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Advances in Groundwater Plume Stability and Plume Diagnostic Evaluations

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October 16, 2014

EarthCon Plume Analytics

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Why look at Plume Stability?

- I have two wells in my well network with increasing trends – my plume must be expanding!
- My most downgradient well now has 2 ppb benzene – my plume must be expanding!
- I have a hydraulic containment system - without the system my plume would be expanding!

Ricker Method® Plume Stability Analysis

- Efficiently assimilates large volumes of historical data into a concise and meaningful analysis
- Excellent groundwater management tool
  - Basis for termination of remediation systems
  - Basis for MNA
  - Monitor progress of remediation system
- It is NOT a Model

- Ricker Method® Highlighted by USEPA Region IV
  - RCRA Showcase Pilot
- Methodology published in Groundwater Monitoring & Remediation 28, no. 4/ Fall 2008/pages 85–94

Ricker Method® endorsed by State Agencies

- Ohio EPA– Review of Corrective Measures Progress Report (Landfill in Ross County, April 2014)

  "Ohio EPA remains encouraged by the findings of this [Plume Stability Analysis] analysis, and considers this a very useful tool in the continued assessment of groundwater conditions..."

- Missouri – A preferred method for site closure analysis

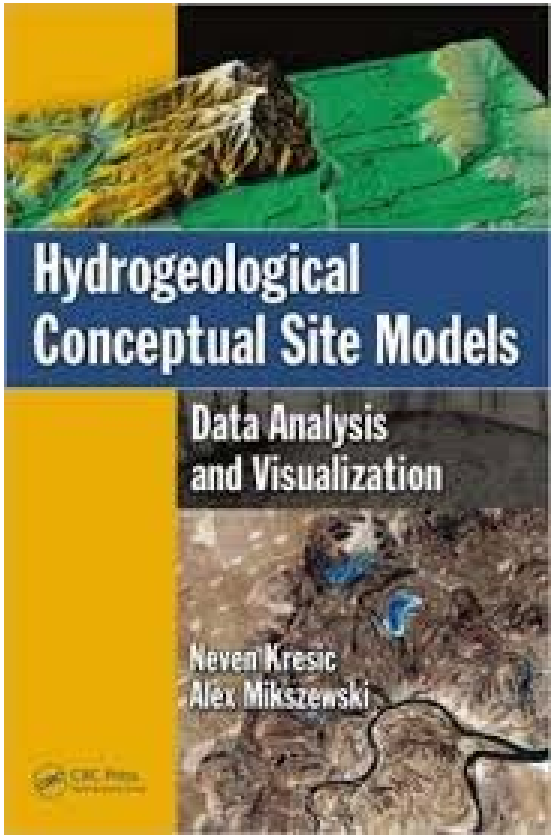
  "The Tanks Section has been using his method and it has greatly helped the section's ability to accurately and timely analyze plume stability."

- New Jersey - MNA Guidance

  "Ricker (2008) provides a straightforward method to evaluate changes in plume mass over time…applied to mapped contaminant concentration distributions."

Ricker Method® Published in Hydrogeological Conceptual Site Models Text Book

" …very useful in demonstrating that the overall plume is clearly decreasing, even though one or some of the wells are stable or increasing. This has always been one of the biggest drawbacks of well by well trend analysis…"



Ricker Method® Published in US Navy Environmental Restoration Program Management and Monitoring Approach Document

Optimization Tools: Ricker Plume Stability Method

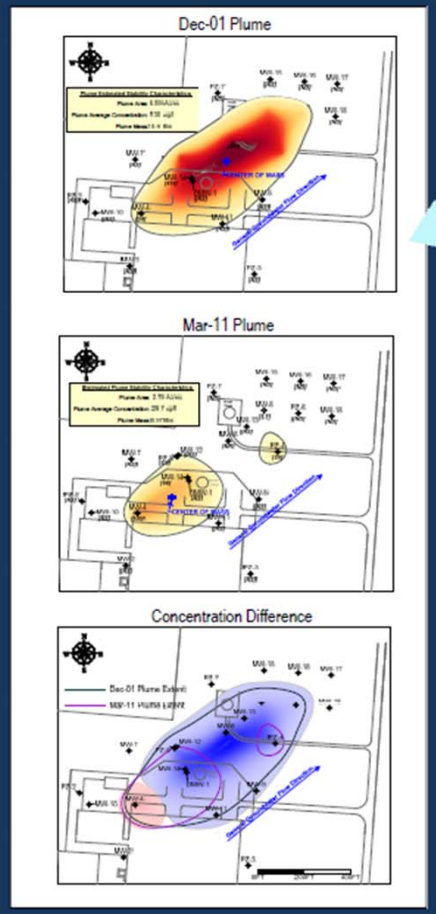
Ricker Plume Stability Method: optimization method that demonstrates plume dynamics in order to evaluate treatment effectiveness and monitored natural attenuation (MNA)

Plume Dynamics Evaluation

- Calculates and assesses historical trends in contaminant plume area,
- Calculates average concentration, contaminant mass, and center of mass
- Calculates overall CVOC molar mass
- Spatially evaluates temporal changes in plume

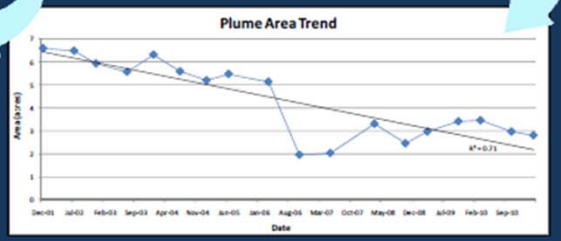
Key Uses:

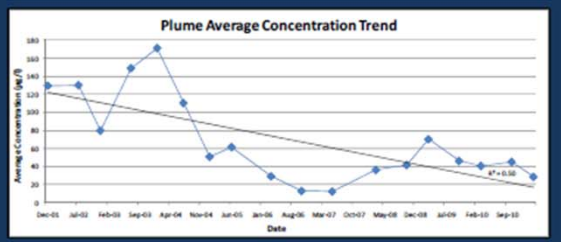
- Demonstrates plume stability
- Helps determine if site is appropriate for MNA
- Evaluates classes of compounds
- Evaluates sites with established monitoring well networks and multiple years of data

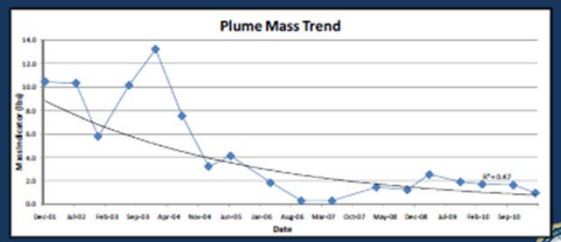


The concentration isopleth maps show the change in spatial plume extent over time. The concentration difference map shows areas and relative magnitude of concentration decreases (blue shading) and increases (pink shading) within the plume.

Trend graphs depicting temporal trends in plume stability characteristics assist in understanding plume dynamics.







Navy Environmental Restoration Program Management and Monitoring Approach 3

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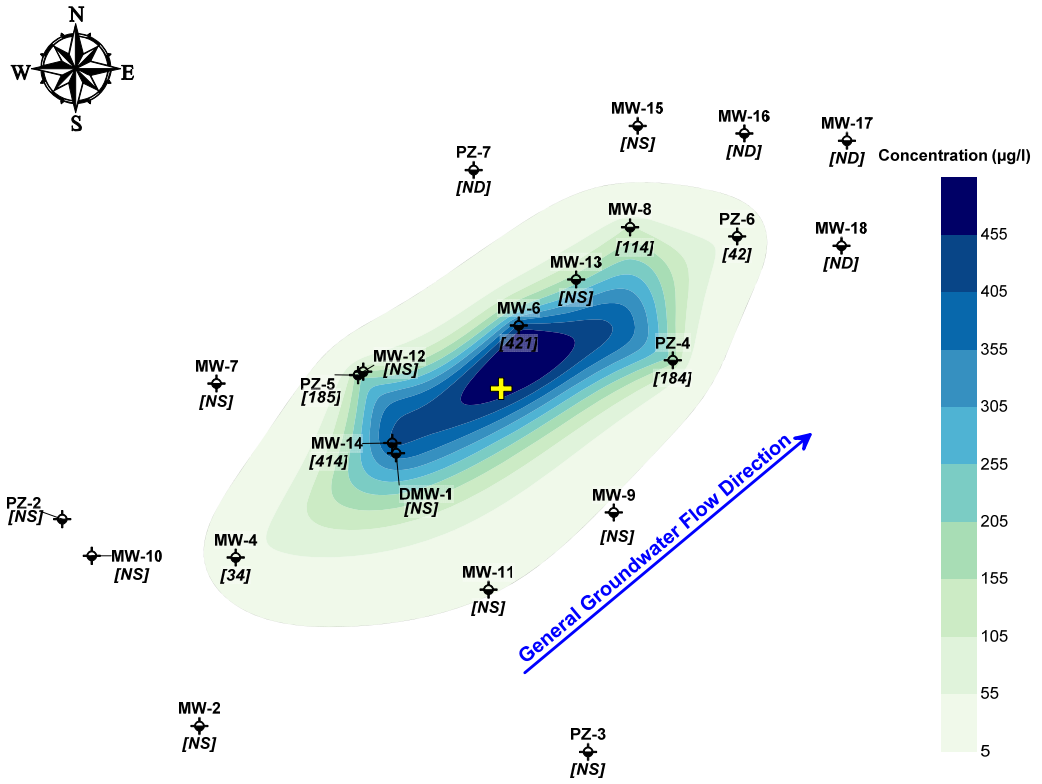
Ricker Method®

