounding areas.

Notes:

Groundwater samples were collected between 6/26/03 and 8/27/03.

Scale: 0, 10, 20 Feet



Frontier Hard Chrome Treated Area Groundwater Confirmation Samples Hexavalent Chromium Results



Groundwater Monitoring Network and Monitoring Program

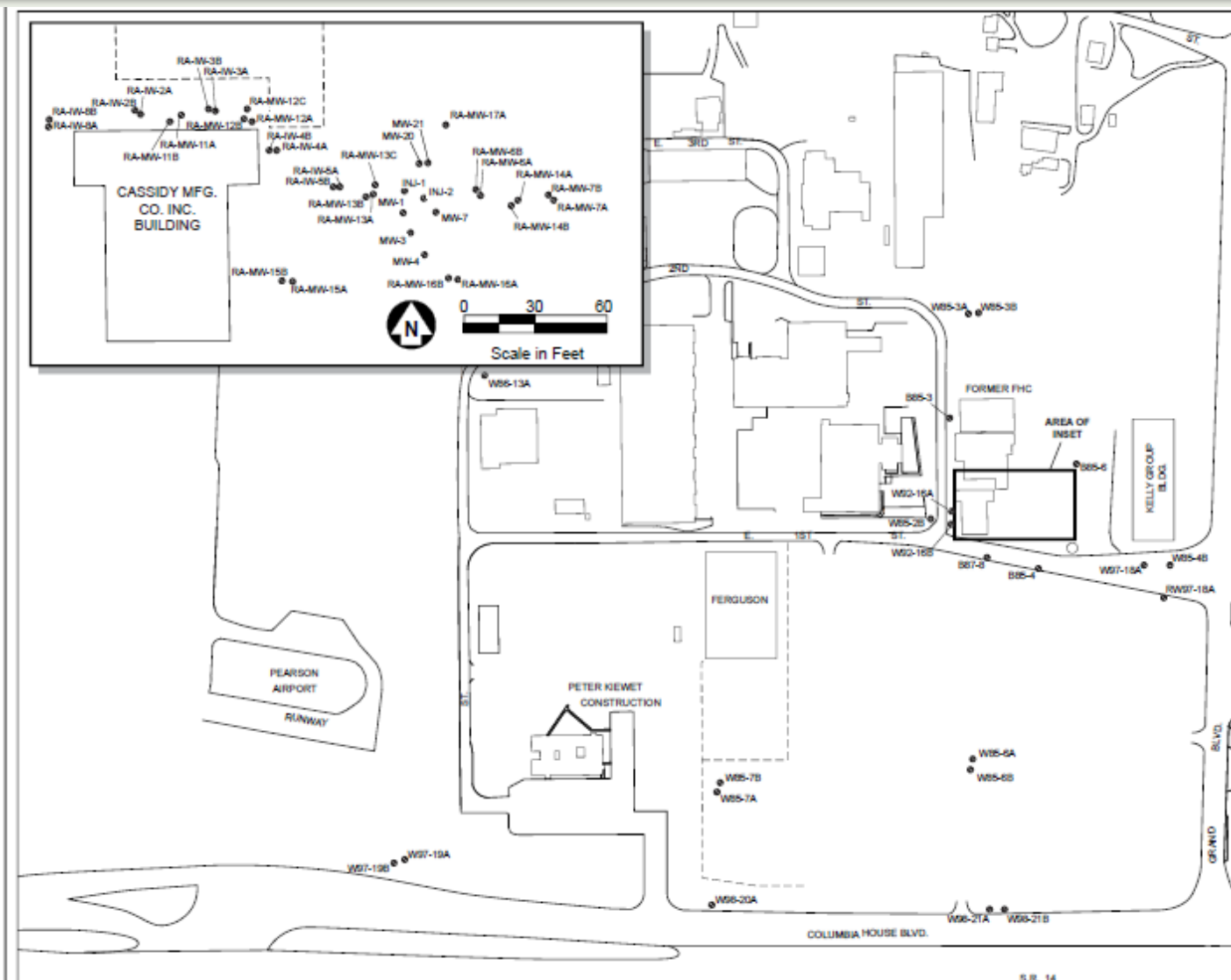


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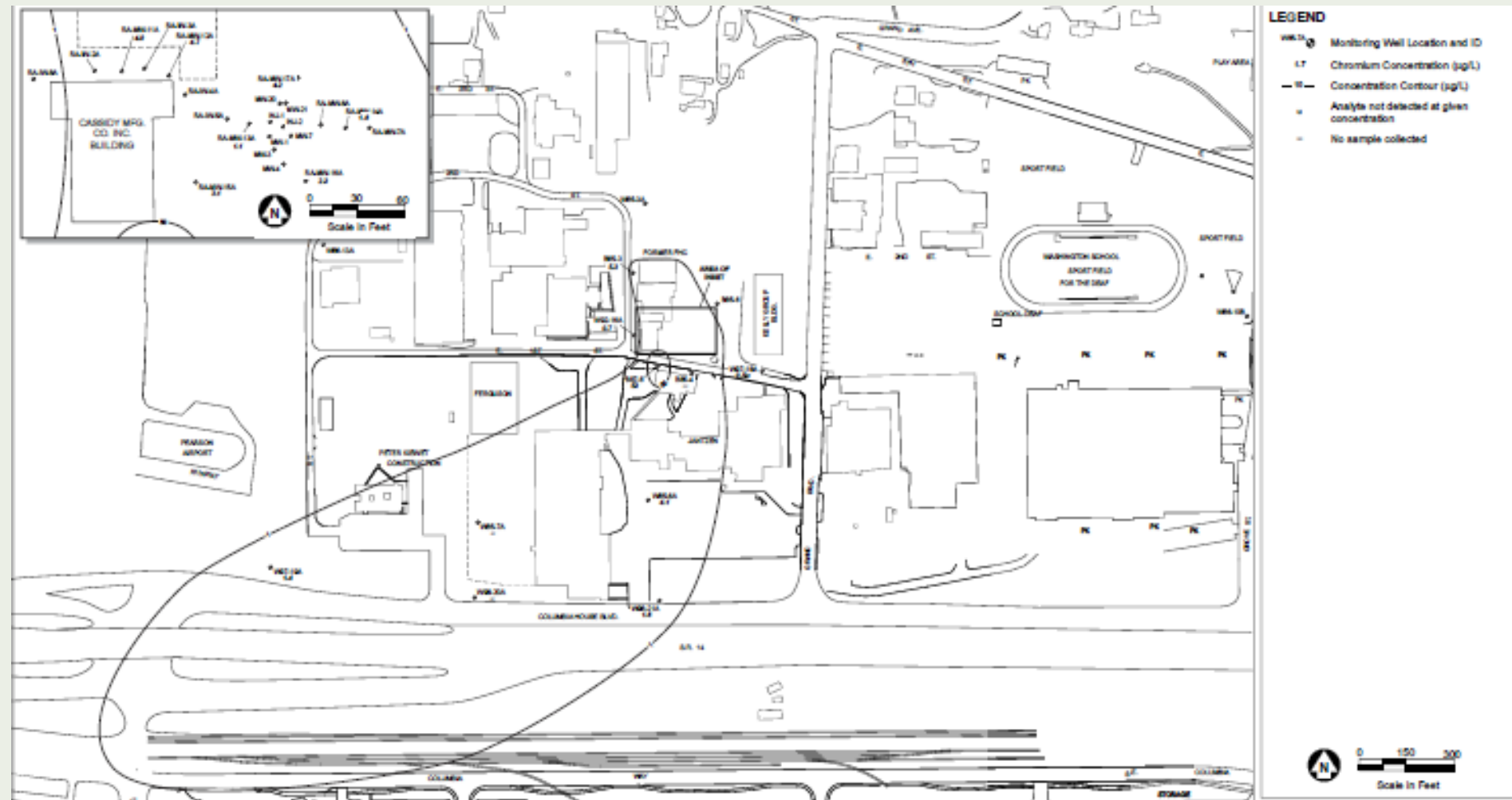
Site Map and Monitoring Well Locations



