DEVELOPMENT OF A STATISTICAL APPROACH TO DETERMINING BACKGROUND GROUNDWATER CONDITIONS AT CONTAMINATED SITES IN ALBERTA

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TRIUM ENVIRONMENTAL SOLUTIONS.
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OVERVIEW

1. Defining the Problem – Background Groundwater Conditions
2. Current Regulatory Framework
3. Developing a Method for Background Groundwater Characterization
4. Real-world Application – Produced Water Spill
5. Real-world Application – Battery Facility
6. Conclusions

DEFINING THE PROBLEM: BACKGROUND CONDITIONS

Background Conditions – What Are They?

- Background Concentration: "Concentration of a substance in an environmental medium in a geographic area, does not include any contribution from man-made sources" (BC Ministry of Water, Land, and Air Protection, *Protocol 9*)
- "Natural background conditions exist when there is no measurable difference between the quality of water now and the quality of water that would exist if there were no human-caused changes" (Idaho Department of Environmental Quality, *Clean Water Act*)

Background Conditions – "Conventional Wisdom"

- Background concentrations should remain ***relatively constant*** over time, given seasonal variability
  - Expect similar data sets from year to year

- Background concentrations should be ***similar*** in all wells across the site installed at the same stratigraphic interval
  - Given soil heterogeneity , variations in flow, etc.

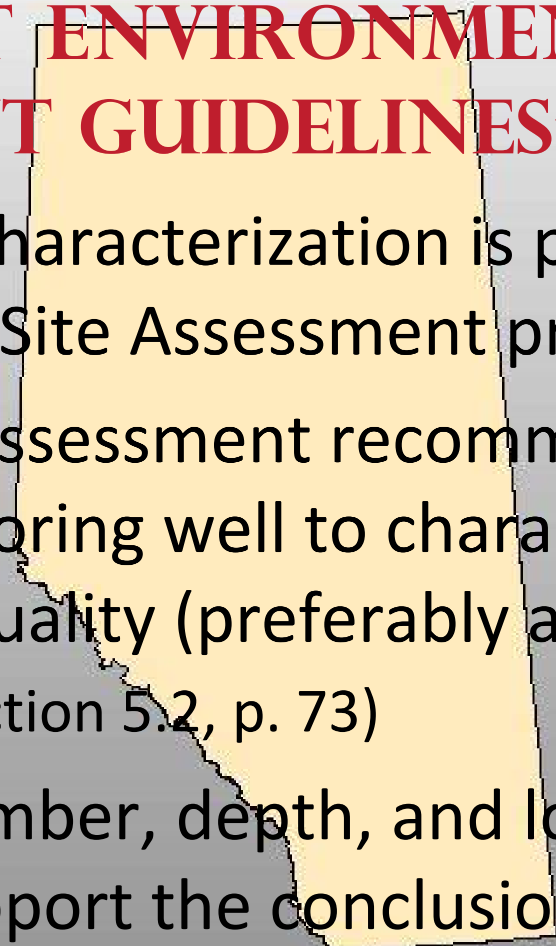
WHAT'S THE PROBLEM?

- How should background concentrations be determined, and compared to other wells on site?
- What are the regulatory requirements?
- How many data points are needed?
- Is there a method that works for all sites?
- What is a "measureable difference" – how different is different?
- What analytes represent background conditions?

Current Regulatory Framework

ALBERTA:

"DRAFT ENVIRONMENTAL SITE ASSESSMENT GUIDELINES" (JUNE 2008)



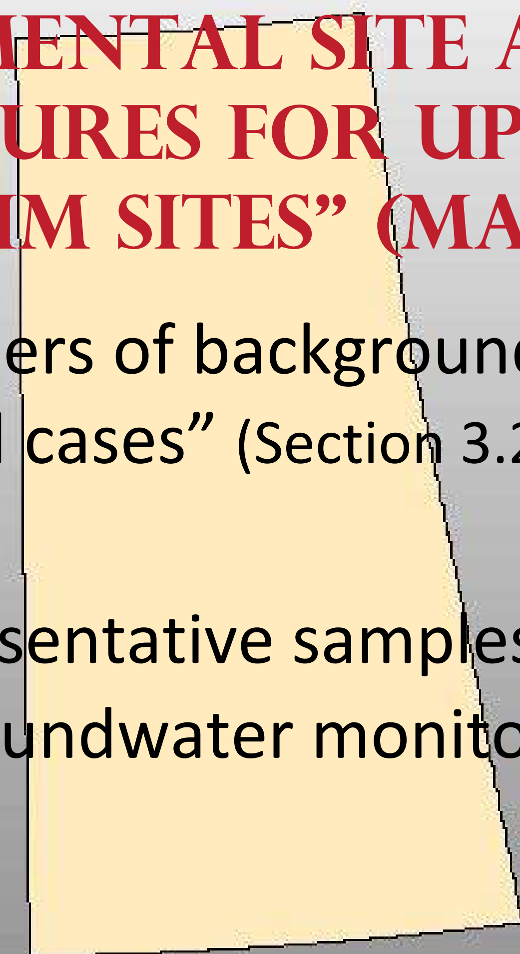
- Groundwater characterization is part of Phase II Environmental Site Assessment process
- Groundwater assessment recommendation: "an up-gradient monitoring well to characterize background groundwater quality (preferably at the property boundary)" (section 5.2, p. 73)
- "The actual number, depth, and location of wells required to support the conclusions will depend on site conditions" (section 5.2, p. 73)

ALBERTA:
"DRAFT ENVIRONMENTAL SITE ASSESSMENT GUIDELINES" (JUNE 2008)

- **What's Missing?**

- How to account for seasonal variations in water quality, if any?
- How many sampling events are required, and what frequency?
- Can this procedure be applied to more complex sites?

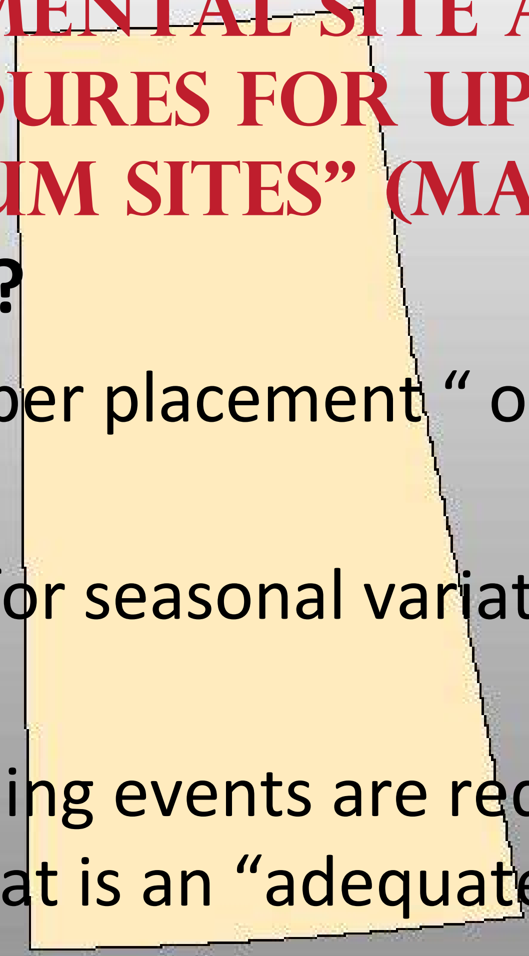
SASKATCHEWAN:
"ENVIRONMENTAL SITE ASSESSMENT PROCEDURES FOR UPSTREAM PETROLEUM SITES" (MARCH 1999)



- "Adequate numbers of background samples should be obtained in all cases" (Section 3.2, p. 6)

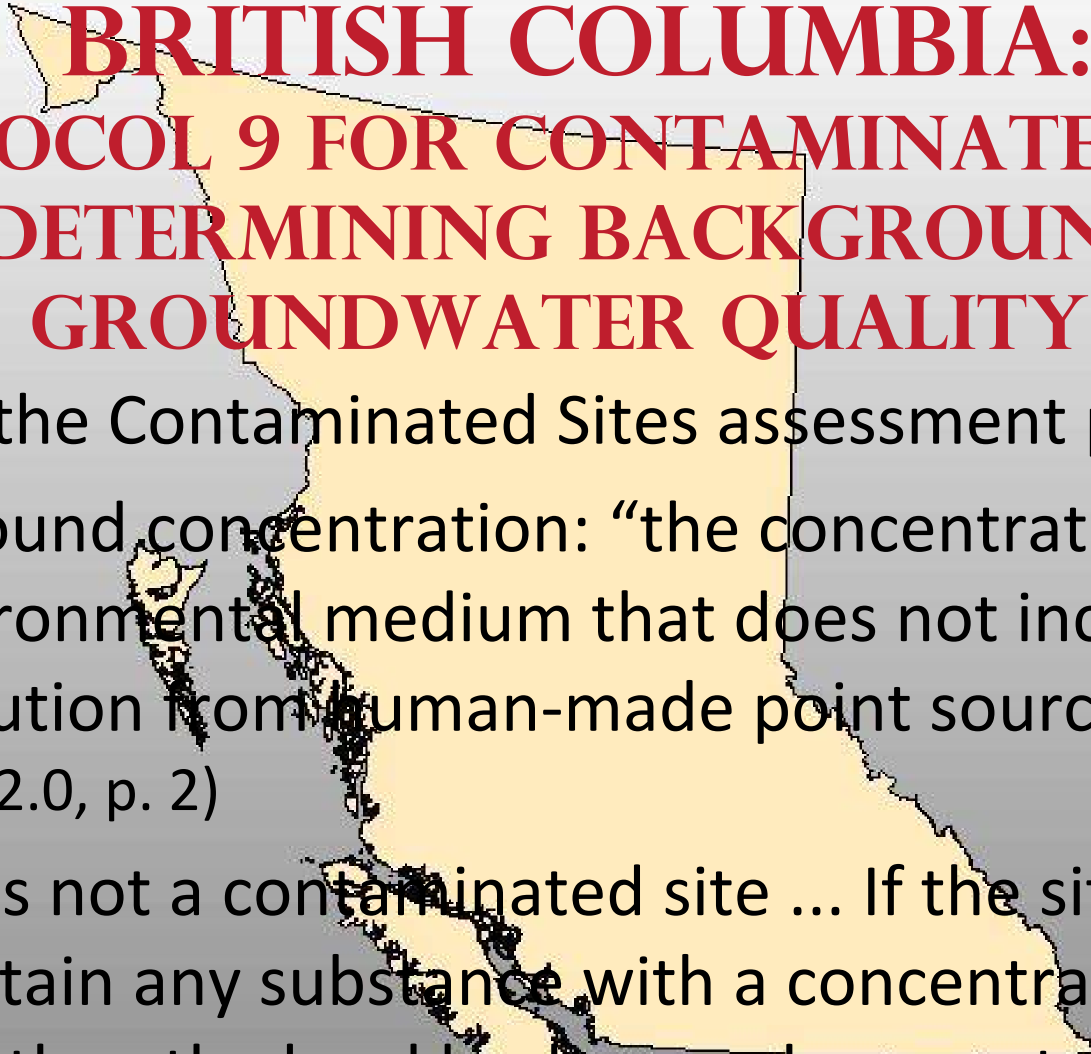
- "To ensure representative samples, proper placement of groundwater monitoring wells is vital" (Section 3.2.2, p. 7)

SASKATCHEWAN:
"ENVIRONMENTAL SITE ASSESSMENT PROCEDURES FOR UPSTREAM PETROLEUM SITES" (MARCH 1999)



- **What's Missing?**
- What is the "proper placement " of monitoring wells?
- How to account for seasonal variations in water quality, if any?
- How many sampling events are required, and what frequency? – What is an "adequate" number?
- Can this procedure be applied to more complex sites?

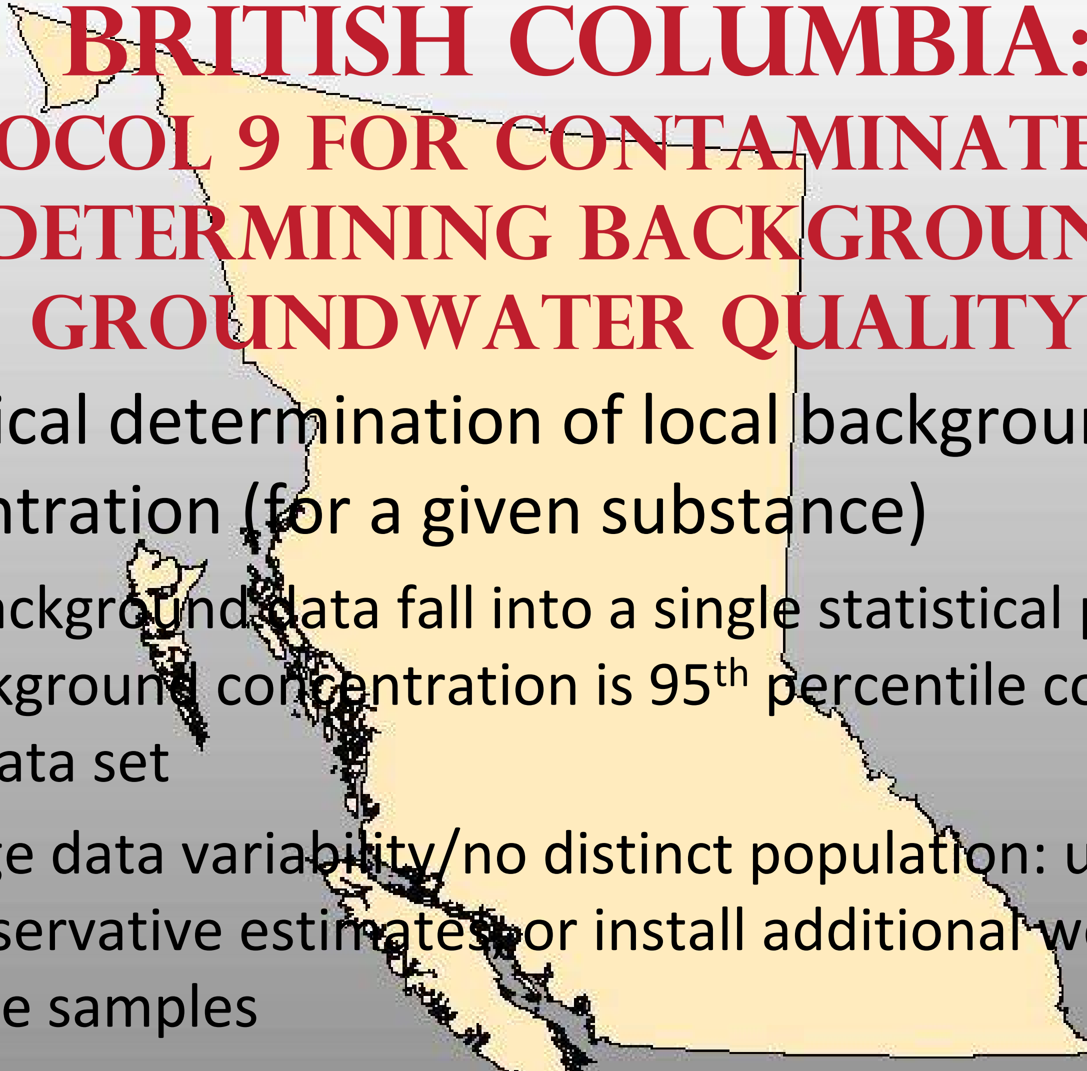
British Columbia:
"Protocol 9 for Contaminated Sites- Determining Background Groundwater Quality"