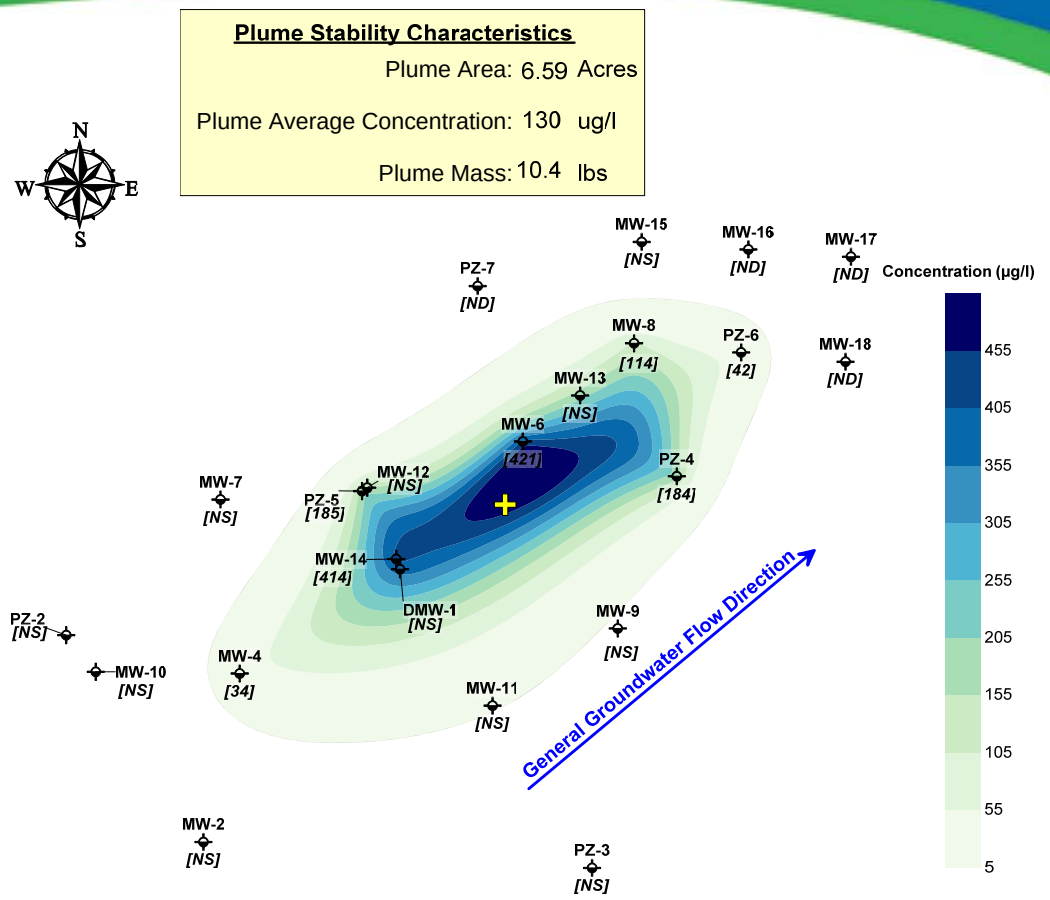
Methodology

- Select indicator compound(s)
- Develop concentration isopleth maps
  - Each indicator compound
  - Each aquifer level (shallow, deep, etc.)
  - Plume boundary defined by MCL or site-specific level



Ricker Method®

- Calculate plume stability characteristics
  - Area
  - Average concentration
  - Mass
  - Center of mass
  - Plume Spread



Ricker Method®

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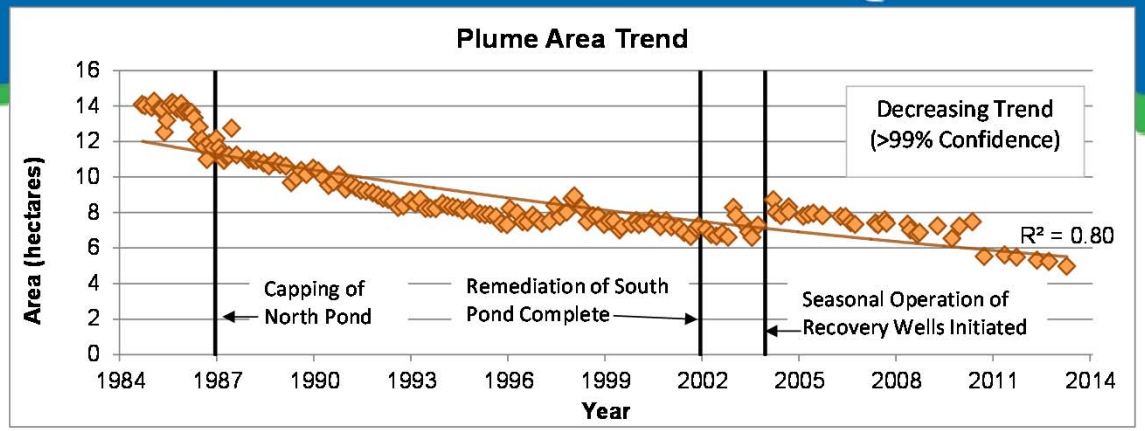
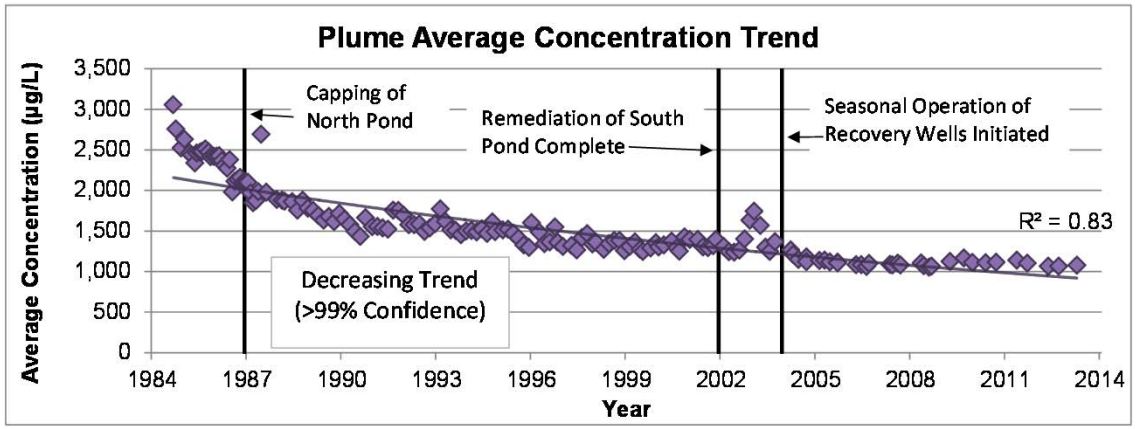
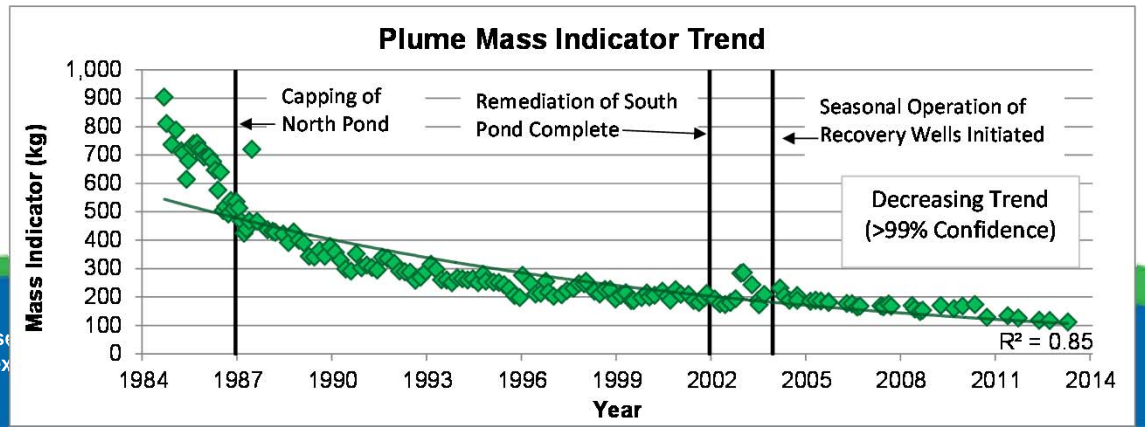
Evaluate temporal trends in plume characteristics