S.R. 14

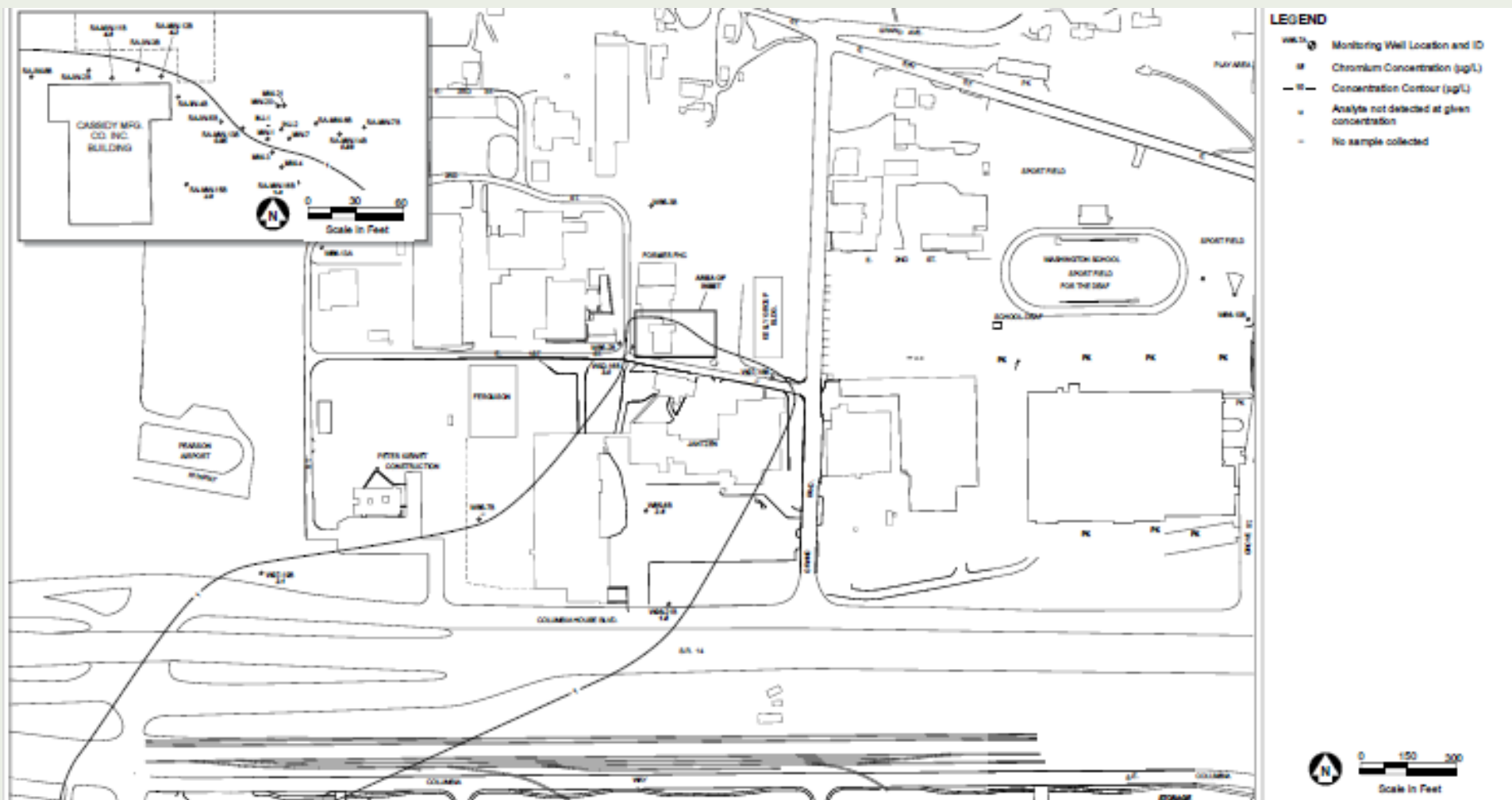
Groundwater Monitoring - A-Zone

Total Chromium Concentration ($\mu\text{g}/\text{l}$) September 2007



Groundwater Monitoring - B-Zone

Total Chromium Concentrations ($\mu\text{g}/\text{l}$) September 2007



Implementation of the Long Term Monitoring Optimization (LTMO)

- ◆ Monitoring And Remediation Optimization Software (MAROS) method was selected for the LTMO and the evaluation was performed in 2007
- ◆ Total of 33-monitoring wells were actively being monitored
 - » 16-wells in the A-zone
 - » 17-wells in the B-zone
- ◆ Sampling frequency was quarterly for the most part

MAROS Uses Several Lines of Evidence to Develop Recommendations for the Monitoring Network

Lines of Evidences	Method
Individual well trend	Mann-Kendall (linear regression)
Plume wide trends	Moment analysis: Total dissolved mass, center of mass, and distribution of mass
Well redundancy and sufficiency	Delaunay triangulation and slope factor calculation, along with area ratios and concentration ratios
Sampling frequency	Modified cost effective sampling
Data Sufficiency	Sequential T-Test, Student's T-Test and Power analysis
Qualitative Evaluation	Hydrogeologic factors, monitoring objectives, stakeholder concerns and all statistical results to develop final recommendations

Results of the LTMO

- ◆ Monitoring network was sufficient
- ◆ General decreasing trend in groundwater quality in all monitoring wells
- ◆ Some monitoring well redundancy
- ◆ Sampling frequency could be reduced from quarterly to semi-annually
- ◆ After 2007 the list of monitoring well locations for sampling changed from 33 to 22

The Statistical Evaluation of the Groundwater Data

- ◆ Recommended Approach for Evaluating Completion of Groundwater Restoration Remedial Actions, March 2014
- ◆ Groundwater Statistical Tool and User's Guide. January 2014

Remediation and Attainment Monitoring

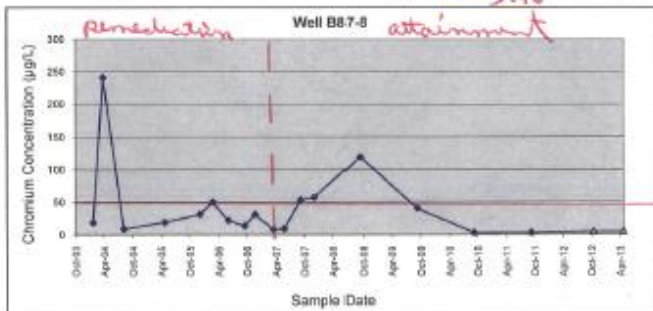
- ◆ The evaluation will be performed on a Well by Well basis per COC
- ◆ Either a statistical approach or non-statistical approach can be used
- ◆ There are two different phases of evaluation groundwater monitoring
 - » Remediation phase monitoring – typically is completed when the data collected and evaluated demonstrate that the groundwater has reached the cleanup levels
 - » Attainment phase monitoring – contaminant cleanup level has been met for each well and will be in the future