- Part of the Contaminated Sites assessment process
- Background concentration: "the concentration...in an environmental medium that does not include any contribution from human-made point sources" (Section 2.0, p. 2)
- "A site is not a contaminated site ... If the site does not contain any substance with a concentration greater than the local background concentration of that substance" (Section 2.0, p. 2)

British Columbia:
"Protocol 9 for Contaminated Sites- Determining Background Groundwater Quality"

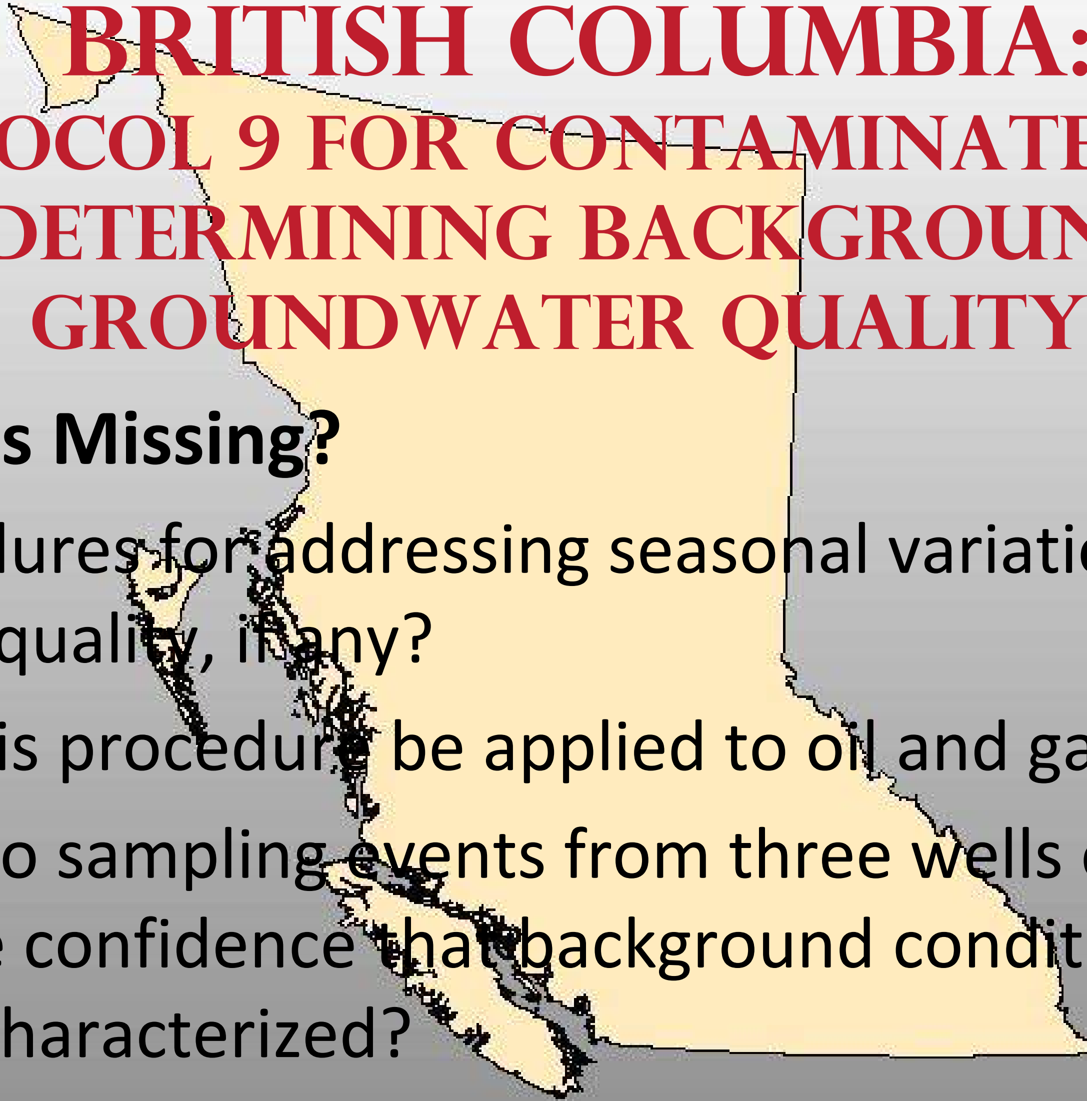
- A minimum of three wells should be installed
  - Cross-gradient or up-gradient
  - Off-site natural areas, parks, or residential
  - Larger sites, greater contamination – more wells may be required
- Sample all wells a minimum of 2 times
  - Provide a "robust data set"
  - Sampling strategy should address seasonal variability



British Columbia:
"Protocol 9 for Contaminated Sites- Determining Background Groundwater Quality"

- Statistical determination of local background concentration (for a given substance)
  - If background data fall into a single statistical population: background concentration is 95th percentile concentration of data set
  - Large data variability/no distinct population: use conservative estimates, or install additional wells and collect more samples
  - More statistical tools – "Technical Guidance 12"

British Columbia:
"Protocol 9 for Contaminated Sites-Determining Background Groundwater Quality"



- **What's Missing?**
- Procedures for addressing seasonal variations in water quality, if any?
- Can this procedure be applied to oil and gas sites?
- Are two sampling events from three wells enough to ensure confidence that background conditions have been characterized?

Procedures in Alberta (and Saskatchewan)?

- Adopt the BC Regulations? – 95th percentile concentrations?
- Rely solely on judgement and conservative estimates?
- Develop an approach that uses site evaluation and statistical tools
  - Multiple lines of evidence
  - Increase confidence in professional opinions – help clients and regulators make informed decisions

METHOD FOR BACKGROUND CHARACTERIZATION

WHAT SHOULD BE INCLUDED?

- Assembling evidence drives the site evaluation process
  - Hypothesis to conclusion
- Preference for stronger evidence in regulatory environment
- Multiple lines/sources are stronger than a single source – make the "Best Case Possible" – confidence
  - Requires a multi-step process
- Quantitative evidence is stronger than qualitative evidence

WHAT SHOULD BE INCLUDED?

- Methods should be defensible and reproducible

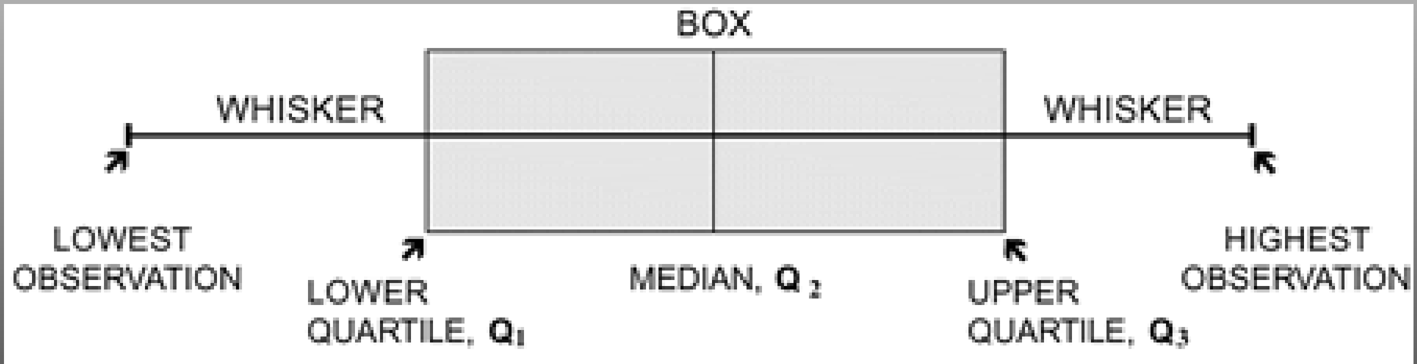
- Process developed should meet the regulatory requirements, if any

FIRST PROPOSED STEP:
EVALUATE SITE CONDITIONS

- Numerical Analysis – Table Trends
- Graphs
- Physical Properties of the Site
- Apply Professional Experience and Expertise

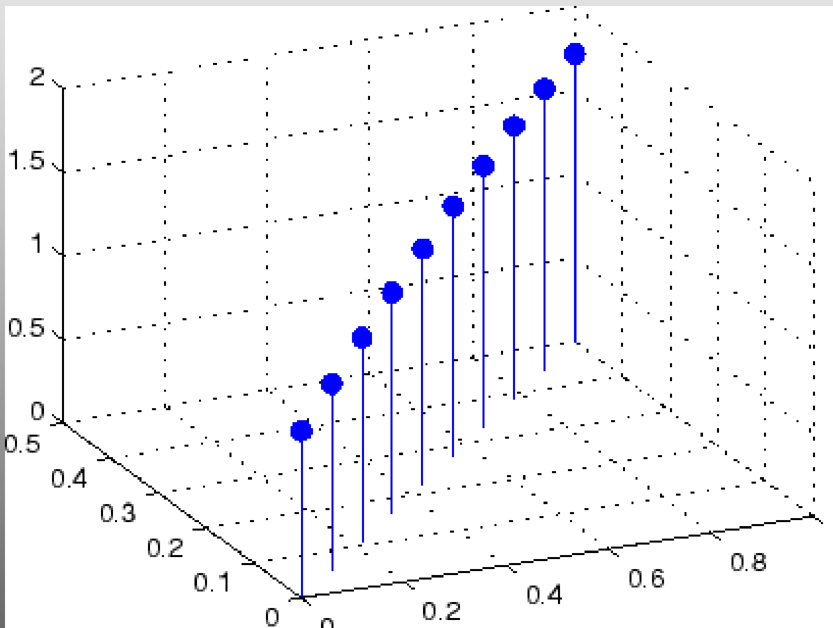
SECOND PROPOSED STEP:
APPLY QUANTITATIVE STATISTICS – POSSIBLE OPTIONS

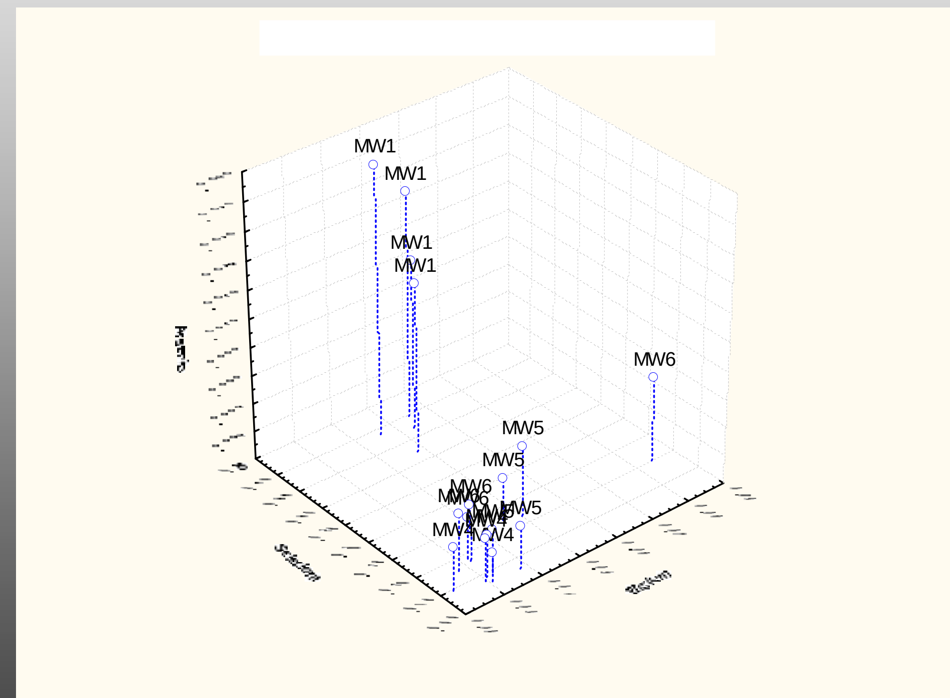
- Box-Whisker Plots
  - 2-Dimensional comparison of numerical distribution among data sets