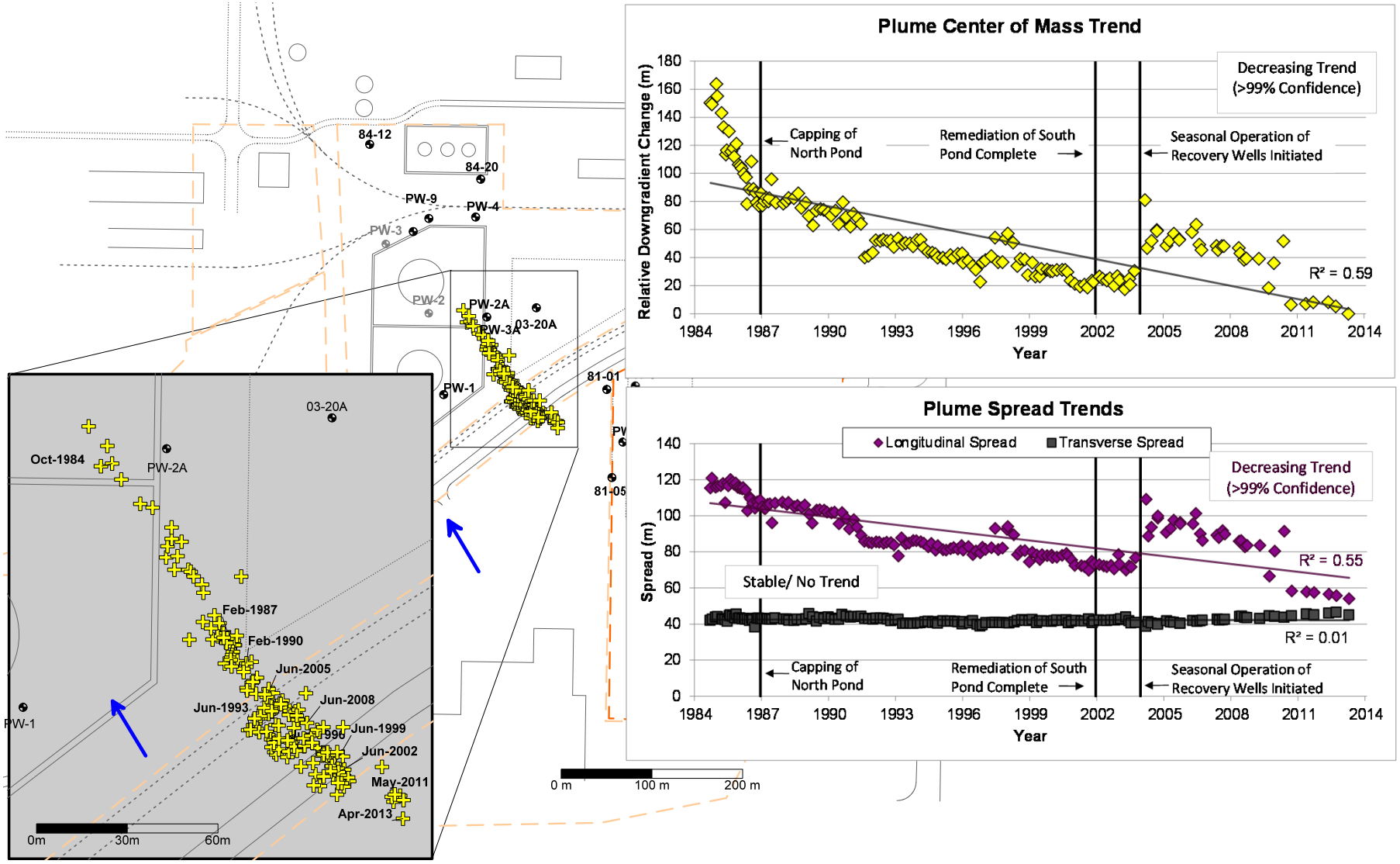






Ricker Method®

Evaluate temporal trends in plume center of mass



Spatial Difference Maps

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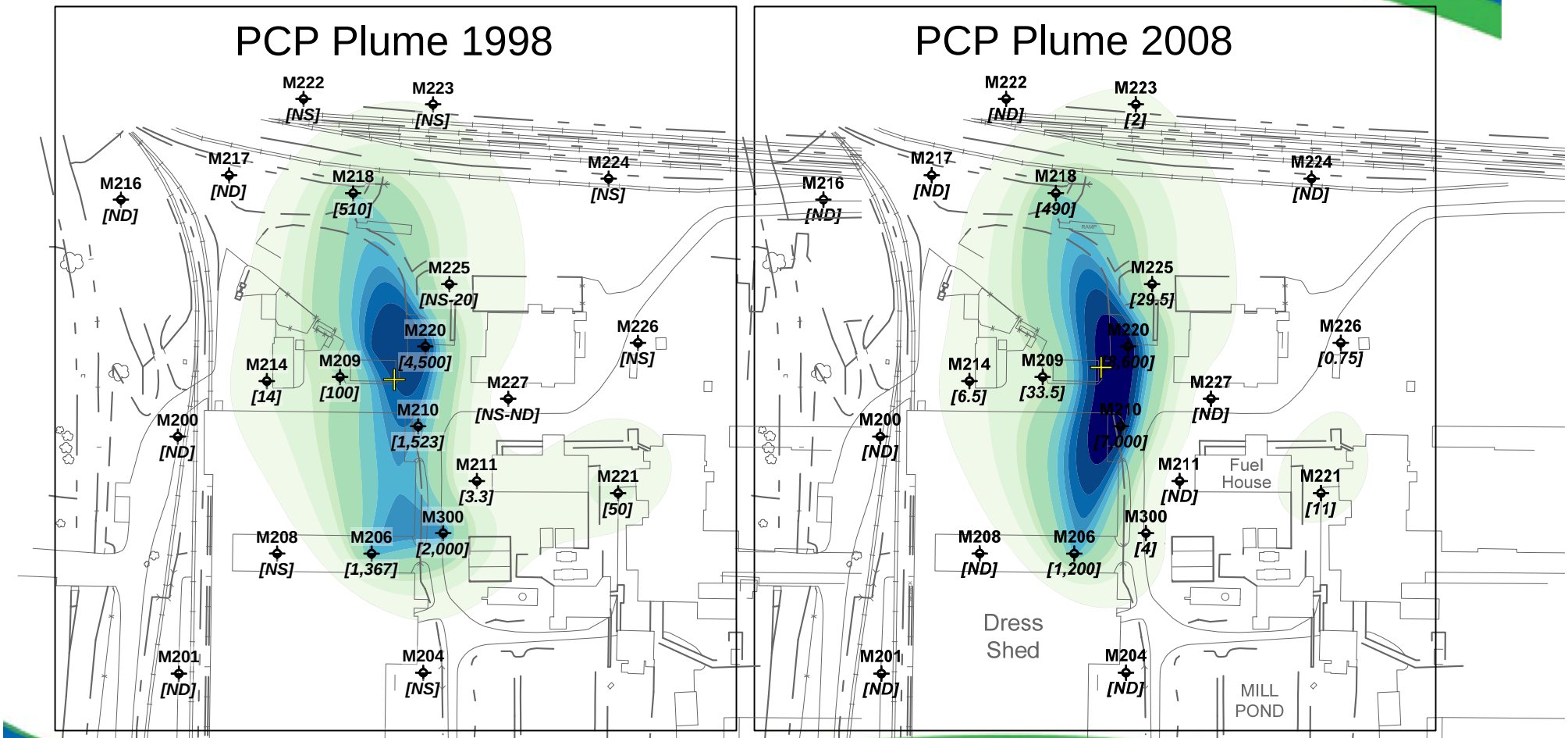