Example of Remediation & Attainment Monitoring

Well B87-8

Sample Number	Matrix	Sample Date	Analyte	Conc.	Units	Qualifier	Station Location	Notes	NTI
MJ2AG9	Water	04-Feb-04	Chromium	18.2	µg/L		B87-8	Total	2.0
MJ2BK0	Water	07-Apr-04	Chromium	24.9	µg/L		B87-8	Total	8.0
MJ4737	Water	18-Aug-04	Chromium	8.5	µg/L	J	B87-8	Dissolved	36.1
184247	Water	04-May-05	Chromium	18.8	µg/L		B87-8	Total	6.5
05504297	Water	13-Dec-05	Chromium	31	µg/L		B87-8	Total	5.1
104236	Water	06-Mar-06	Chromium	50	µg/L		B87-8	Total	8.0
244308	Water	14-Jun-06	Chromium	21.5	µg/L		B87-8	Total	3.0
394204	Water	27-Sep-06	Chromium	13.4	µg/L		B87-8	Dissolved	13.1
494082	Water	02-Dec-06	Chromium	31	µg/L		B87-8	Total	0.1
134251	Water	30-Mar-07	Chromium	7.8	µg/L		B87-8	Dissolved	11.1
234089	Water	06-Jun-07	Chromium	9.2	µg/L		B87-8	Dissolved	9.6
394552	Water	18-Sep-07	Chromium	53.3	µg/L		B87-8	Dissolved	2.1
504144	Water	11-Dec-07	Chromium	56.9	µg/L		B87-8	Dissolved	8.4
8394098	Water	21-Sep-08	Chromium	119	µg/L		B87-8	Dissolved	13.1
90908520	Water	16-Sep-09	Chromium	40.5	µg/L		B87-8	Dissolved	16.1
1009085-20	Water	15-Sep-10	Chromium	2.71	µg/L		B87-8	Dissolved	5.6
1009085-10	Water	14-Sep-11	Chromium	3	µg/L		B87-8	Dissolved	2.2
1210057-13	Water	17-Oct-12	Chromium	5.00	µg/L		B87-8	Dissolved	7.4
1304072-01	Water	25-Apr-13	Chromium	5.00	µg/L		B87-8	Dissolved	5.4

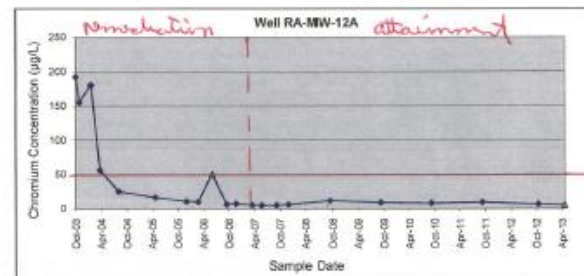
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U 5.96



Note: Where a dissolved concentration is used, the NTU value listed is the pre-filtering value.

Well RA-MW-12A

Sample Number	Matrix	Sample Date	Analyte	Conc.	Units	Qualifier	Station Location	Notes	NTU
MJ2524	Water	17-Dec-03	Chromium	192	µg/L		RA-MW-12A	Dissolved	>10
MJ27F5	Water	12-Nov-03	Chromium	155	µg/L		RA-MW-12A	Dissolved	>10
MJ2AF0	Water	02-Feb-04	Chromium	180	µg/L		RA-MW-12A	Total	7.00
MJ28H9	Water	06-Apr-04	Chromium	55.8	µg/L		RA-MW-12A	Dissolved	17.00
MJ4725	Water	17-Aug-04	Chromium	24.9	µg/L		RA-MW-12A	Dissolved	12.00
184233	Water	05-May-05	Chromium	16	µg/L		RA-MW-12A	Dissolved	32.00
05504282	Water	12-Dec-05	Chromium	10.2	µg/L		RA-MW-12A	Dissolved	86.00
104243	Water	07-Mar-06	Chromium	9.8	µg/L		RA-MW-12A	Dissolved	60.00
244313	Water	15-Jun-06	Chromium	50	µg/L	U	RA-MW-12A	Dissolved	47.00
394218	Water	28-Sep-06	Chromium	6.0	µg/L		RA-MW-12A	Dissolved	80.00
494110	Water	04-Dec-06	Chromium	6.8	µg/L		RA-MW-12A	Dissolved	12.00
134295	Water	30-Mar-07	Chromium	5.0	µg/L		RA-MW-12A	Dissolved	85.00
234091	Water	05-Jun-07	Chromium	4.0	µg/L		RA-MW-12A	Dissolved	55.00
394550	Water	18-Sep-07	Chromium	4.7	µg/L		RA-MW-12A	Dissolved	11.00
504161	Water	12-Dec-07	Chromium	5.7	µg/L		RA-MW-12A	Dissolved	60.00
8394103	Water	23-Sep-08	Chromium	11.2	µg/L		RA-MW-12A	Dissolved	200.00
80908523	Water	16-Sep-09	Chromium	8.68	µg/L		RA-MW-12A	Dissolved	102.00
1009085-25	Water	15-Sep-10	Chromium	7.77	µg/L		RA-MW-12A	Dissolved	>10
1009084-24	Water	15-Sep-11	Chromium	9	µg/L		RA-MW-12A	Dissolved	40.00
1210057-25	Water	18-Oct-12	Chromium	6.08	µg/L		RA-MW-12A	Dissolved	12.10
1304072-02	Water	25-Apr-13	Chromium	5.00	µg/L	U	RA-MW-12A	Dissolved	5.10