APPLY QUANTITATIVE STATISTICS – POSSIBLE OPTIONS

- 3-Dimensional Plots

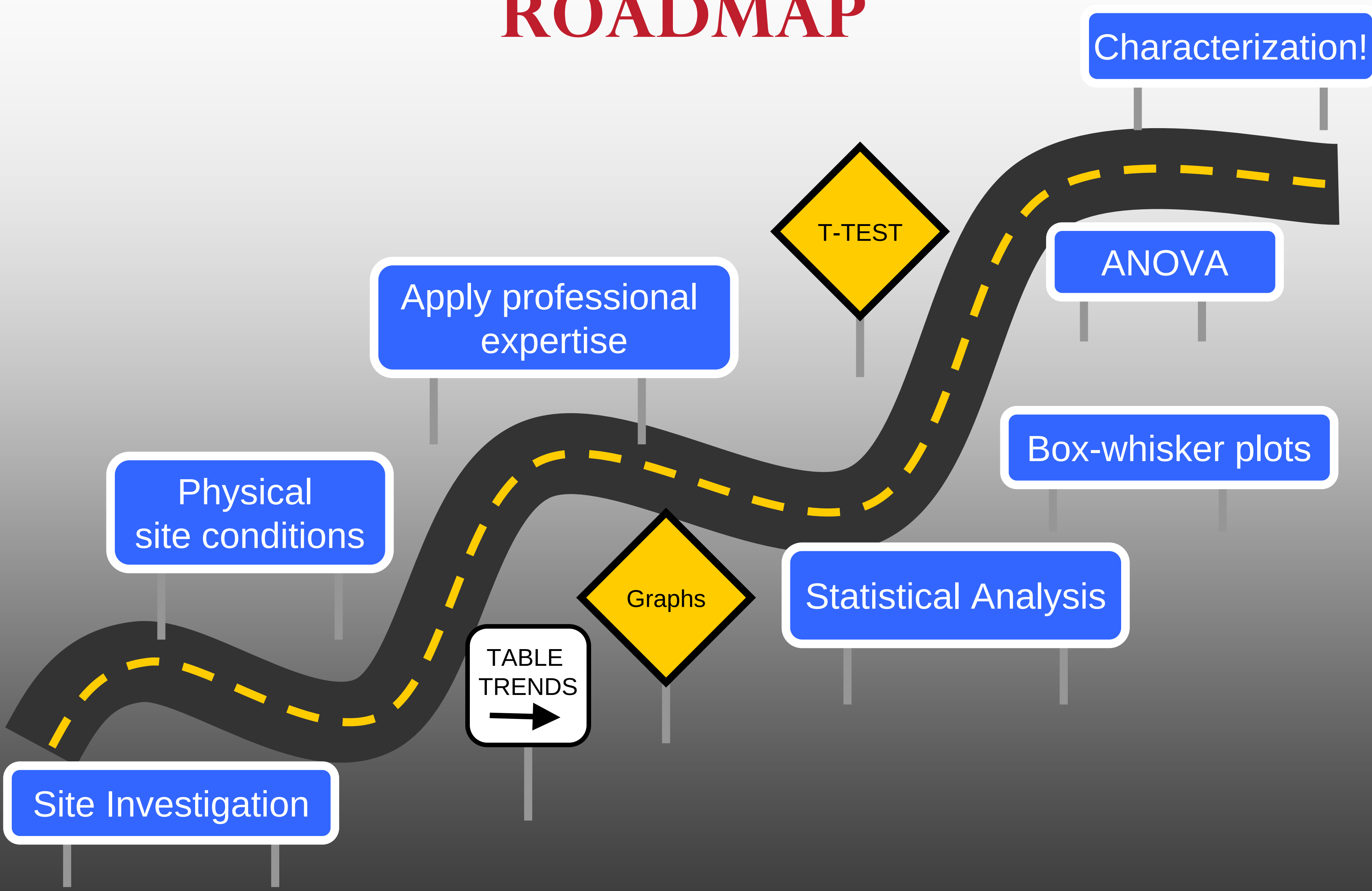




APPLY QUANTITATIVE STATISTICS – POSSIBLE OPTIONS

- Analysis of Variance
  - T-test for 2 sample locations
  - ANOVA – Single Factor
    - Effect of a factor on the variance of means
- Multi-Factor ANOVA and COVANOVA
  - One or more factors may control variance
  - Co-variance may also exist among data set/s

GROUNDWATER EVALUATION ROADMAP



DEFINING DRIVEN EXCLUSIVE

APPLY QUANTITATIVE STATISTICS – BENEFITS TO SITE EVALUATION

- Support initial Site Evaluation
  - Cases where no clear relationship between impacts and background can be inferred
- Increase confidence in professional expertise
- Apply qualitative methods that can be defended and reproduced

REAL-WORLD GROUNDWATER EVALUATION: BATTERY FACILITY

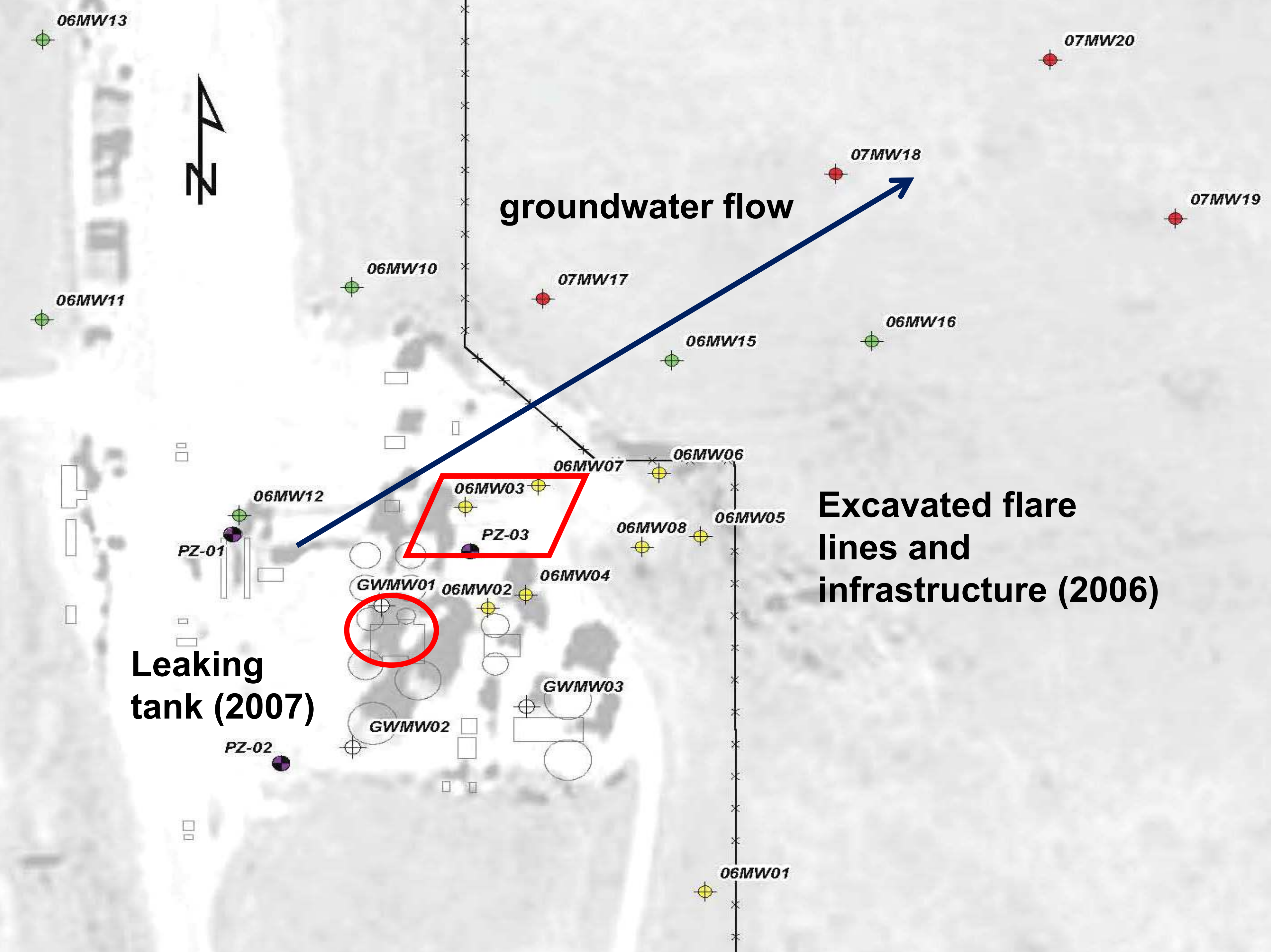
GROUNDWATER EVALUATION:
BATTERY FACILITY

OBJECTIVE:

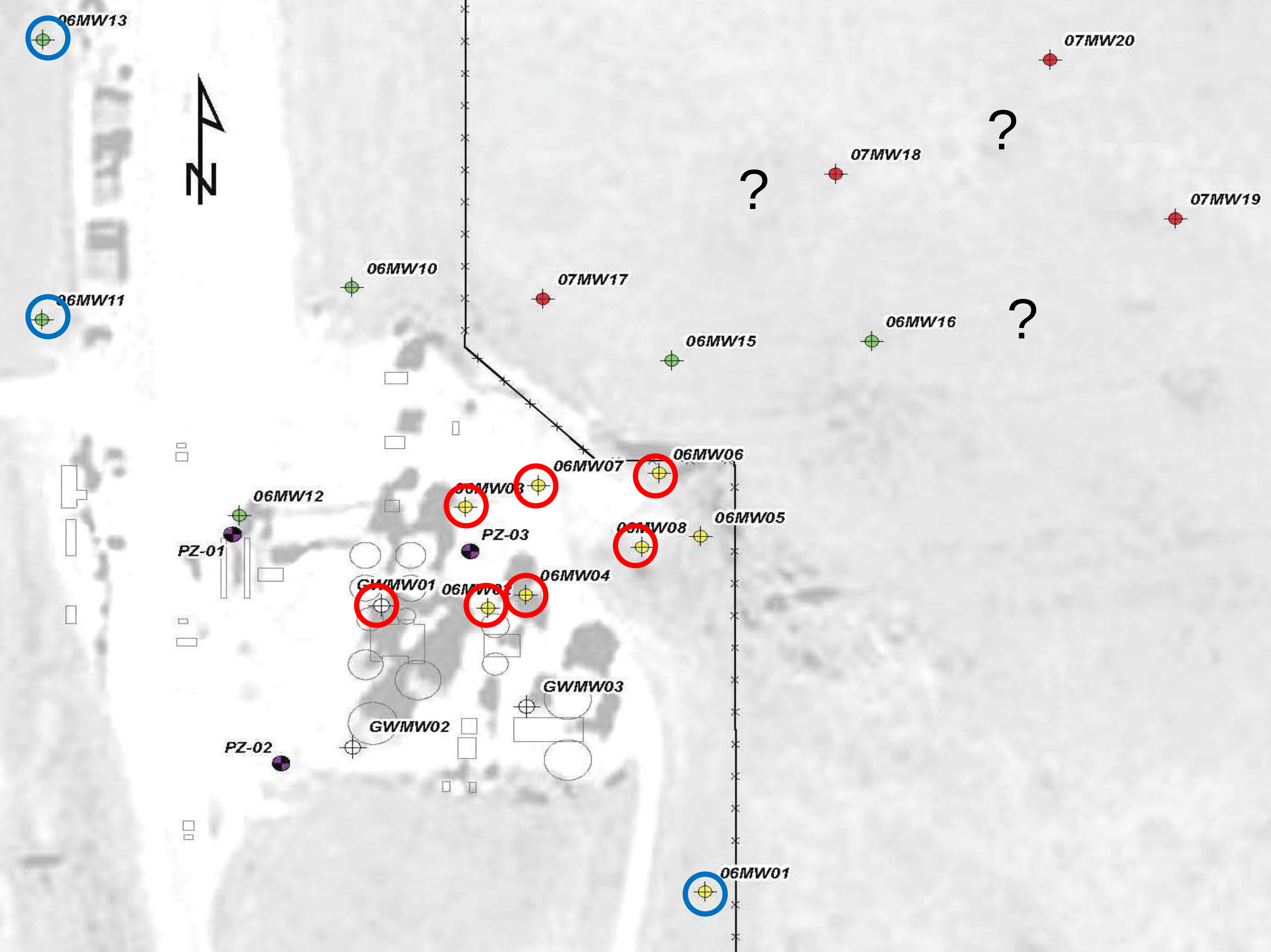
- Compare concentrations in wells outside of soil impact area to concentrations within impact area – can “background” concentrations be seen in wells across the site?
- Characterize background conditions for select individual analytes across the site, not just for concentrations in one well

FIRST LEVEL OF EVIDENCE:
"QUALITATIVE" EVALUATION

- **Physical Properties of the Site**



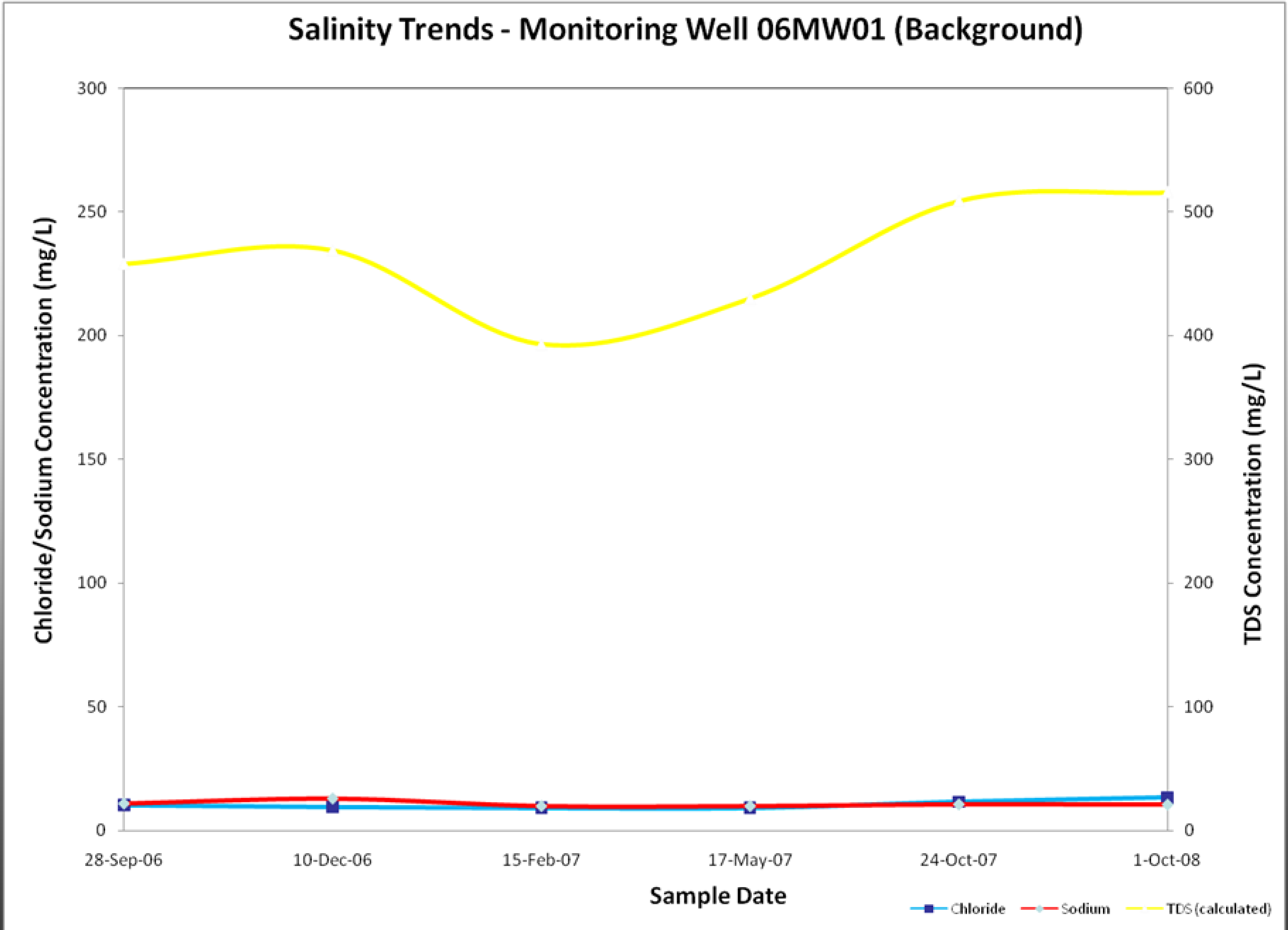
06MW13
07MW20
N
07MW18
groundwater flow
07MW19
06MW10
07MW17
06MW11
06MW16
06MW15
06MW06
06MW07
06MW03
06MW12
Excavated flare lines and infrastructure (2006)
06MW08
06MW05
PZ-03
PZ-01
06MW04
GWMW01
06MW02
Leaking tank (2007)
GWMW03
GWMW02
PZ-02
06MW01