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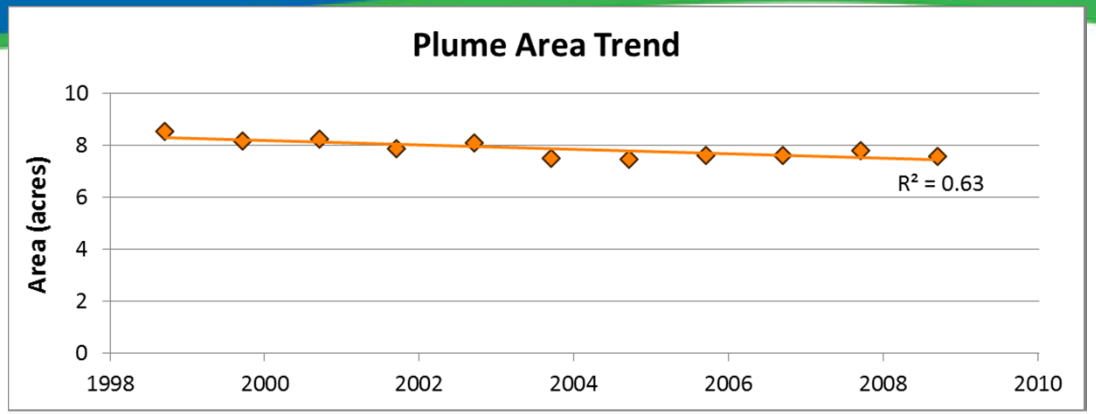
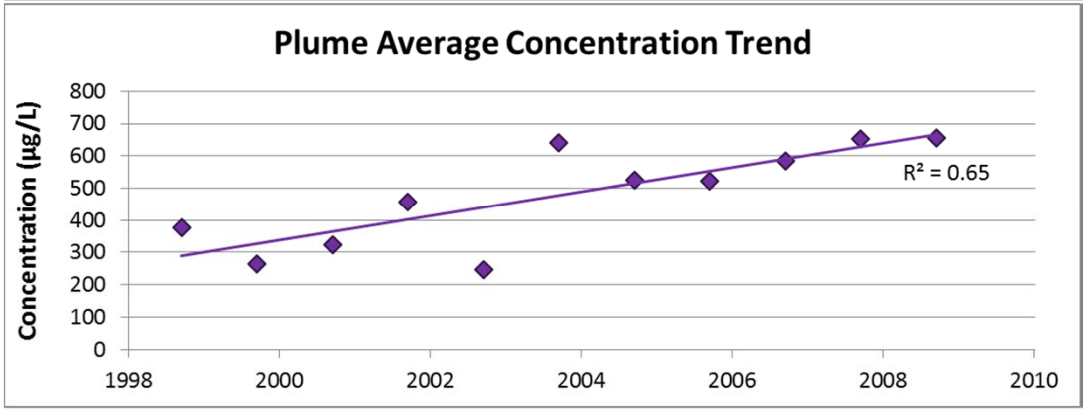
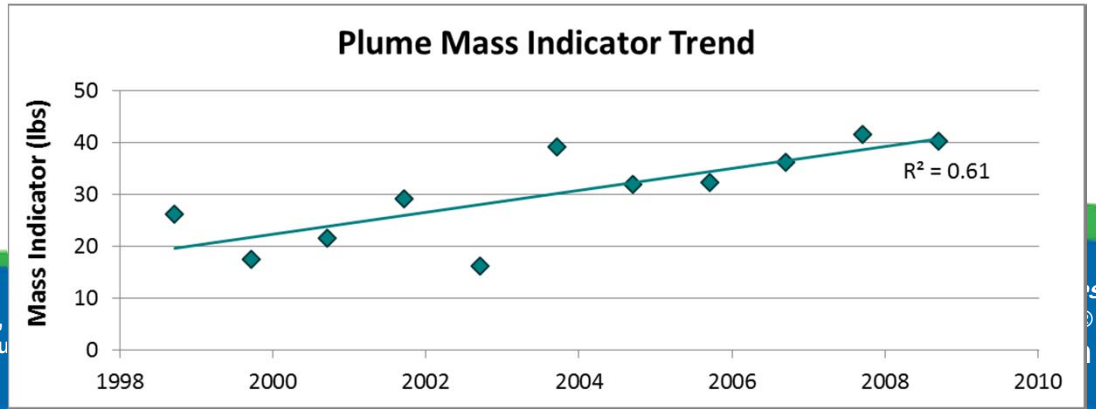
Spatial Difference Maps