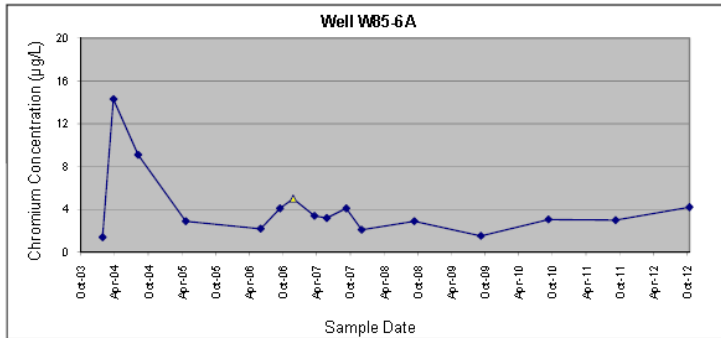


Note: Where a dissolved concentration is used, the NTU value listed is the pre-filtering value.

Examples of Attainment Monitoring Non-Statistical

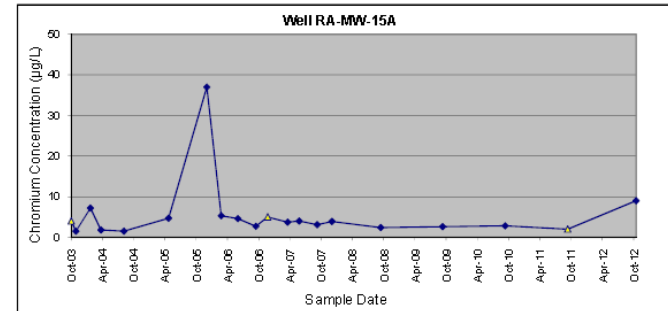
Well W85-6A

Sample Number	Matrix	Sample Date	Analyte	Conc.	Units	Qualifier	Station Location	Notes
MJ2A08	Water	09-Feb-04	Chromium	1.4	µg/L	J	W85-6A	Total
MJ2BL0	Water	08-Apr-04	Chromium	14.3	µg/L		W85-6A	Total
MJ4747	Water	19-Aug-04	Chromium	9.1	µg/L	J	W85-6A	Total
184235	Water	04-May-05	Chromium	2.9	µg/L		W85-6A	Total
244284	Water	12-Jun-06	Chromium	2.2	µg/L		W85-6A	Total
394182	Water	25-Sep-06	Chromium	4.1	µg/L		W85-6A	Total
494113	Water	05-Dec-06	Chromium	5	µg/L	U	W85-6A	Total
134245	Water	30-Mar-07	Chromium	3.4	µg/L		W85-6A	Total
234072	Water	05-Jun-07	Chromium	3.2	µg/L		W85-6A	Total
384545	Water	18-Sep-07	Chromium	4.1	µg/L		W85-6A	Total
504132	Water	10-Dec-07	Chromium	2.1	µg/L		W85-6A	Total
8394083	Water	20-Sep-08	Chromium	2.9	µg/L		W85-6A	Total
90906501	Water	15-Sep-09	Chromium	1.53	µg/L		W85-6A	Total
1009065-03	Water	15-Sep-10	Chromium	3.06	µg/L		W85-6A	Total
1009064-03	Water	13-Sep-11	Chromium	3	µg/L		W85-6A	Total
1210057-03	Water	16-Oct-12	Chromium	4.21	µg/L		W85-6A	Total