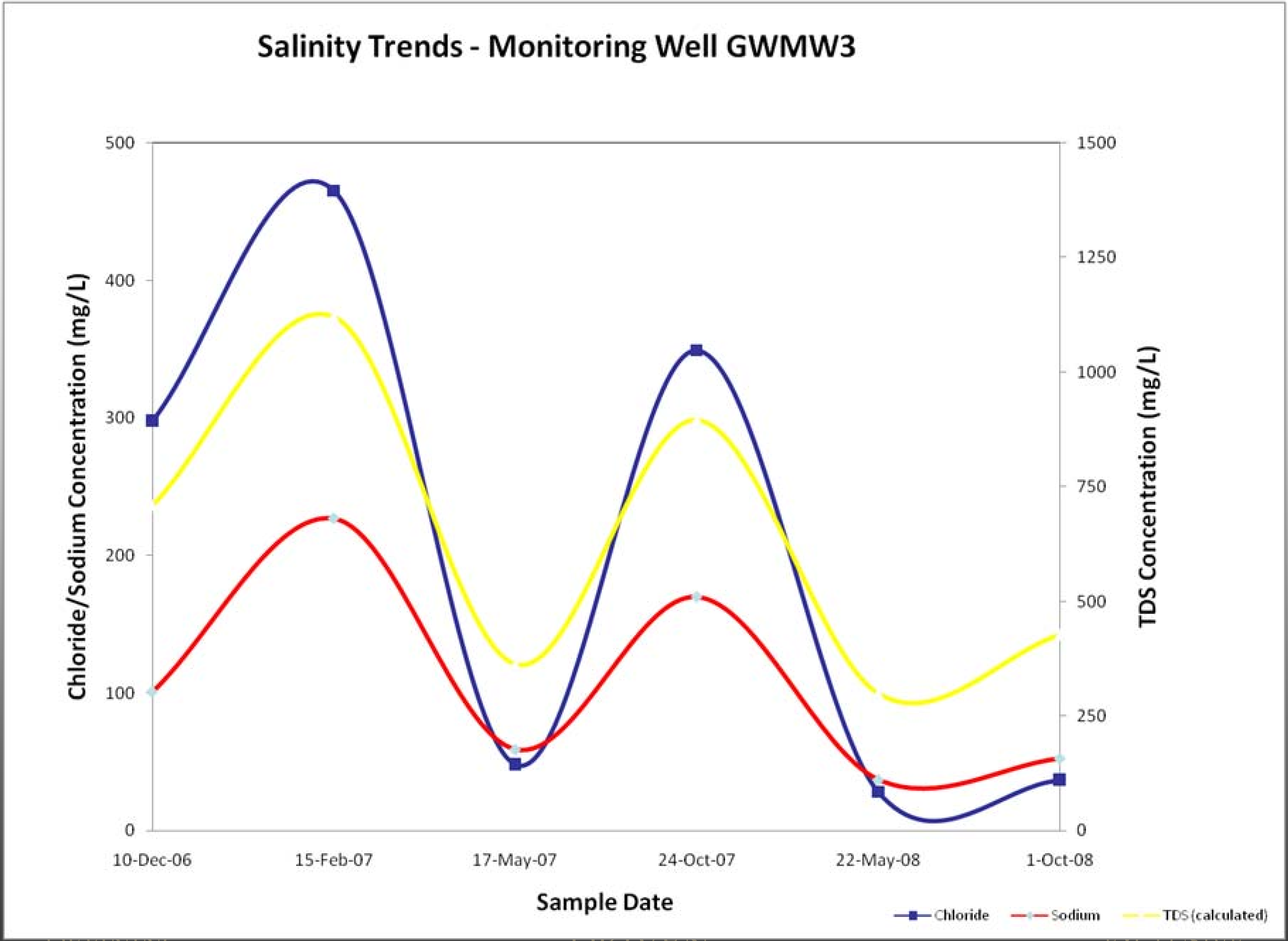
06MW13
N
07MW20
07MW18
07MW19
06MW10
07MW17
06MW11
06MW16
06MW15
06MW06
06MW07
06MW12
06MW05
PZ-03
PZ-01
06MW04
GWMW01
GWMW03
GWMW02
PZ-02
06MW01

FIRST LEVEL OF EVIDENCE:
"QUALITATIVE" EVALUATION

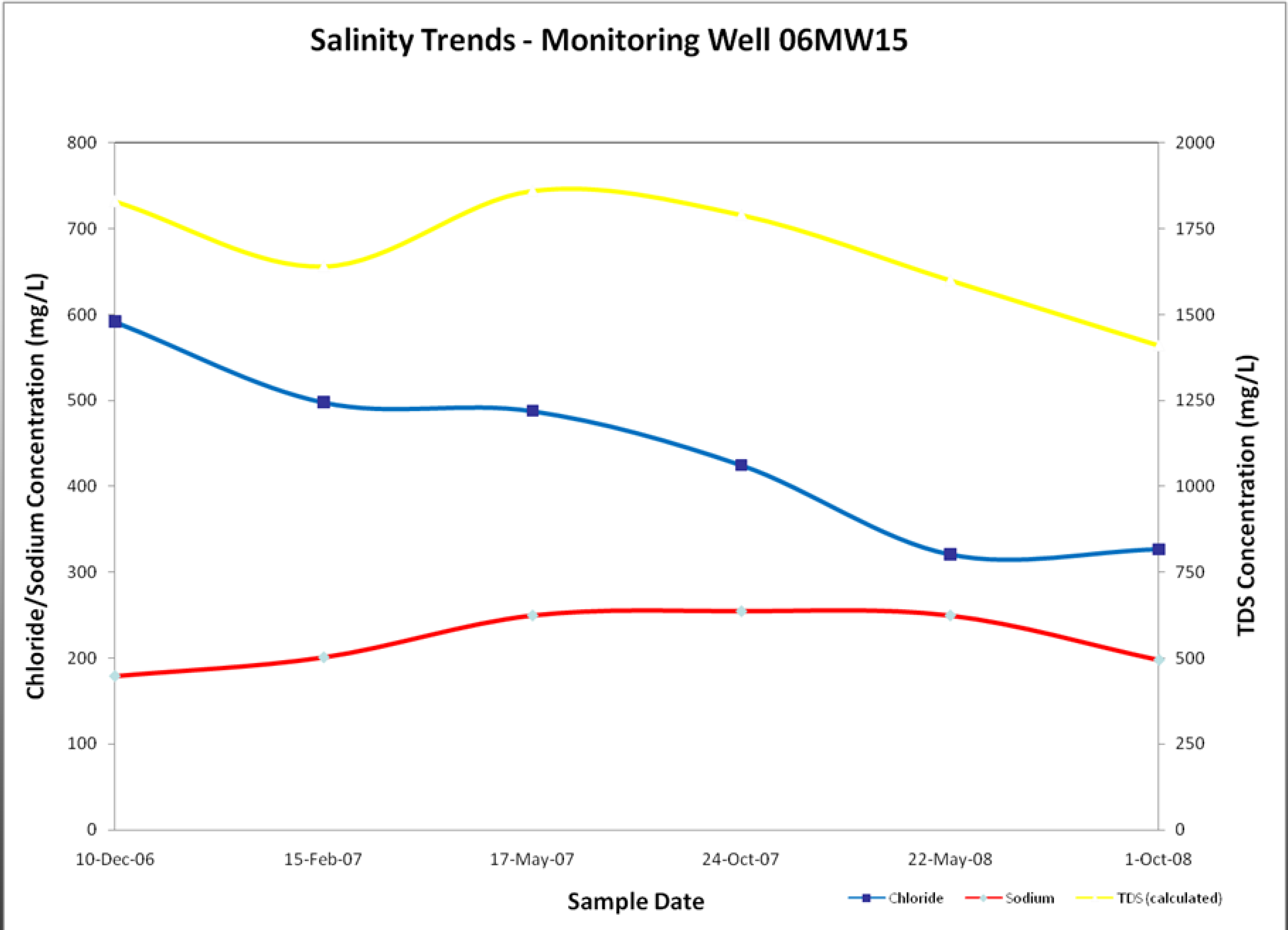
- Physical Properties of the Site
- **Graphs – Look for trends and patterns**