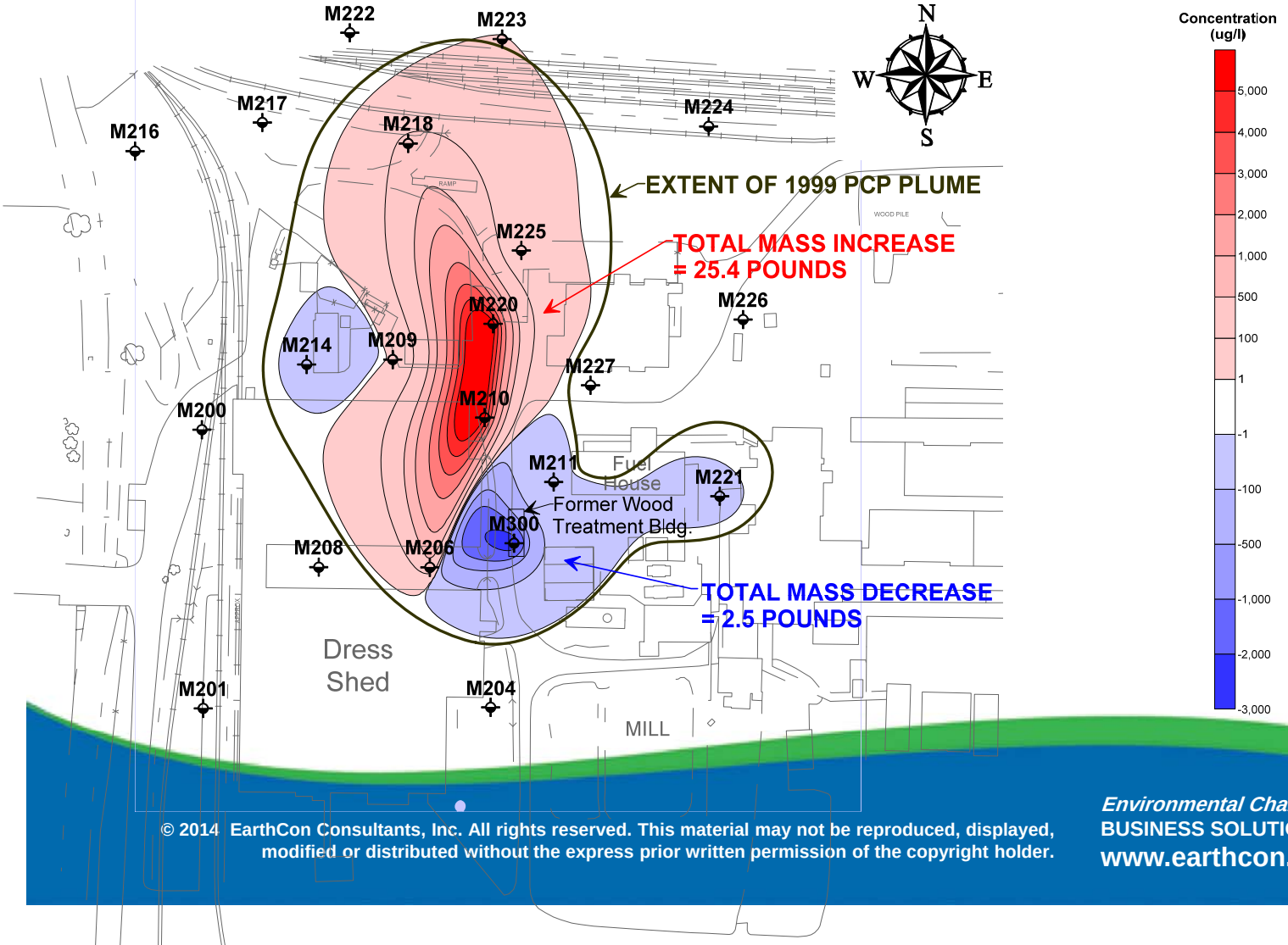






Spatial Difference Maps

- Spatial evaluation of plume change over time



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Spatial Difference Maps

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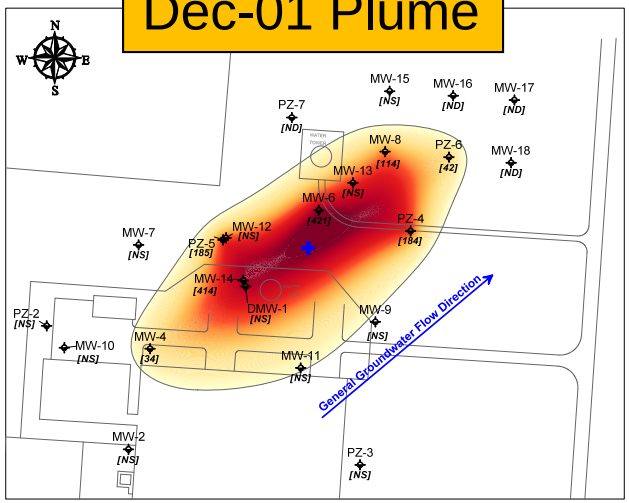
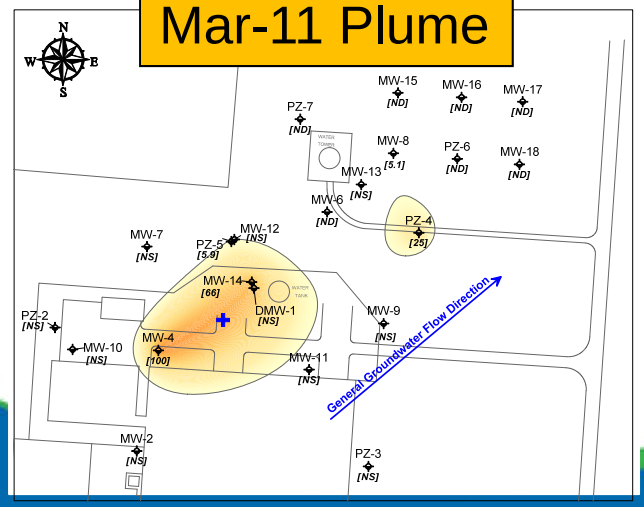
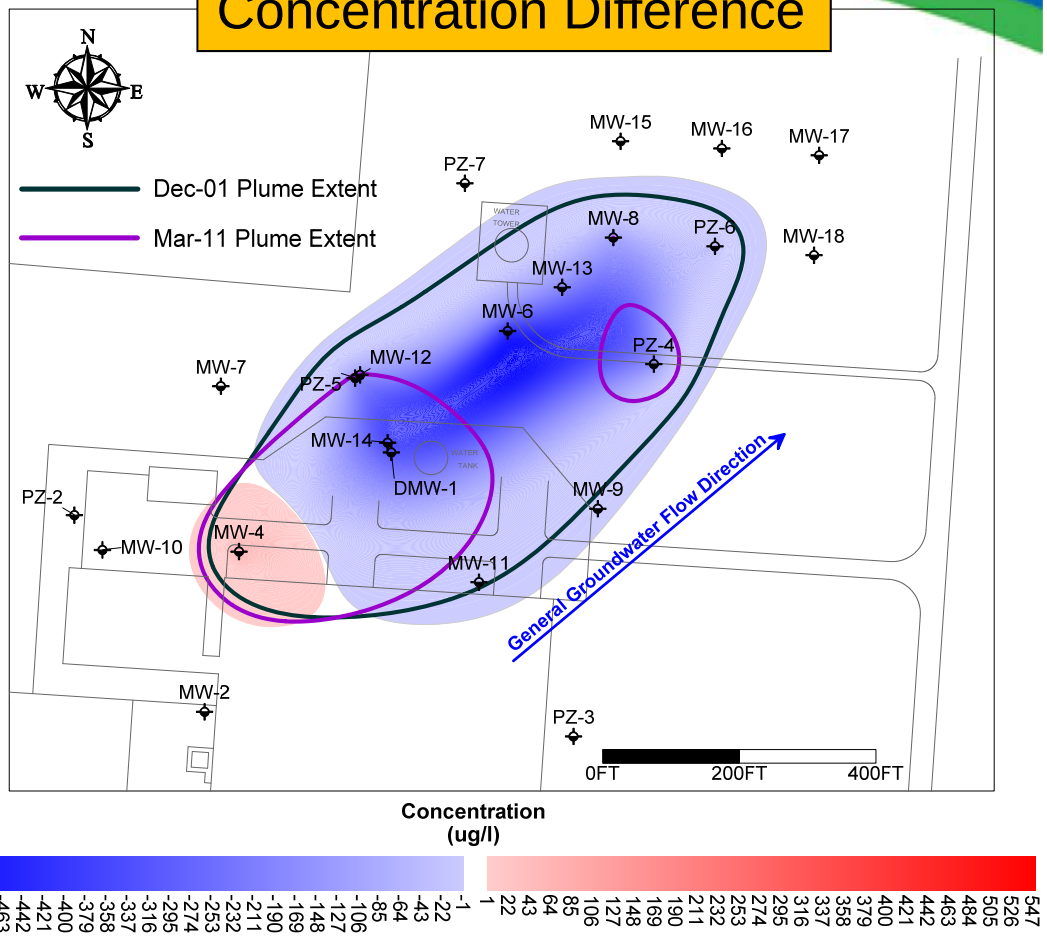
Dec-01 Plume



Mar-11 Plume



Concentration Difference



Concentration (ug/l)

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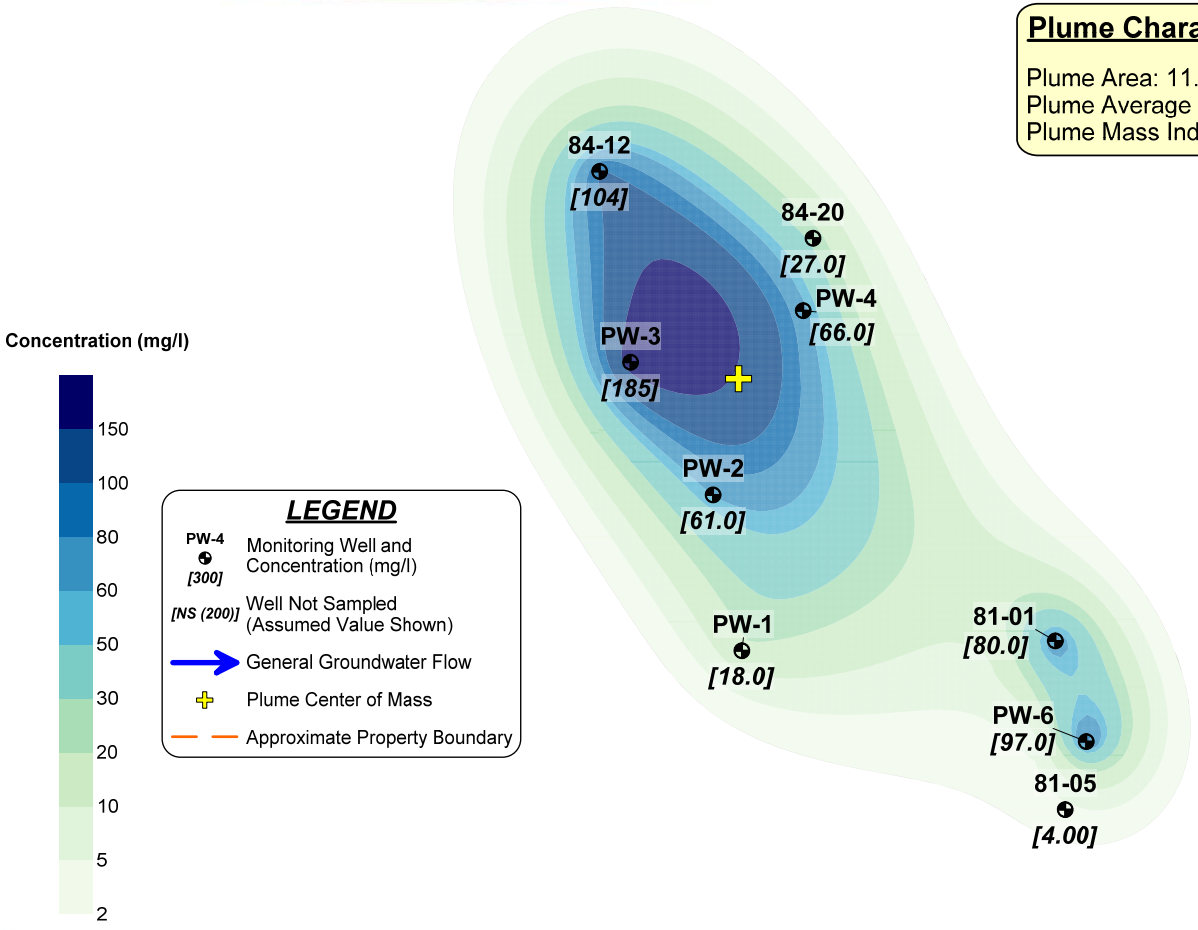
Example Site Analysis