Well RA-MW-15A

Sample Number	Matrix	Sample Date	Analyte	Conc.	Units	Qualifier	Station Location	Notes	NTU
MJ2506	Water	15-Oct-03	Chromium	4	µg/L	U	RA-MW-15A	Total	<10
MJ27E8	Water	11-Nov-03	Chromium	1.5	µg/L	BJ	RA-MW-15A	Total	<10
MJ2AG7	Water	04-Feb-04	Chromium	7.2	µg/L	J	RA-MW-15A	Total	1.00
MJ2BH1	Water	05-Apr-04	Chromium	1.8	µg/L	J	RA-MW-15A	Total	0.00
MJ4722	Water	17-Aug-04	Chromium	1.5	µg/L	J	RA-MW-15A	Total	0.00
184248	Water	04-May-05	Chromium	4.7	µg/L		RA-MW-15A	Total	2.00
05504290	Water	13-Dec-05	Chromium	37	µg/L		RA-MW-15A	Total	1.30
104251	Water	07-Mar-06	Chromium	5.3	µg/L		RA-MW-15A	Total	0.00
244290	Water	12-Jun-06	Chromium	4.6	µg/L		RA-MW-15A	Total	0.60
394192	Water	25-Sep-06	Chromium	2.7	µg/L		RA-MW-15A	Total	0.20
494090	Water	02-Dec-06	Chromium	5.0	µg/L	U	RA-MW-15A	Total	2.00
134241	Water	29-Mar-07	Chromium	3.7	µg/L		RA-MW-15A	Total	0.30
234068	Water	04-Jun-07	Chromium	4.0	µg/L		RA-MW-15A	Total	0.50
384541	Water	17-Sep-07	Chromium	3.1	µg/L		RA-MW-15A	Total	0.40
504153	Water	12-Dec-07	Chromium	3.9	µg/L		RA-MW-15A	Total	1.10
8394093	Water	21-Sep-08	Chromium	2.4	µg/L		RA-MW-15A	Total	0.30
90906514	Water	17-Sep-09	Chromium	2.62	µg/L		RA-MW-15A	Total	1.32
1009065-19	Water	16-Sep-10	Chromium	2.82	µg/L		RA-MW-15A	Total	<10
1009064-16	Water	15-Sep-11	Chromium	2	µg/L	U	RA-MW-15A	Total	2.46
1210057-18	Water	18-Oct-12	Chromium	9.00	µg/L		RA-MW-15A	Total	0.18



Note: Where a dissolved concentration is used, the NTU value listed is the pre-filtering value.

Groundwater Statistics Tool - Data input

Groundwater Statistics Tool

Data input worksheet

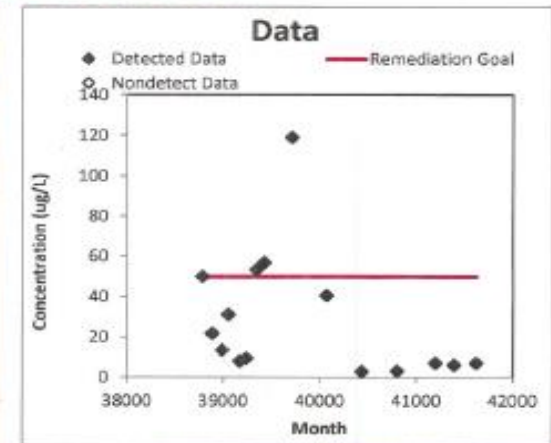
Site Name	Test
Operating Unit (OU)	Test
Type of Evaluation	Attainment
Date of Evaluation	4/7/2014
Person performing analysis	Bernie Zavala

Chemical of Concern	Chromium
Well Name/Number	B-87-8
Date Units	Date
Concentration Units	ug/L

Confidence Level Desired	95%
Remediation Goal	50
Source of cleanup goal (e.g. MCL or risk-based concentration)	risk-based
Risk of False Outlier Rejection	1%
Random Seed (may be left blank)	
Significant figures to use	3

Number of data points:	15
Number of detected results:	15
Number of nondetect results:	0
Detection frequency:	100%

Date (Date)	Chromium Concentration (ug/L)	Data Qualifier	Detected? (Yes or No)
3/5/2006	50		Yes
6/14/2006	21.8		Yes
9/27/2006	13.4		Yes
12/2/2006	31		Yes
3/30/2007	7.8		Yes
6/6/2007	9.2		Yes
9/18/2007	53.3		Yes
12/11/2007	56.9		Yes
9/21/2008	119		Yes
9/16/2009	40.5		Yes
9/15/2010	2.71		Yes
9/14/2011	3		Yes
10/17/2012	6.86		Yes
4/25/2013	5.96		Yes
12/11/2013	6.86		Yes