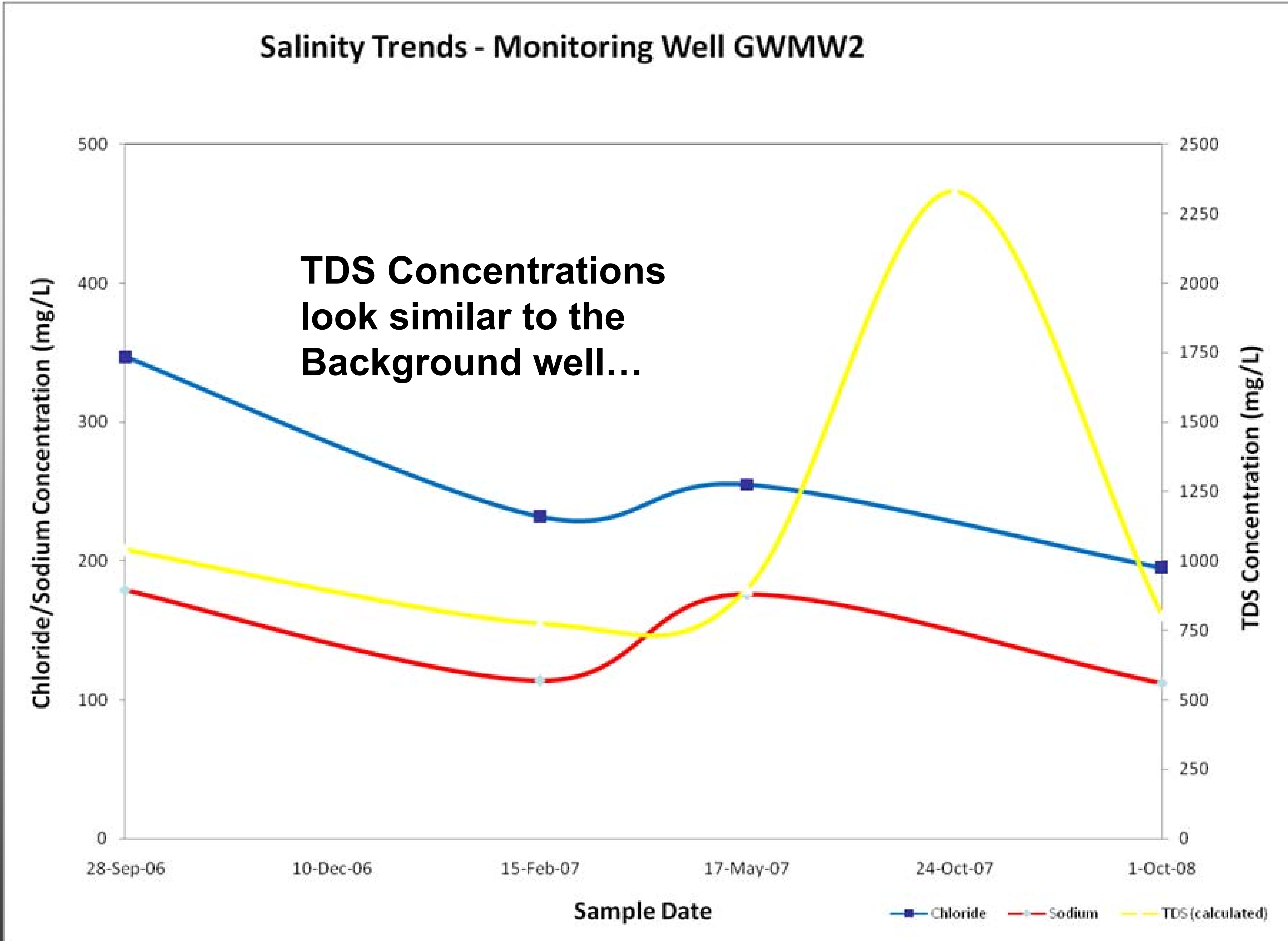
DEFINING DRIVEN EXCLUSIVE



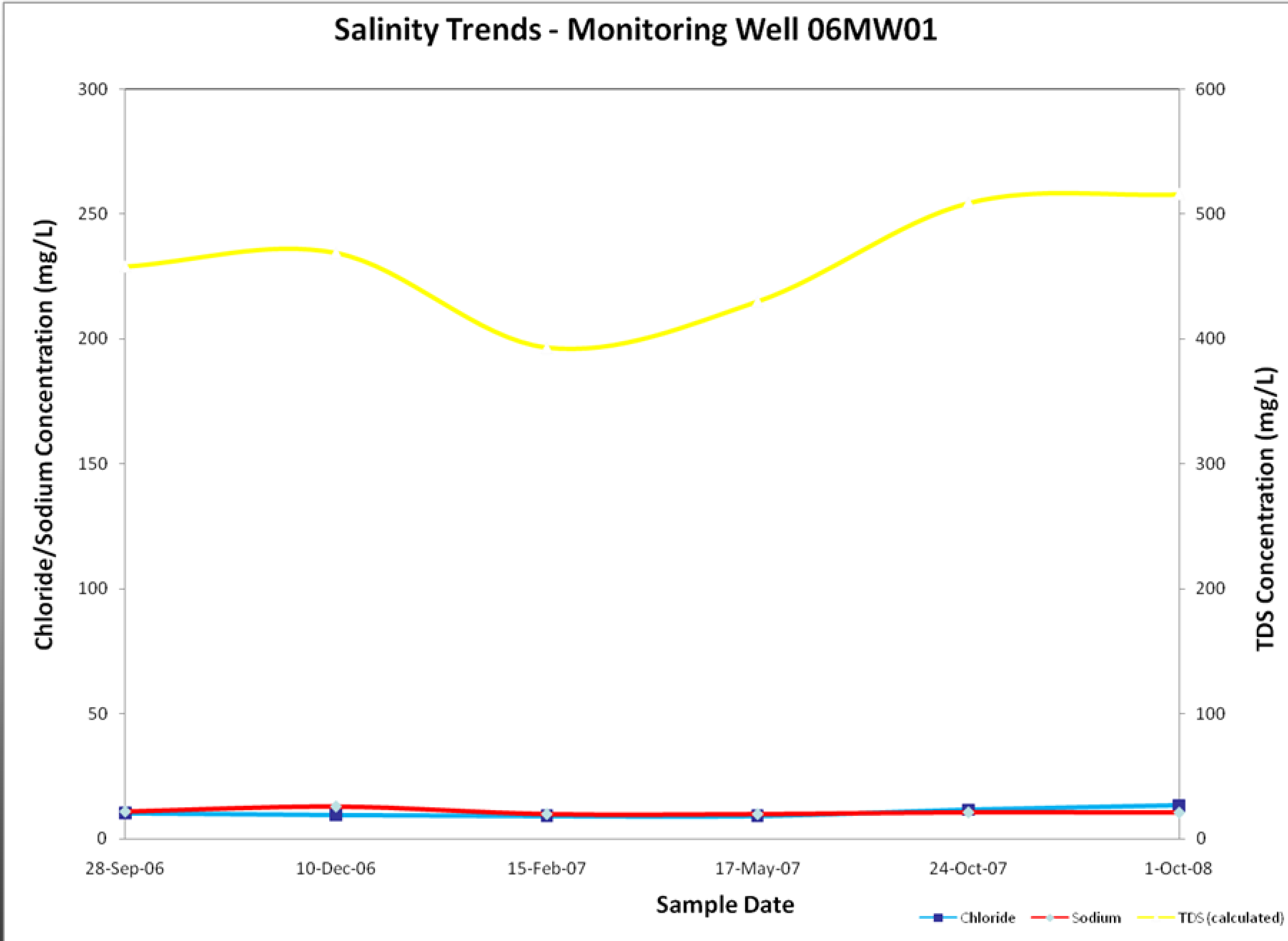
DEFINING DRIVEN EXCLUSIVE



DEFINING DRIVEN EXCLUSIVE



TDS Concentrations look similar to the Background well…



DEFINING DRIVEN EXCLUSIVE

FIRST LEVEL OF EVIDENCE:
"QUALITATIVE" EVALUATION

- Physical Properties of the Site
- Graphs – Look for trends and patterns
- **Table trends – compare known "Background well" to other wells on site**

Chloride Concentrations in Groundwater – Battery Facility Site

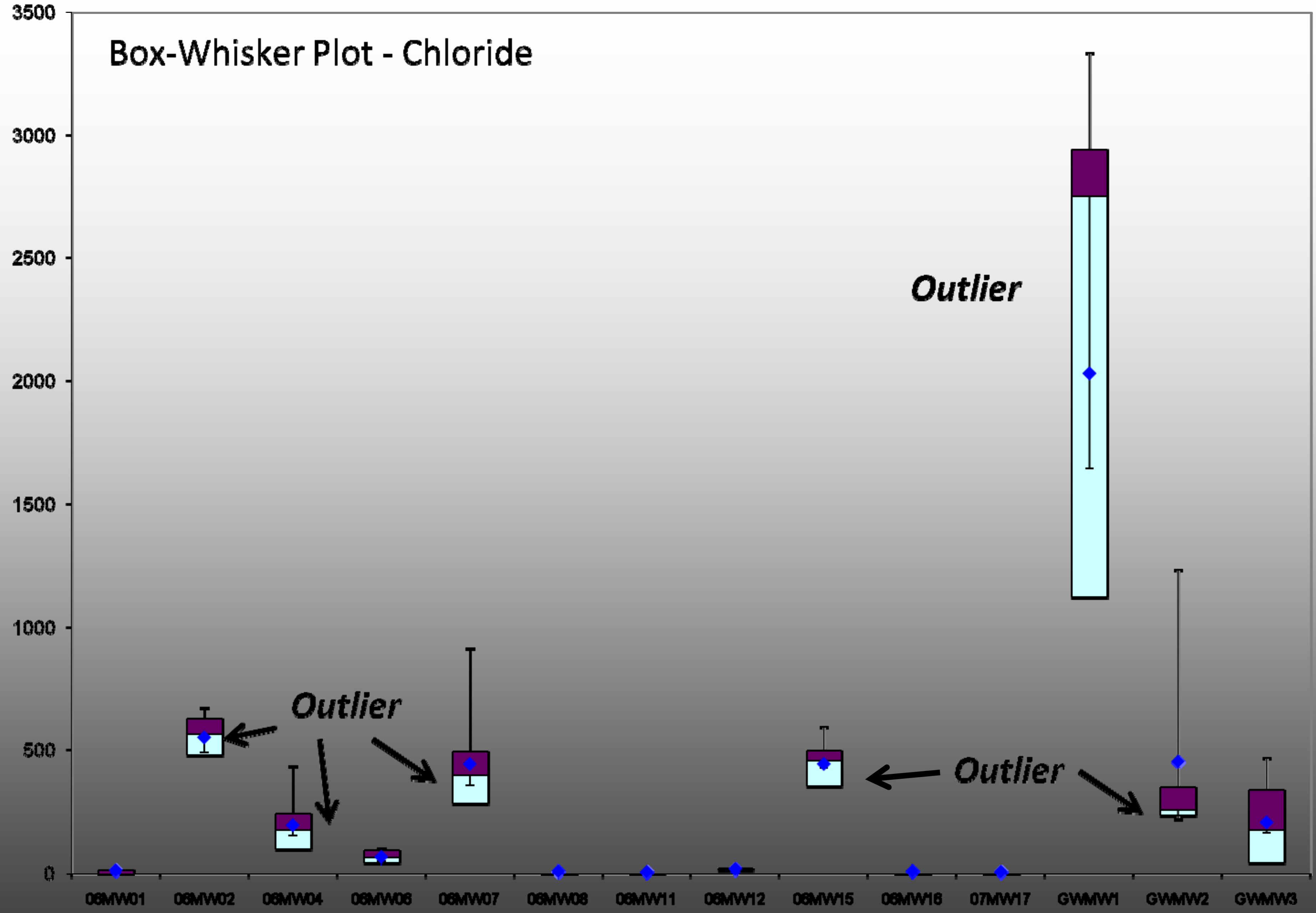
	06MW01	06MW02	06MW04	06MW06	06MW07	06MW08	06MW11
28-Sep-06	10.2	562	112	97.6	913	ns	ns
10-Dec-06	9.5	405	204	97.1	398	9.2	3.7
16-Feb-07	9.1	525	174	ns	473	6.3	ns
18-May-07	9.1	670	279	77.9	236	6.4	2.0
24-Oct-07	11.6	432	70.6	48.9	280	6.2	3.53
22-May-08	ns	614	431	37.5	511	4.13	4.64
1-Oct-08	13.3	641	79.2	23.1	281	4.94	6.68

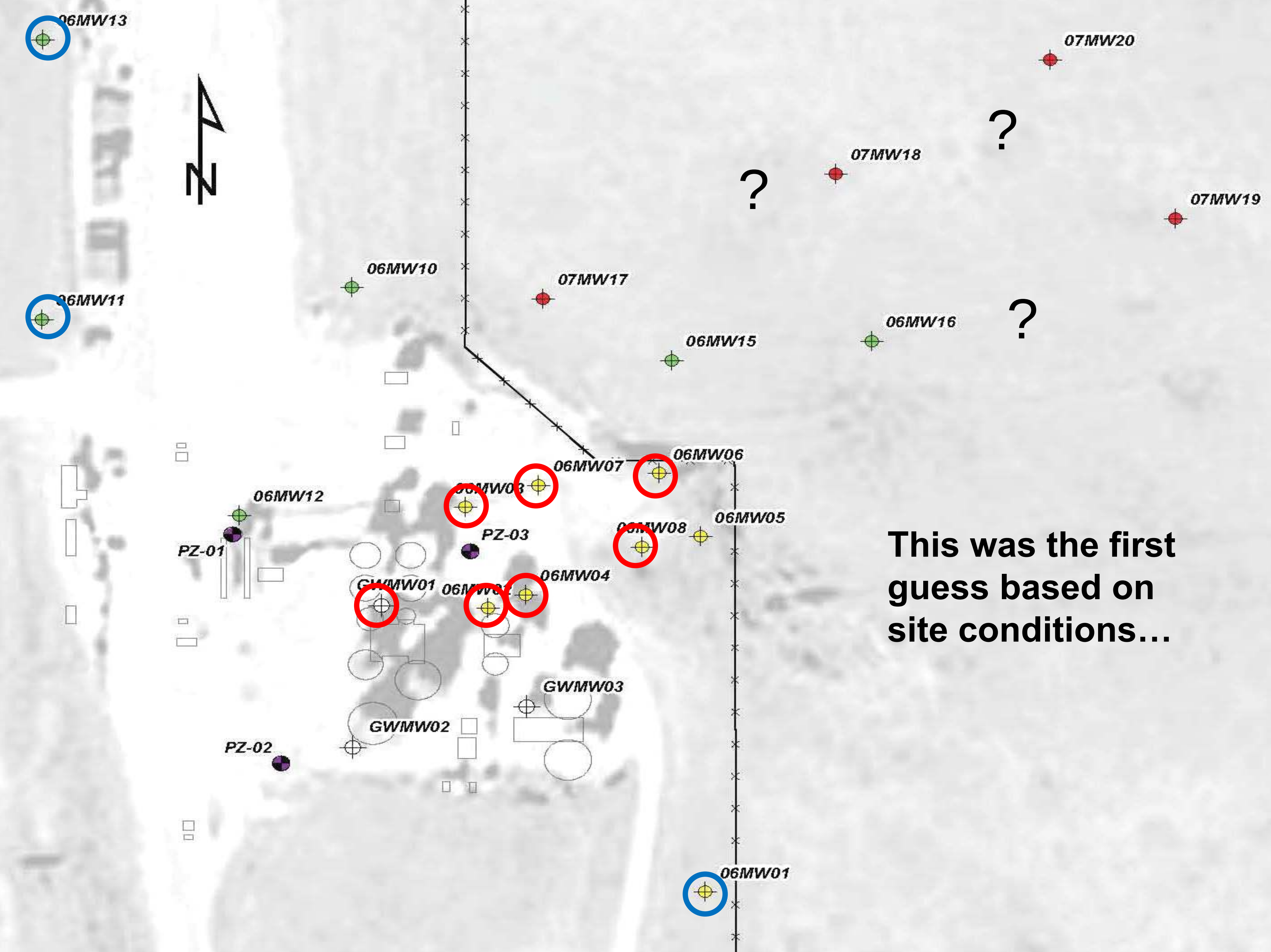
	06MW12	06MW15	06MW16	07MW17	GWMW1	GWMW2	GWMW3
28-Sep-06	ns	ns	ns	ns	ns	ns	ns
10-Dec-06	15.3	592	ns	ns	3330	347	298
16-Feb-07	7.1	498	9.7	6.7	2940	ns	465
18-May-07	14.8	488	7.0	3.4	2750	232	48
24-Oct-07	15.2	425	7.2	2.6	1120	255	349
22-May-08	26.1	321	5.13	4.26	ns	1230	28
1-Oct-08	18.3	327	5.77	6.75	13.3	195	36.6

- What trends do the data suggest?
- Do areas with concentrations below the guidelines represent background conditions or “impacted” areas?