- **Example site analysis for closed industrial site in Alberta**
- **Ricker Method® used evaluate plume dynamics and termination of remediation system**
- **CVOCs evaluated**
  - 2,4-D
  - 2,4,5-T
  - Phenol

Phenol Plume
October 1984

Plume Characteristics

Plume Area: 11.50 hectares
Plume Average Concentration: 33.73 mg/l
Plume Mass Indicator: 8144 kg



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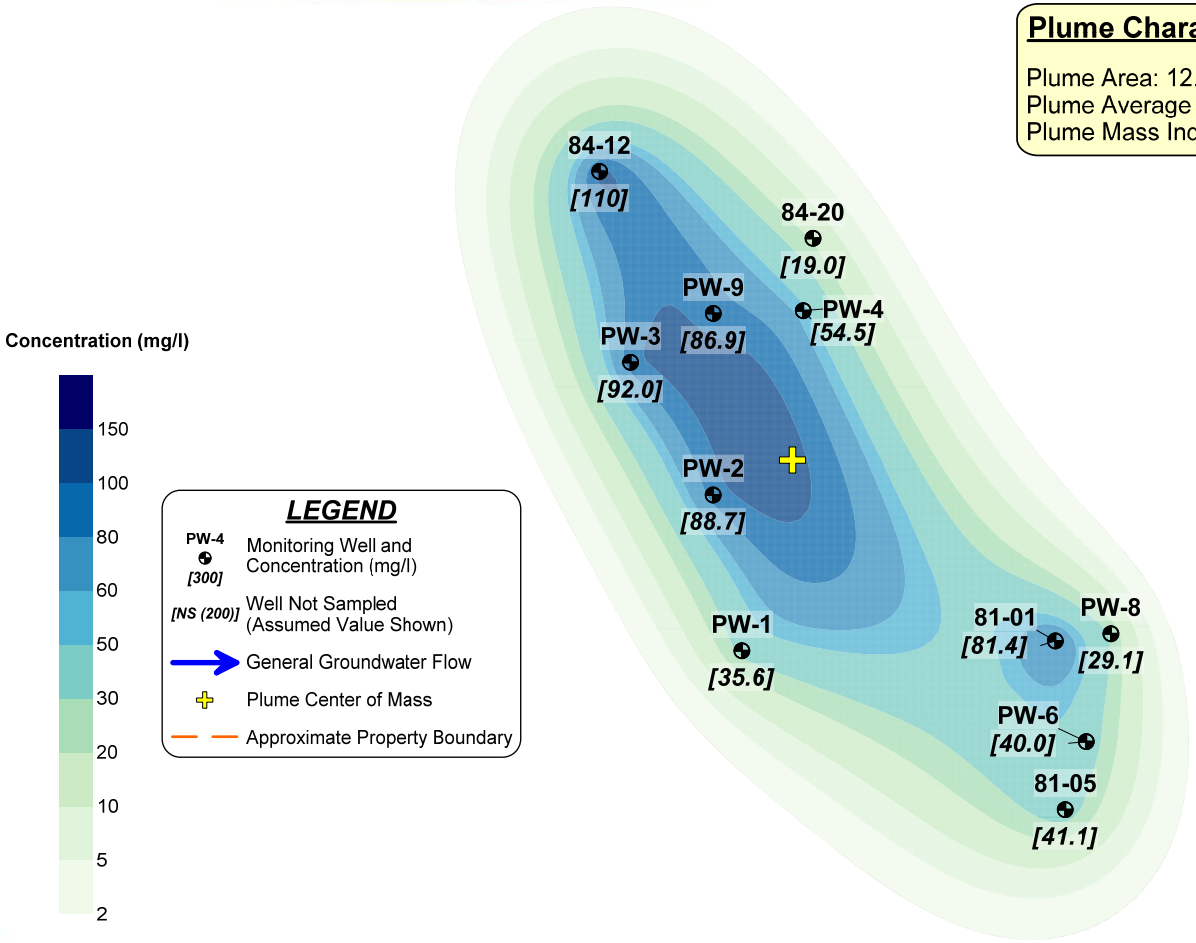
Phenol Plume
February 1987

Plume Characteristics

Plume Area: 12.99 hectares
Plume Average Concentration: 33.65 mg/l
Plume Mass Indicator: 9180 kg



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Phenol Plume
April 1990

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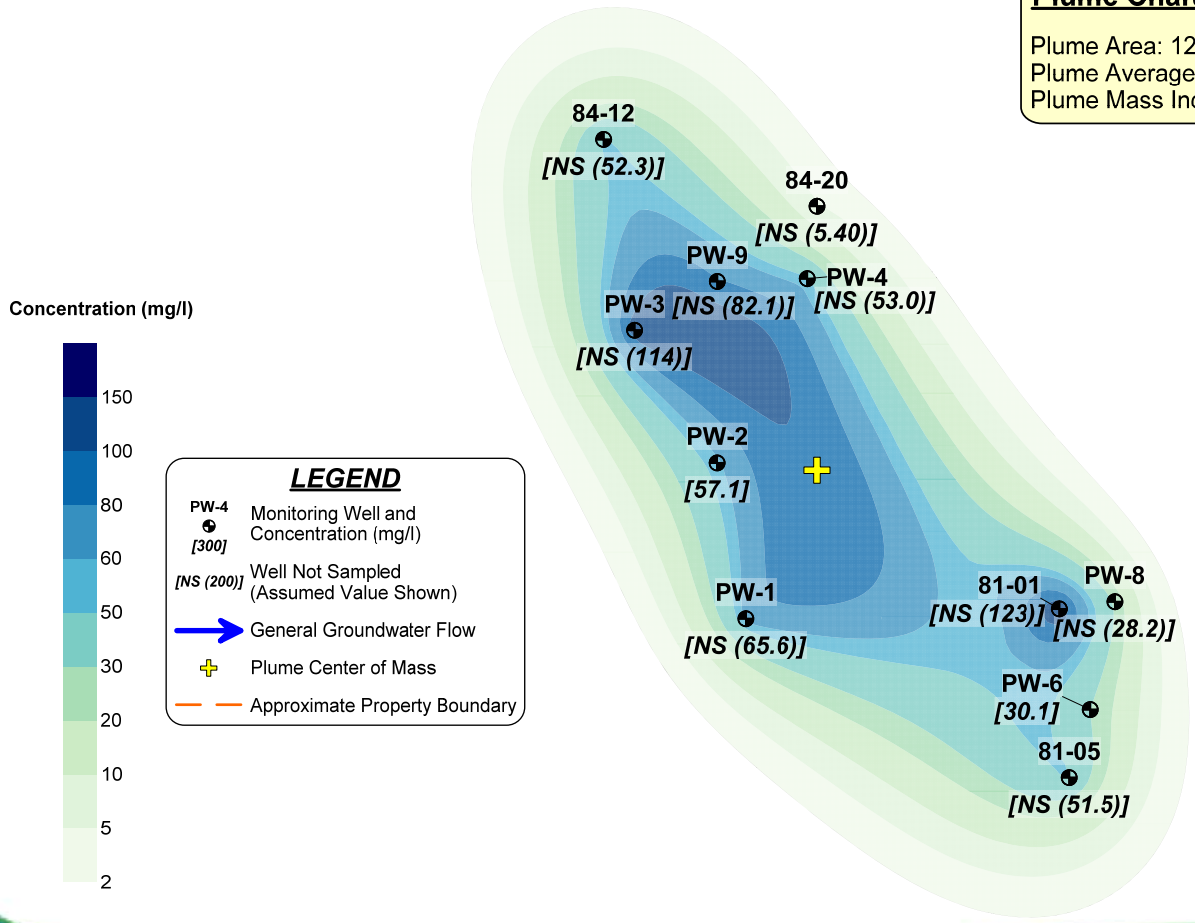
Plume Characteristics