Axis Values			
Time		Concentration	
Min	Max	Min	Max
Auto	Auto	Auto	Auto

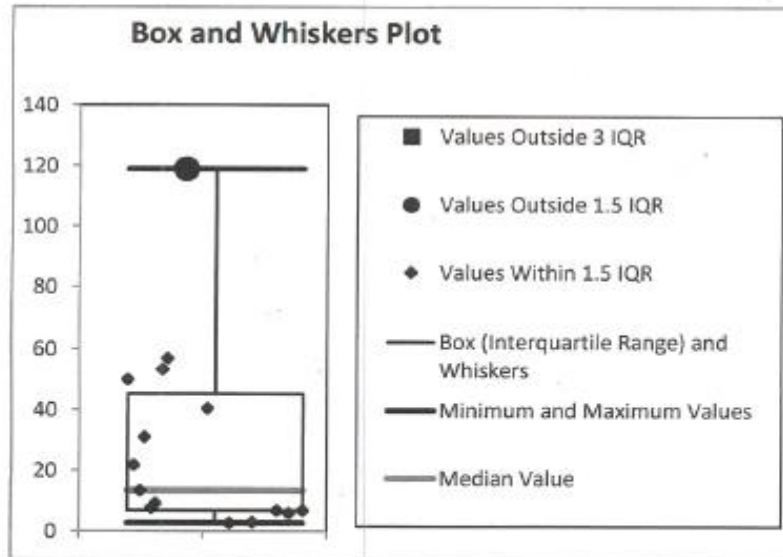
Reset Concentration Axis

Data Review		Recommendations	
Are all necessary data fields entered, and in proper format?	Yes		None
Are sufficient data points (>8) present for statistical analysis?	Yes		None
Are detection limits for nondetects ≤ maximum detected value?	Yes		None
Are all data within chart axis limits?	Yes		None

Groundwater Statistics Tool

Groundwater Statistics Tool Outlier testing worksheet

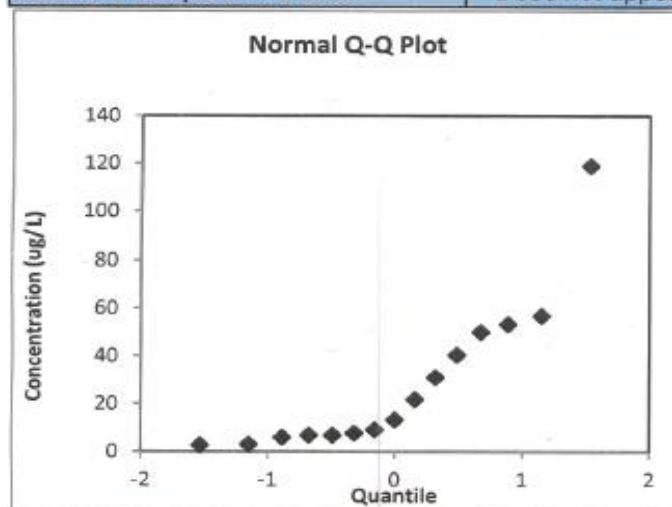
Dixon's Outlier Test Results		
Number of data points	15	
Risk of false rejection	1%	
Critical value	0.616	
Outlier type	Low	High
Test statistic	0.0642	0.5812
Potential Outlier?	No	No
Validity of Dixon's Test	Valid	



Groundwater Statistics Tool

Groundwater Statistics Tool Normality Testing Worksheet

Normality Test Results		
Parameter	All Data ⁿ	Minus Outliers
Number of data points		15
Shapiro-Wilk alpha value	5%	N/A
Slope	31.9190286	N/A
Intercept	28.55266667	N/A
Correlation, R	0.875145548	N/A
Exact Test Value	0.7806649	N/A
Critical Value	0.881	N/A
Conclude sample distribution:	Does not appear normal	N/A