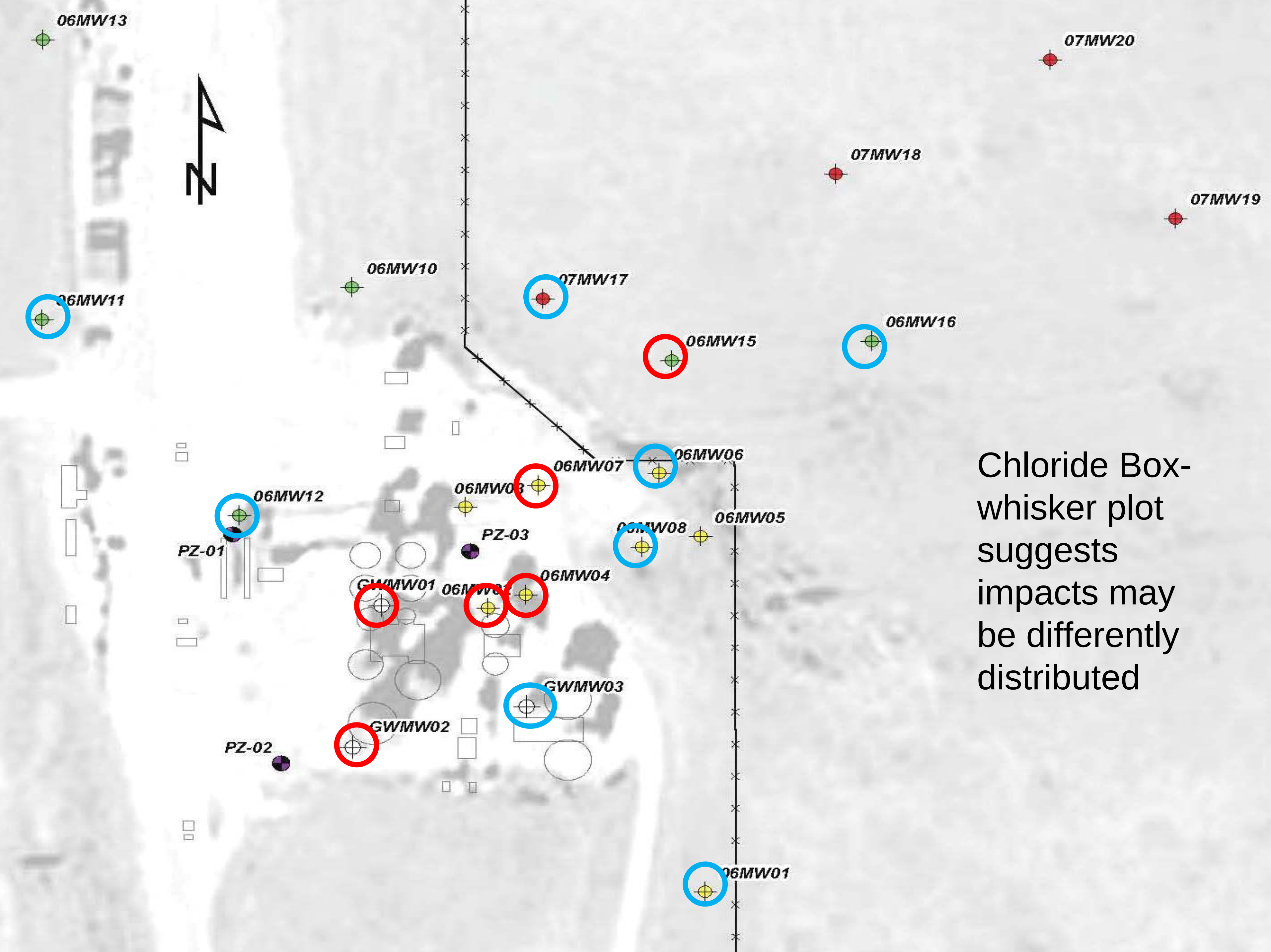
Second Level of Evidence:
Statistical Evaluation

- **Box – Whisker Plots**


Box-Whisker Plot - Chloride
3500
3000
2500
2000
1500
1000
500
0
Outlier
Outlier
Outlier
06MW01
06MW02
06MW04
06MW06
06MW07
06MW08
06MW11
06MW12
06MW15
06MW16
07MW17
GWMW1
GWMW2
GWMW3



This was the first guess based on site conditions…



Chloride Box-whisker plot suggests impacts may be differently distributed

Chloride Concentrations in Groundwater – Battery Facility Site

	06MW01	06MW02	06MW04	06MW06	06MW07	06MW08	06MW11
28-Sep-06	10.2	562	112	97.6	913	ns	ns
10-Dec-06	9.5	405	204	97.1	398	9.2	3.7
16-Feb-07	9.1	525	174	ns	473	6.3	ns
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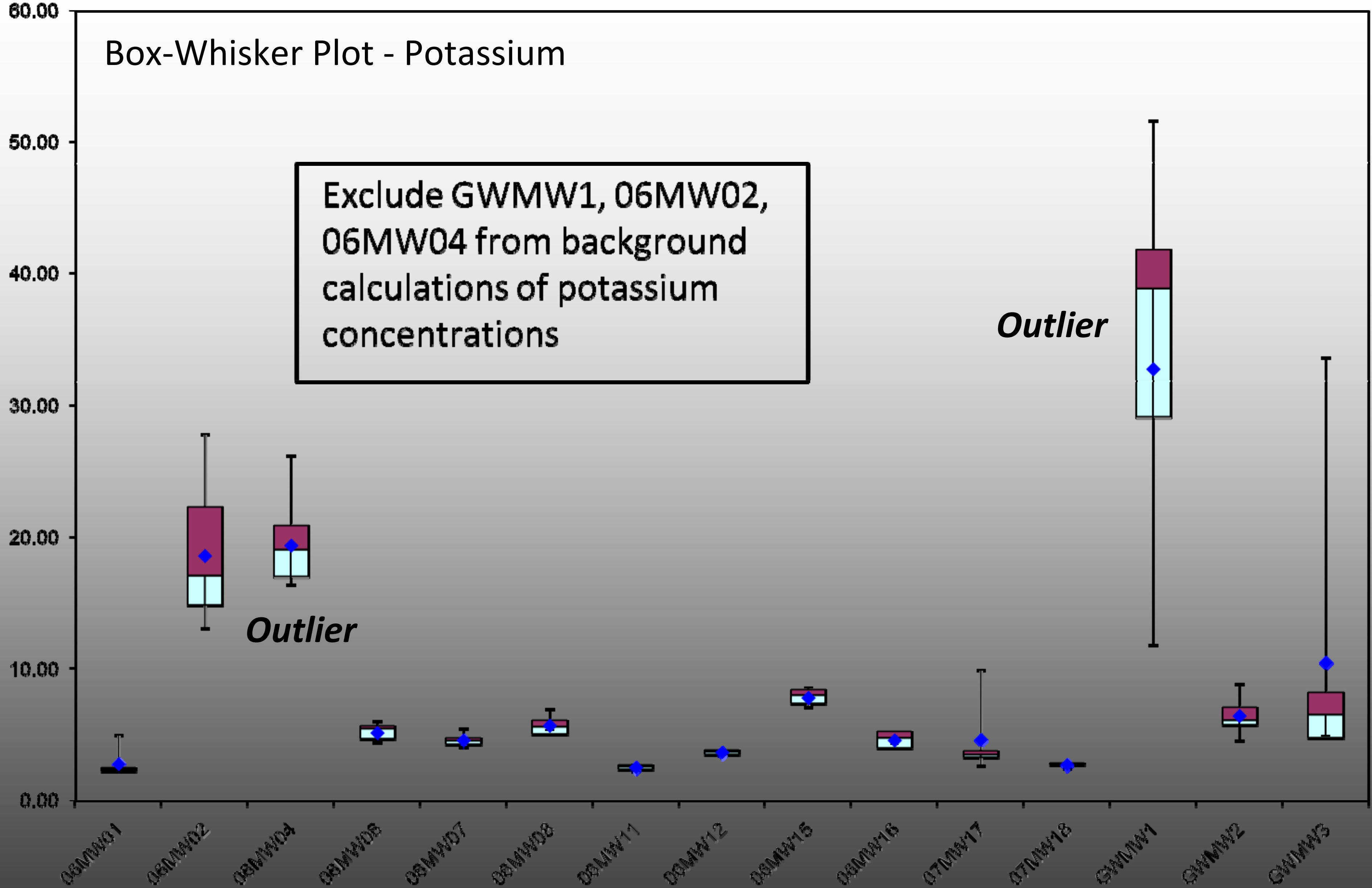
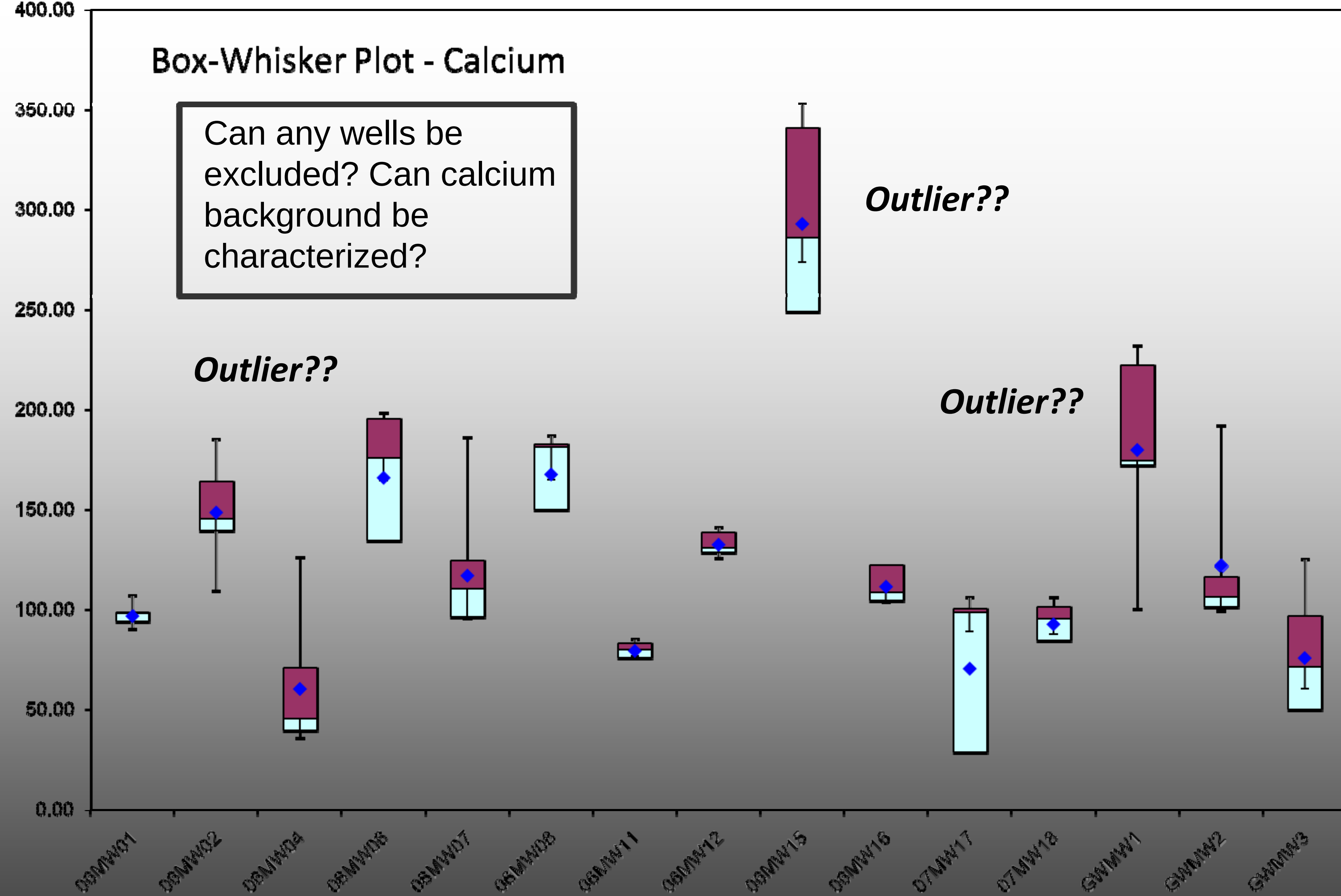
	06MW12	**06MW15**	**06MW16**	**07MW17**	**GWMW1**	**GWMW2**	**GWMW3**
28-Sep-06	ns	ns	ns	ns	ns	ns	ns
10-Dec-06	15.3	592	ns	ns	3330	347	298
16-Feb-07	7.1	498	9.7	6.7	2940	ns	465
18-May-07	14.8	488	7.0	3.4	2750	232	48
24-Oct-07	15.2	425	7.2	2.6	1120	255	349
22-May-08	26.1	321	5.13	4.26	ns	1230	28
1-Oct-08	18.3	327	5.77	6.75	13.3	195	36.6

- Box-whisker plots suggest the concentrations in these wells do not resemble background concentrations (MW01, MW11) for chloride – exclude from analysis of background concentrations
- Should the remaining wells be included?