Plume Area: 12.54 hectares
Plume Average Concentration: 34.09 mg/l
Plume Mass Indicator: 8977 kg



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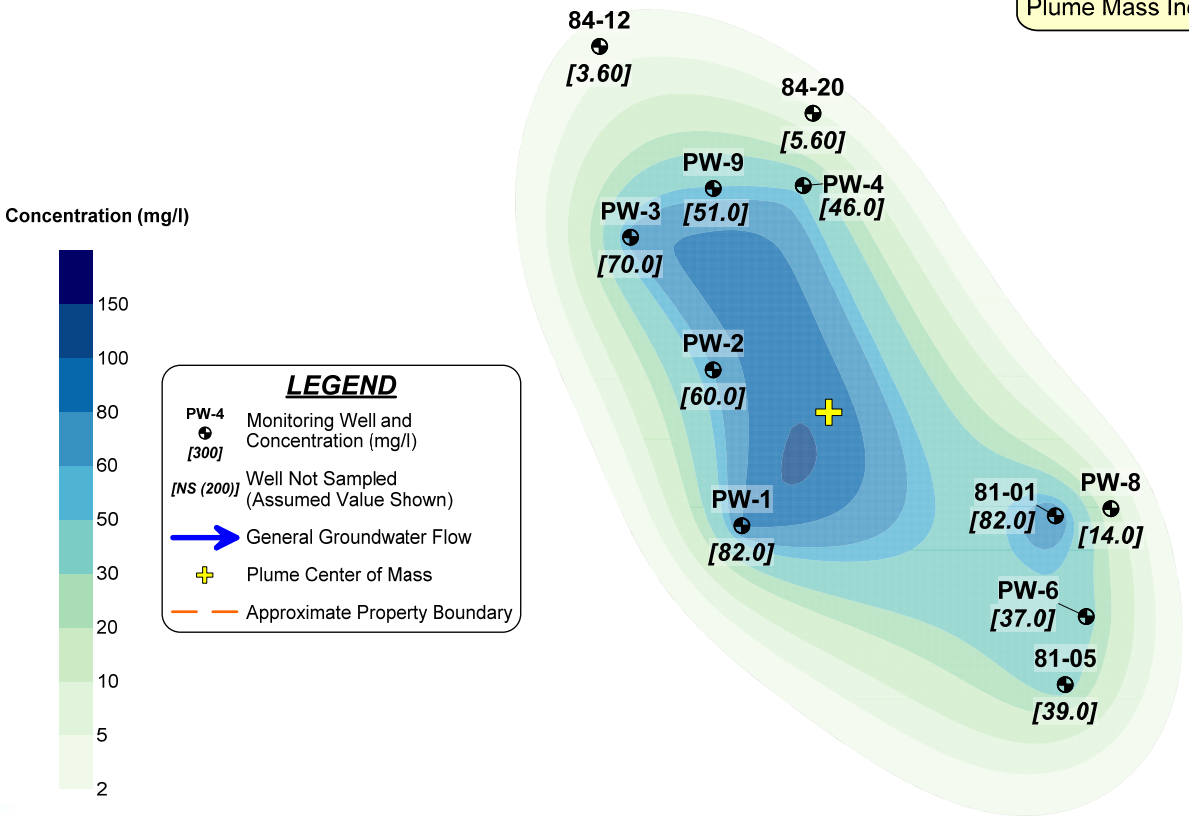
Phenol Plume
June 1993

Plume Characteristics

Plume Area: 11.07 hectares
Plume Average Concentration: 30.31 mg/l
Plume Mass Indicator: 7045 kg



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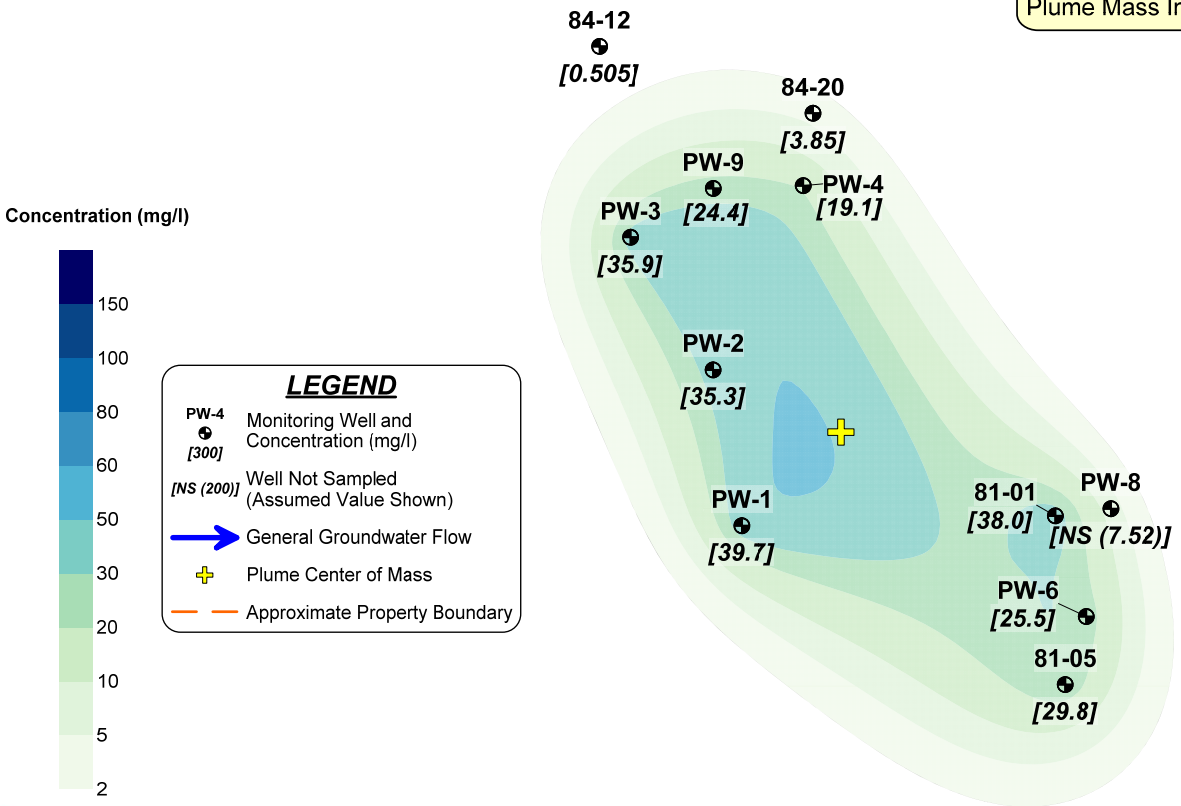
Phenol Plume
June 1996

Plume Characteristics

Plume Area: 9.61 hectares
Plume Average Concentration: 18.82 mg/l
Plume Mass Indicator: 3798 kg