Previous Step: Outliers Screen

Next Step: Trend Screen

Skip Step: UCL Screen

Groundwater Statistics Tool

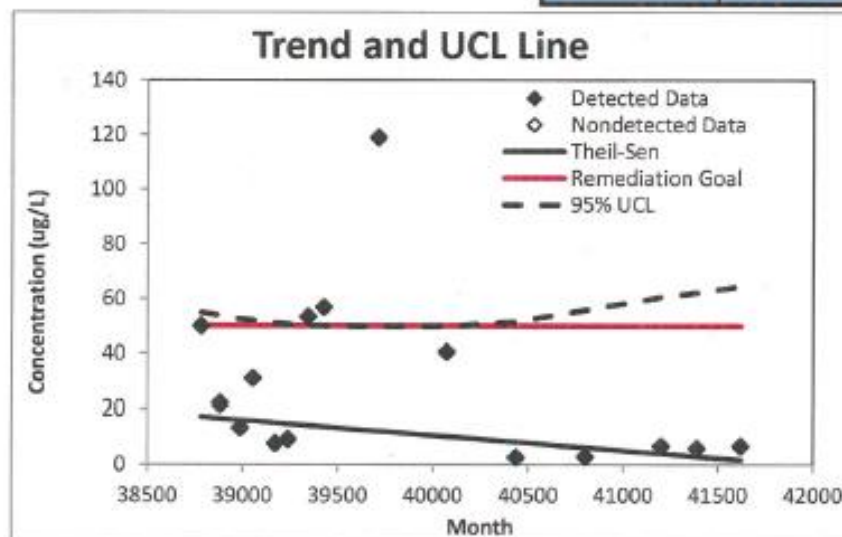
Groundwater Statistics Tool

Trend test results for datasets nonparametrically distributed residuals

i	t (Days)	C (ug/L)	C Predicted	Residual	95 UCL Line
1	38782	50	17.3	32.7	54.8
2	38882	21.8	16.7	5.1	53.8
3	38987	13.4	16.1	-2.7	52.4
4	39053	31	15.8	15.2	52
5	39171	7.8	15.1	-7.3	50.9
6	39239	9.2	14.8	-5.6	50.5
7	39343	53.3	14.2	39.1	50.3
8	39427	56.9	13.7	43.2	50
9	39712	119	12.2	106.8	49.7
10	40072	40.5	10.2	30.3	49.9
11	40436	2.71	8.22	-5.51	51.5
12	40800	3	6.23	-3.23	55.8
13	41199	6.86	4.05	2.81	60.7
14	41389	5.96	3.02	2.94	62.3
15	41619	6.86	1.76	5.1	64.6
16					
17					
18					
19					
20					

Mann-Kendall	
Test Result	No trend
Test Statistic (S)	-30
Normalized S	-1.437
Critical Value	1.645

Theil-Sen	
Slope	-0.00546
Intercept	229
When is the concentration predicted to exceed the MCL?	Not applicable - slope is not statistically increasing



Groundwater Statistics Tool

Groundwater Statistics Tool

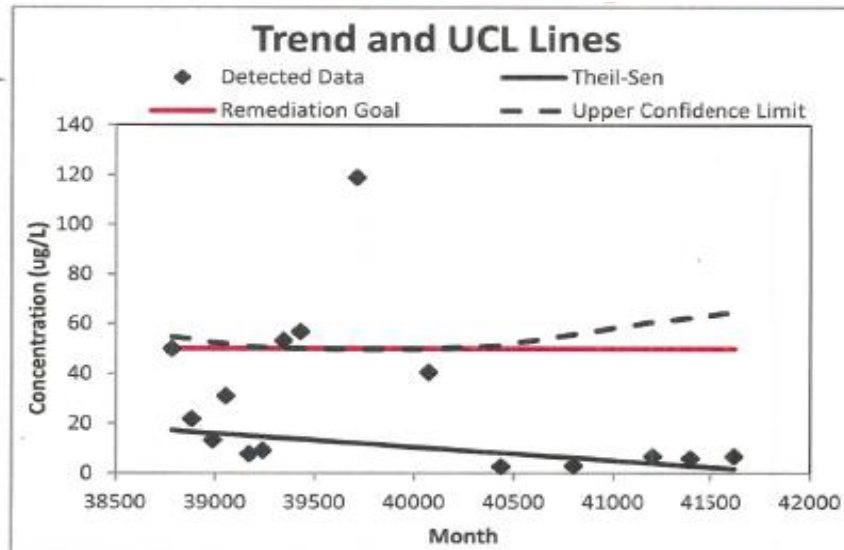
Summary and UCL calculations for nonparametric data sets

Site Name	Test
Operating Unit (OU)	Test
Type of Evaluation	Attainment
Date of Evaluation	4/7/2014
Person performing analysis	Bernie Zavala

Chemical of Concern	Chromium
Well Name/Number	B-87-8
Date Units	Date
Concentration Units	ug/L

Confidence Level	95%
Number of results	15
Number < remediation goal	11
Are any potential outliers present?	No
Mean of concentration	28.6
Standard deviation of concentration	31.7

95% Upper Confidence Limit (UCL)	64.3
Method for calculating UCL	Chebyshev UCL
Value of 95% Upper Confidence Band value at final sampling event	64.6
Trend calculation method	Theil-Sen/Mann-Kendall
Remediation goal	50
Source of remediation goal	risk-based
Is the trend decreasing or statistically insignificant?	Yes



When is the concentration predicted to exceed the MCL?	Not applicable - slope is not statistically increasing
Random Seed Used	58608.94141

Results and Recommendations

- ◆ No, this site has not attained the chromium cleanup level throughout the plume
- ◆ The 95% UCL is 64.3 ug/L cleanup level 50 ug/L
- ◆ Yes, the trend is decreasing or not statistically significant
- ◆ Recommendation: Continue sampling for two additional quarters and redo the evaluation

Comparison of Case Study to the EPA's Guidance for Evaluating of Groundwater Restoration

- ◆ Discussion of the evolving CSM
- ◆ Remedial Technologies and monitoring confirms the DQOs were meet
- ◆ Adequate groundwater monitoring program (LTMO) - Groundwater monitoring network was sufficient
- ◆ Statistical Evaluation of the groundwater data on a “well-by-well basis” for each COC
- ◆ Evaluated remediation monitoring and then attainment monitoring through a statistical tool
- ◆ Statistical analysis for each well determined that additional monitoring is needed to demonstrate completion of the restoration remedial action
- ◆ Once groundwater restoration has been met, it will be recommended to pursue site deletion.

Questions?



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