Box-Whisker Plot - Potassium
Exclude GWMW1, 06MW02, 06MW04 from background calculations of potassium concentrations
Outlier
Outlier
60.00
50.00
40.00
30.00
20.00
10.00
0.00
06MW01
06MW02
06MW04
06MW07
06MW08
06MW11
06MW12
06MW15
06MW16
07MW17
07MW18
GWMW1
GWMW2
GWMW3



Box-Whisker Plot - Calcium
Can any wells be excluded? Can calcium background be characterized?
Outlier??
Outlier??
Outlier??
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
06MW08
06MW11
06MW12
07MW17
07MW18
GWMW1
GWMW2
GWMW3

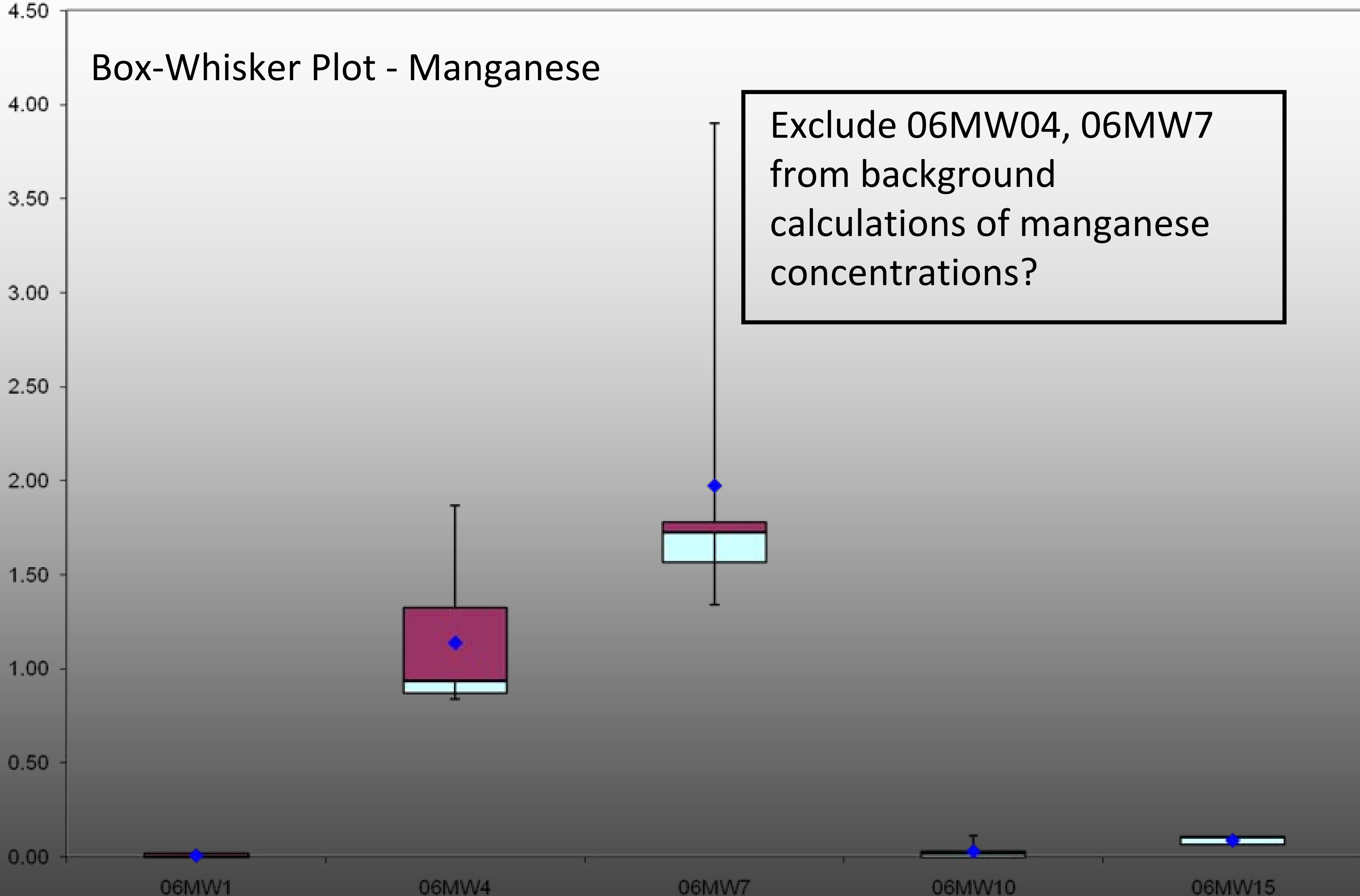
WHAT ABOUT METALS?

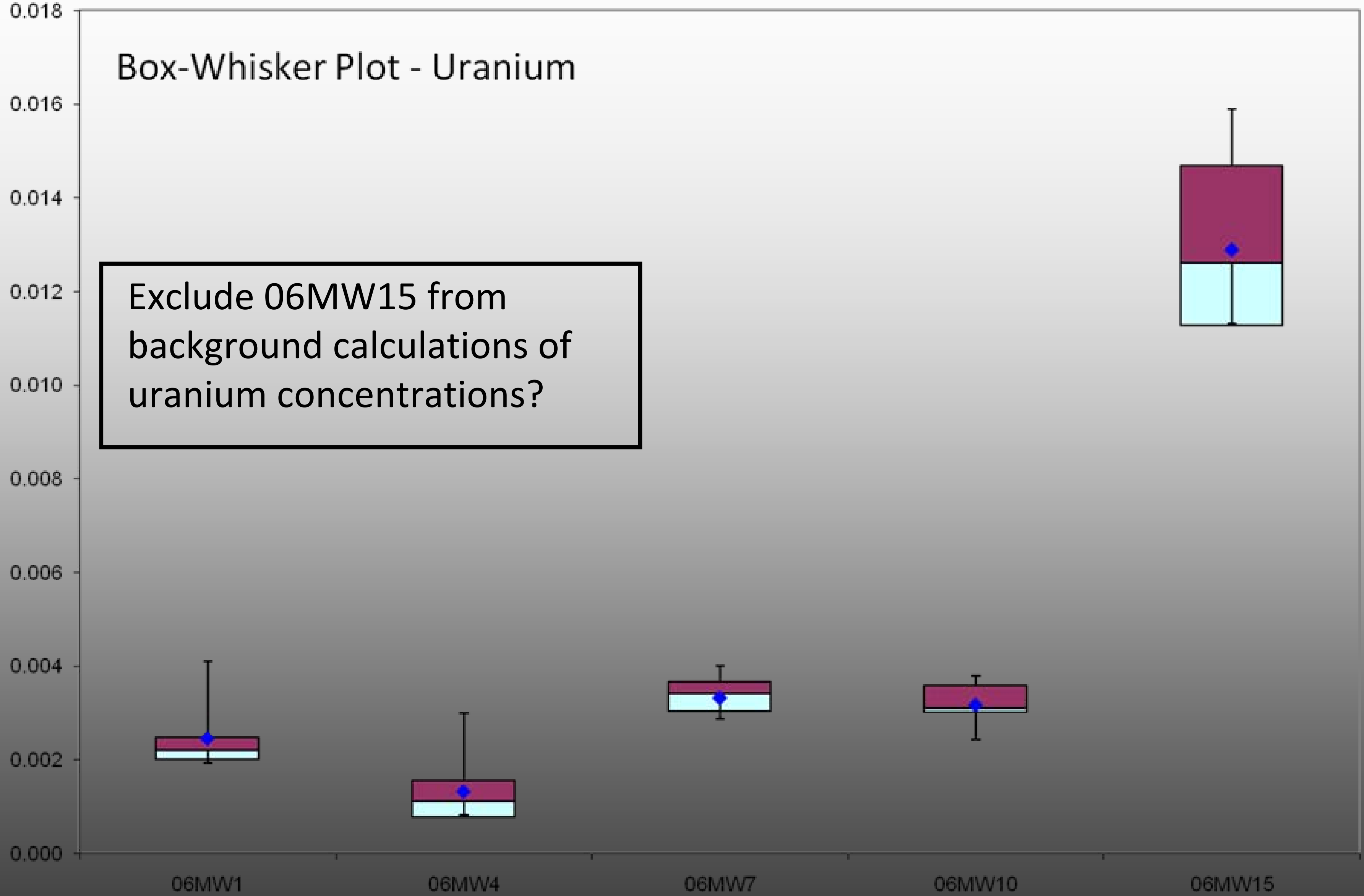
Dissolved Metals Concentrations in Groundwater – Battery Facility Site (selected analytes)

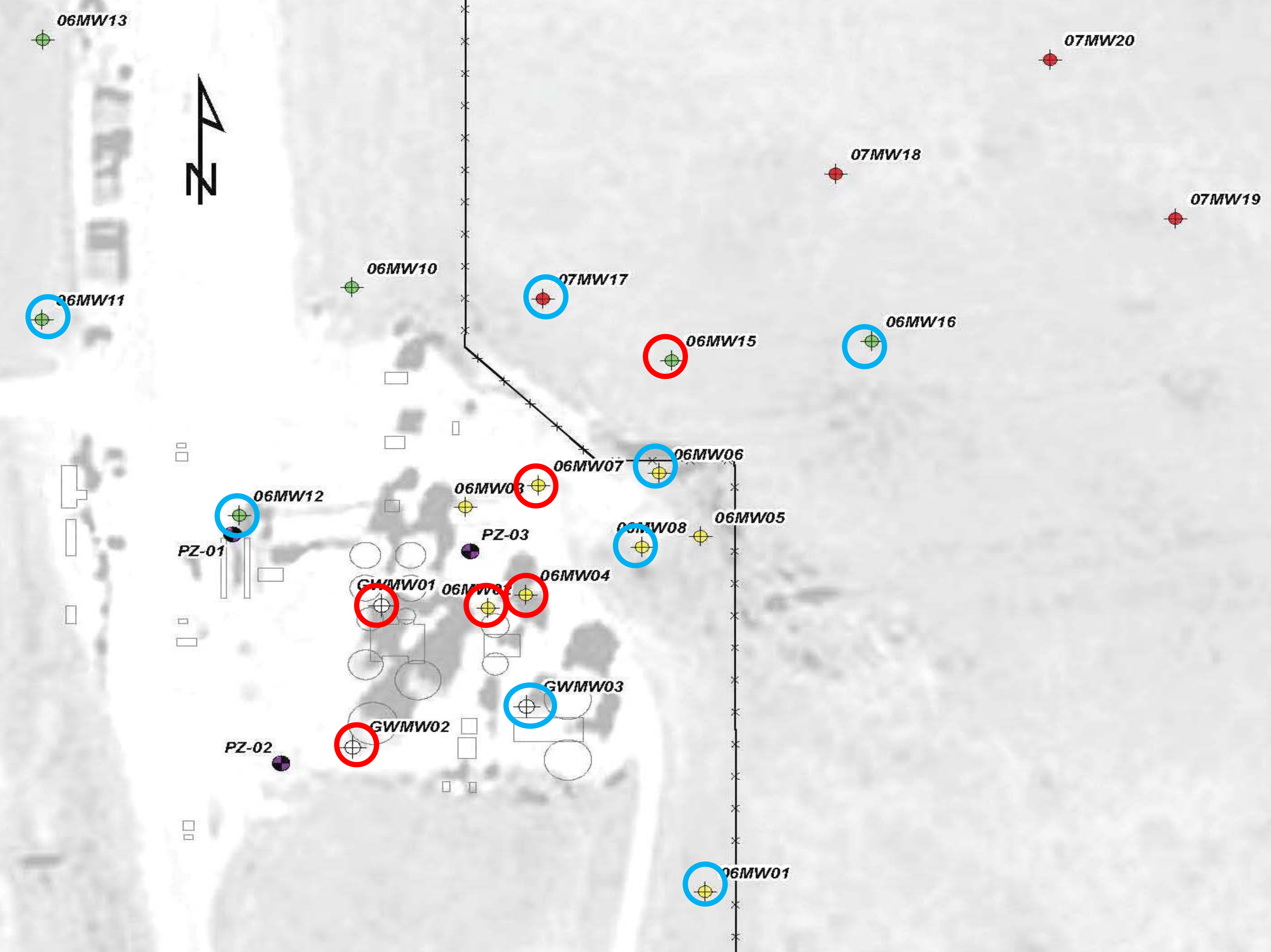
	06MW1	06MW4	06MW7	06MW10	06MW15	MANGANESE
28-Sep-06	ns	**1.05**	ns	ns	ns	
10-Dec-06	0.021	**0.777**	**3.9**	**0.113**	**0.06**	
16-Feb-07	0.02	**0.844**	**1.68**	0.028	**0.055**	
18-May-07	0.002	**1.87**	**1.77**	0.009	**0.099**	
24-Oct-07	0.003	**0.93**	**1.18**	0.009	**0.107**	
22-May-08	0.001	**1.59**	**1.53**	0.012	**0.105**	
1-Oct-08	0.0005	**0.904**	**1.78**	0.014	**0.105**	

	06MW1	06MW4	06MW7	06MW10	06MW15	URANIUM
28-Sep-06	ns	0.001	ns	ns	ns	
10-Dec-06	0.0025	0.0011	0.0033	0.0037	**0.0159**	
16-Feb-07	0.0041	0.0011	0.0025	0.0032	**0.0131**	
18-May-07	0.0024	0.0020	0.0035	0.0038	**0.0152**	
24-Oct-07	0.0017	0.0006	0.0037	0.0023	**0.0121**	
22-May-08	0.002	0.003	0.00293	0.0030	**0.011**	
1-Oct-08	0.002	0.0005	0.004	0.0030	**0.0100**	

- What trends do the data suggest?
- Do areas with concentrations above the guidelines represent background conditions or impacted areas?


Box-Whisker Plot - Manganese
Exclude 06MW04, 06MW7 from background calculations of manganese concentrations?
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
06MW1
06MW4
06MW7
06MW10
06MW15

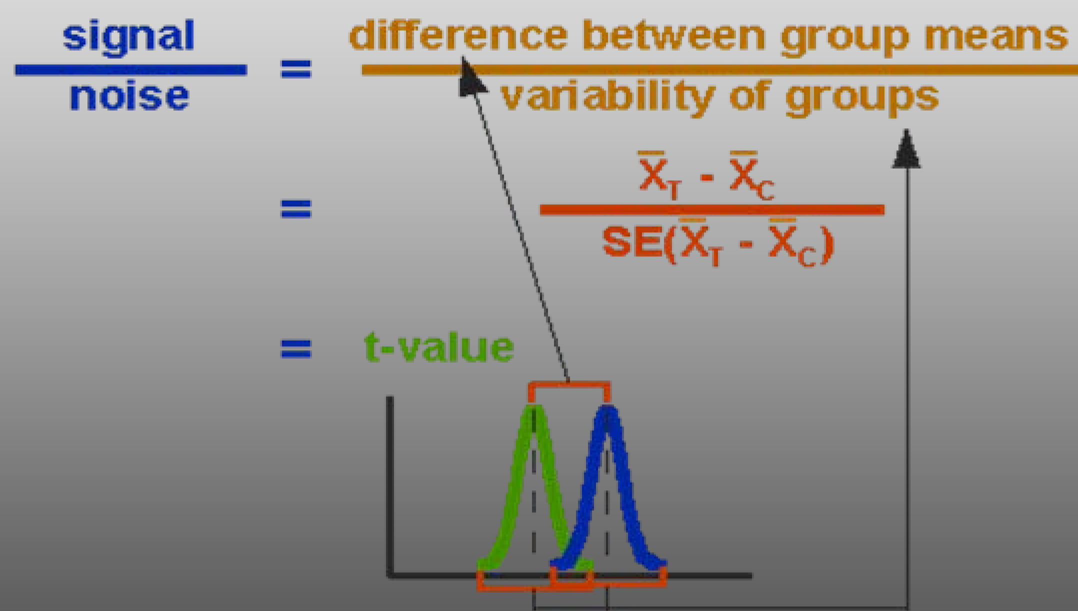

Box-Whisker Plot - Uranium
Exclude 06MW15 from background calculations of uranium concentrations?
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
06MW1
06MW4
06MW7
06MW10
06MW15


06MW13
N
07MW20
07MW18
07MW19
06MW10
07MW17
06MW16
06MW15
06MW06
06MW07
06MW12
06MW05
PZ-03
PZ-01
06MW04
GWMW03
GWMW02
PZ-02

Second Level of Evidence:
Statistical Evaluation - Variance

- T-Test
  - Compare difference between means among 2 well data sets

$$t = \frac{\overline{X}_D - \mu_0}{s_D/\sqrt{N}}.$$



Second Level of Evidence: Statistical Evaluation - Variance

- Analysis of Variance (ANOVA)
  - Single-Factor Evaluation
  - Compare variance among several well data sets – "Multiple T-Tests" and factor influence
  - Test a hypothesis (H_1) about differences between means – there is a factor (i.e. sample location) that explains the variation in means that we see
  - If the variance is not significant, the factor does not apply
  - Assumes that the population is normally distributed and that variance is relatively homogeneous

Second Level of Evidence:
Statistical Evaluation - Variance

- **Battery Facility T-Test:**
  - Perform T-test with each analyte using **two wells** believed to represent background conditions
  - Evaluate the hypothesis (H_1) that the variance of the means is significant – means are not similar
  - If the variance of the means is not significant, H_0 is true - the means of the data sets are similar
  - Concentrations in the selected wells represent background conditions

SECOND LEVEL OF EVIDENCE:
STATISTICAL EVALUATION - VARIANCE

- **Battery Facility ANOVA:**
  - Perform an ANOVA on each analyte using the accumulated data sets from **selected wells** outside impact area
  - Evaluate the hypothesis (H_1) that the variance in the means is significant and that the location of the well explains the variance of the means
  - If the variance of the means is not significant, H_0 is true - the well location must not be a factor
  - Background conditions may be represented in all of these wells

Battery Facility Analysis:
Chloride T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Two upgradient wells (06MW01 and 06MW11)
    - P = 3.16E-5, the means are different – the samples are from different populations
  - 06MW11 and well outside the plume (07MW17)
    - P = 0.43 – the samples are from the same population
  - 06MW11 and 07MW17 may represent background concentrations

Battery Facility Analysis:
Chloride T-test and ANOVA

SUMMARY

Groups	Count	Sum	Average	Variance
06MW01	6	62.8	10.46667	2.810667
06MW11	5	20.55	4.11	2.9606
06MW12	6	96.8	16.13333	37.79467
06MW16	5	34.81	6.962	3.08417
07MW17	5	23.67	4.734	3.66498

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	548.8275	4	137.2069	12.48028	1.89E-05	2.81670834
Within Groups	241.8657	22	10.99389			
Total	790.6932	26				

- Exclude all wells believed to be within impacted area
- F value indicates that H_1 is true – location is a factor
    - variation is significant – these wells do not collectively represent background for chloride

Battery Facility Analysis: Potassium T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Two upgradient wells (06MW01 and 06MW11)
    - P = 0.641, the means are similar – the samples are from the same population
  - 06MW11 and well outside the plume (07MW17)
    - P = 0.197 – the samples are from the same population
  - 06MW01, 06MW11 and 07MW17 may represent background concentrations

Battery Facility Analysis:
Potassium T-Test and ANOVA

SUMMARY

Groups	Count	Sum	Average	Variance
06MW01	6	16.1	2.683333	1.201667
06MW11	5	12.1	2.42	0.077
06MW12	6	21.4	3.566667	0.058667
07MW17	5	22.6	4.52	9.277

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	14.01506	3	4.671687	1.923487	0.161967	3.159908
Within Groups	43.71767	18	2.428759			
Total	57.73273	21				

- Exclude all wells believed to be within impacted area
- F value indicates that H_1 is false – location is not a factor – these wells represent background for potassium concentrations

Battery Facility Analysis:
Manganese T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Two wells outside plume (06MW01, 06MW10)
    - P = 0.159, the means are similar – the samples are from the same population
  - 06MW01, 06MW10 may represent background concentrations for manganese

Battery Facility Analysis: Manganese T-Test and ANOVA

SUMMARY

Groups	Count	Sum	Average	Variance
06MW1	6	0.0475	0.007917	9.58E-05
06MW4	7	7.968	1.138286	0.176902
06MW7	6	11.84	1.973333	0.940547
06MW10	6	0.185	0.030833	0.00167
06MW15	6	0.531	0.0885	0.000586

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.83602	4	4.709005	21.1974	7.17E-08	2.742594
Within Groups	5.775904	26	0.22215			
Total	24.61192	30				

Box-whisker plot indicated MW4, MW7, MW15 should be excluded…

- All wells (set of values above MDL is too small)
- F value indicates that H_1 is true– location is a factor – these wells collectively do not represent background for manganese concentrations

Battery Facility Analysis:
Zinc T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Two wells outside plume (06MW01, 06MW10)
    - P = 0.0.489, the means are similar – the samples are from the same population
  - 06MW01, 06MW10 may represent background concentrations for manganese

Battery Facility Analysis:
Zinc T-Test and ANOVA

SUMMARY

Groups	Count	Sum	Average	Variance
06MW1	6	0.397	0.066167	0.011583
06MW4	7	0.564	0.080571	0.016775
06MW7	6	0.249	0.0415	0.00103
06MW10	6	0.446	0.074333	0.013971
06MW15	6	0.35	0.058333	0.013109

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.005806	4	0.001451	0.126163	0.97166	2.742594
Within Groups	0.299113	26	0.011504			
Total	0.304918	30				

- All wells (set of values above MDL is too small)
- F value indicates that H_1 is false– location is not a factor – these wells may collectively represent background for zinc concentrations

Battery Facility Analysis: Findings

- Statistical tests are enlightening
  - Analysis of table trends and graphs didn't yield enough confidence in background characterization
- Box-whisker plots revealed several "outliers" within impacted areas for multiple analytes
  - Showed that further analysis on calcium concentrations not productive
- T-tests showed that pairs of wells that were upgradient or outside plume appear to represent background for potassium, magnesium, chloride, manganese, zinc

Battery Facility Analysis: Findings

- ANOVA
  - Background concentrations not accurately characterized across the site for chloride, manganese
  - Background concentrations may be accurately characterized across the site for potassium, zinc
- ***Reminder*** - Seasonal variation has not been examined in single-factor ANOVA

GROUNDWATER EVALUATION: PRODUCED WATER SPILL

GROUNDWATER EVALUATION:
PRODUCED WATER SPILL

- **OBJECTIVE:**
- Compare concentrations in wells outside of soil impact area to concentrations within impact area – can “background” concentrations or produced water impacts be seen in wells across the site?
- Characterize background conditions for select individual analytes across the site, not just for concentrations in one well

First Level of Evidence:
"Qualitative" Evaluation

- Physical Properties of the Site
- **Table trends – compare known "Background well" to other wells on site**

W/C
07MW5
07MW6
07MW1
07MW4
07MW2
07MW3

W/C
07MW5
07MW6
07MW1
07MW4
07MW2
07MW3

FIRST LEVEL OF EVIDENCE:
"QUALITATIVE" EVALUATION

- **Physical Properties of the Site**

Analyte Concentrations in Groundwater – Produced Water Site

CHLORIDE

07MW1	**07MW4**	**07MW5**	**07MW6**
79.6	45.2	30.4	21
79.4	40.8	25.3	14.7
80.3	63.6	26.5	17.2
78.1	64.5	27.3	23
81.8	60.8	28.8	25.6

SULFATE

07MW1	07MW4	07MW5	07MW6
3110	**2070**	**2820**	**2640**
2860	**1180**	**2730**	**2460**
2890	**1290**	**2600**	**2460**
2850	**1490**	**2410**	**2540**
2890	**1490**	**2550**	**2680**

SODIUM

07MW1	07MW4	07MW5	07MW6
170	**243**	**206**	158
174	145	**207**	156
177	187	198	153
168	**206**	195	165
162	191	188	159

- What trends do the routine water data suggest?
- Do areas with concentrations below the guidelines represent background conditions or “impacted” areas?

Dissolved Metals Concentrations in Groundwater – Produced Water Site

	07MW1	07MW4	07MW5	07MW6	IRON
25-Oct-07	ns	0.002	ns	0.001	
24-Mar-08	0.007	0.008	0.031	0.006	
27-May-08	0.008	0.004	0.005	0.008	
27-Aug-08	0.008	0.004	0.008	0.005	
29-Sep-08	0.008	0.001	0.02	0.002	

	07MW1	07MW4	07MW5	07MW6	ZINC
25-Oct-07	ns	0.007	ns	0.009	
24-Mar-08	0.012	0.008	0.011	0.006	
27-May-08	0.009	0.007	0.016	0.015	
27-Aug-08	0.015	0.006	**0.054**	0.012	
29-Sep-08	0.016	0.012	0.014	**0.28**	

	07MW1	07MW4	07MW5	07MW6	BARIUM
25-Oct-07	ns	0.058	ns	0.041	
24-Mar-08	0.053	0.031	0.046	0.032	
27-May-08	0.055	0.031	0.05	0.032	
27-Aug-08	0.048	0.03	0.038	0.028	
29-Sep-08	0.046	0.023	0.033	0.084	

- What trends do the metals data suggest?
- Do areas with concentrations below the guidelines represent background conditions or “impacted” areas?

Spill Site Analysis:
Chloride T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Background and spill wells (07MW01, 07MW5)
    - P = 6.37E-7, the means are different – the samples are from different populations
  - Background and spill wells (07MW01, 07MW6)
    - 5.99E-6, the means are different – the samples are from different populations
    - Chloride concentrations may not be comparable inside and outside the spill

Spill Site Analysis: Chloride T-Test and ANOVA

SUMMARY

Groups	Count	Sum	Average	Variance
07MW1	5	851	170.2	33.2
07MW4	5	972	194.4	1250.8
07MW5	5	994	198.8	62.7
07MW6	5	791	158.2	19.7

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5657.2	3	1885.733	5.520297	0.008509	3.238872
Within Groups	5465.6	16	341.6			
Total	11122.8	19				

- Include all wells – data set is small
- F value indicates that H_1 is true – location is a factor
  - variation in means is significant – these wells do not collectively represent background for chloride

Spill Site Analysis: Sulphate T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Background and spill wells (07MW01, 07MW5)
    - P = 0.004, the means are different – the samples are from different populations
  - Background and spill wells (07MW01, 07MW6)
    - 0.001, the means are different – the samples are from different populations
    - Chloride concentrations may not be comparable inside and outside the spill

Spill Site Analysis:
Potassium T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - Background and spill wells (07MW01, 07MW5)
    - P = 0.848, the means are similar – the samples are from the same populations
  - Background and spill wells (07MW01, 07MW6)
    - 0.065, the means are similar – the samples are from the same populations
    - Potassium concentrations may be comparable inside and outside the spill

Spill Site Analysis: Summary of Sulfate and Potassium ANOVA

- *Sulfate*: $F = 99.50$, $F_{CRIT} = 3.24$
- F value indicates that H_1 is true – location is a factor
  - variation in means is significant – these wells may not collectively represent background for sulfate
- *Potassium*: $F = 46.30$, $F_{CRIT} = 3.24$
- F value indicates that H_1 is true – location is a factor
  - variation in means is significant – these wells may not collectively represent background for potassium

Spill Site Analysis:
Metals T-Test and ANOVA

- **Paired, 2-tailed T-Test (α=0.05):**
  - ***Iron***: Background and spill wells 07MW01, 07MW5 and 07MW1, 07MW6
    - P = 0.12 and 0.06, background iron concentrations may be in both locations
  - ***Zinc***: Background and spill wells 07MW01, 07MW5 and 07MW1, 07MW6
    - P = 0.35 and 0.06, background iron concentrations may be in both locations

Spill Site Analysis: Summary of Metals ANOVA

- *Iron*: $F = 3.87$, $F_{CRIT} = 3.34$
- F value indicates that H_1 is true – location is a factor
  - variation in means is significant – these wells may not collectively represent background for iron
- *Zinc*: $F = 0.75$, $F_{CRIT} = 3.24$
- F value indicates that H_1 is false– location is not factor
  - variation in means is not significant – these wells may collectively represent background for zinc

Spill Site Analysis: Findings

- Statistical tests are enlightening
  - Analysis of table trends added more uncertainty in characterizing background concentrations
- T-tests showed that analyte concentrations in background well were not comparable to those within spill area for chloride, sulfate
- T-tests showed that analyte concentrations in background well were comparable to those within spill area for potassium, iron, zinc

Battery Facility Analysis: Findings

- ANOVA
  - Background concentrations not represented inside and outside the spill for chloride, sulfate, and potassium
  - Background concentrations may be accurately characterized across the site for zinc
- ***Reminder*** - Seasonal variation has not been examined in single-factor ANOVA
- ***Reminder 2*** – the data set for this spill site is extremely small – 4 wells, 4-5 samples per well

CONCLUSIONS

The Statistical Method: Advantages

- Useful when combined with the initial site evaluation
  - Multiple lines of evidence for observations
  - Reveals relationships that manual analysis (tables and graphs) cannot determine
- Increased confidence when data are not clear-cut
- Defensible and reproducible
  - Methods to update the analysis when new data come in

The Statistical Method:
Drawbacks

- Time-consuming – potentially expensive
- Requires a large, robust data set with detectable concentrations
- Requires normal, homogeneous sample populations
- Multiple tests may be required to account for seasonal variablity
- QAQC and Data Verification is incredibly important – must have confidence in the data set – small differences in reported values can be crucial

GROUNDWATER EVALUATION: RECOMMENDATIONS

- Combine site observations with statistical analytical tools
- Use a multi-step approach – Box-Whisker plots then analysis of variance – to characterize groundwater concentrations
- Design sample plans to collect enough data, from enough wells, for statistical analysis

GROUNDWATER EVALUATION: STATISTICAL METHODS - WHAT ELSE IS NEEDED?

- Procedures for incorporating seasonal variations in groundwater ?
- Different procedures for evaluating small and large sites, and various families of analytes?
- Additional regulatory input and guidance

QUESTIONS?

TRIUM

트 리 엄