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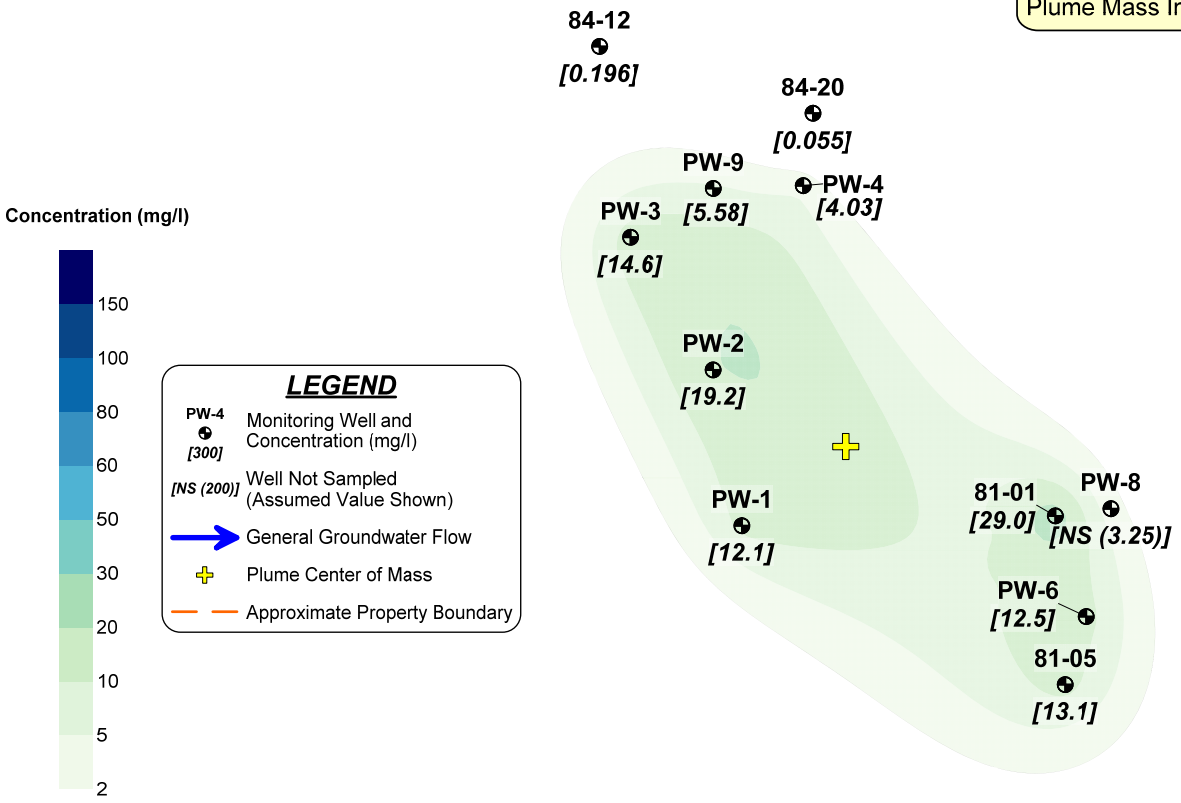
Phenol Plume
June 1999

Plume Characteristics

Plume Area: 7.21 hectares
Plume Average Concentration: 8.70 mg/l
Plume Mass Indicator: 1317 kg



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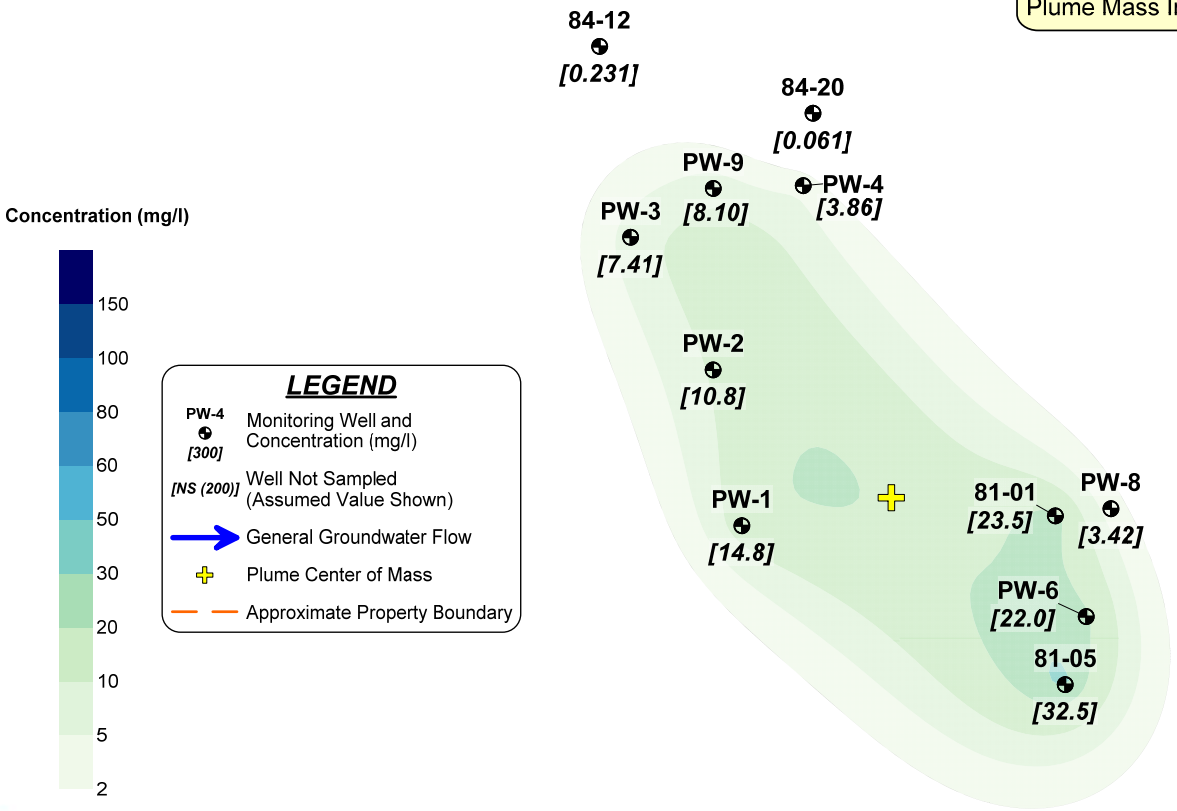
Phenol Plume
June 2002

Plume Characteristics

Plume Area: 7.69 hectares
Plume Average Concentration: 10.49 mg/l
Plume Mass Indicator: 1694 kg



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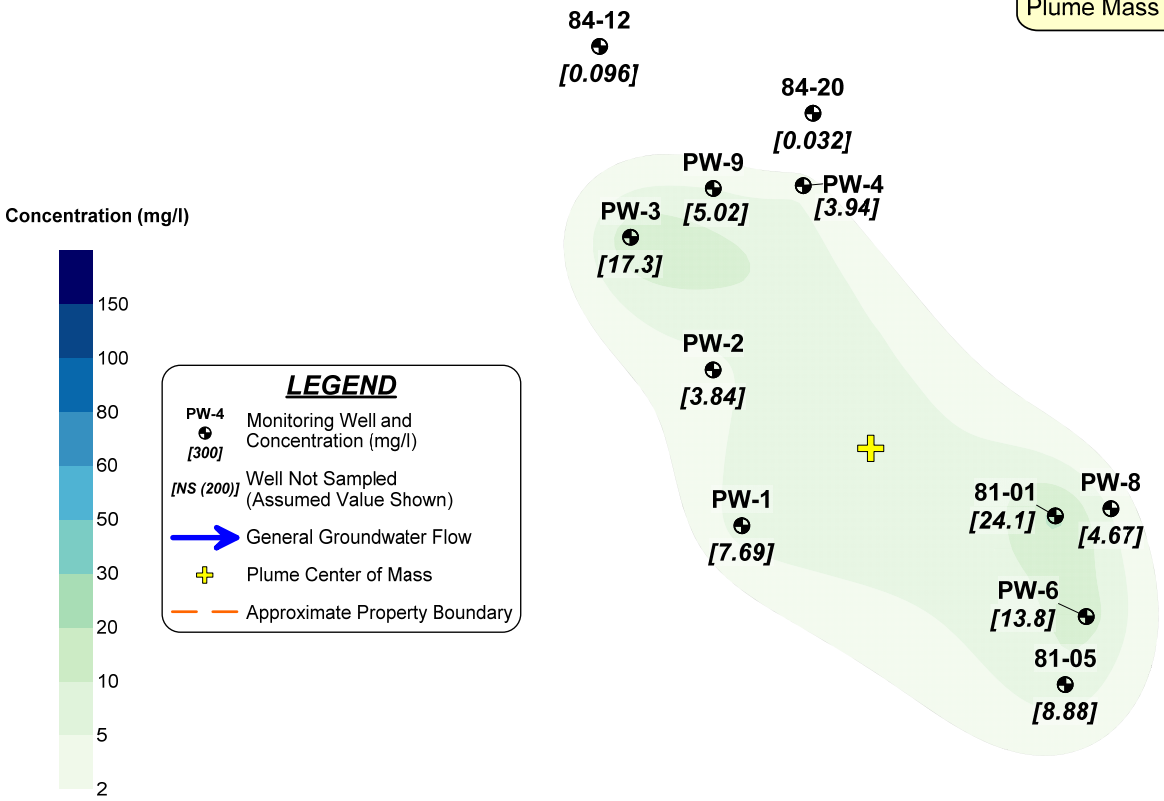
Phenol Plume
April 2005

Plume Characteristics

Plume Area: 6.63 hectares
Plume Average Concentration: 6.20 mg/l
Plume Mass Indicator: 863 kg



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Phenol Plume
May 2008

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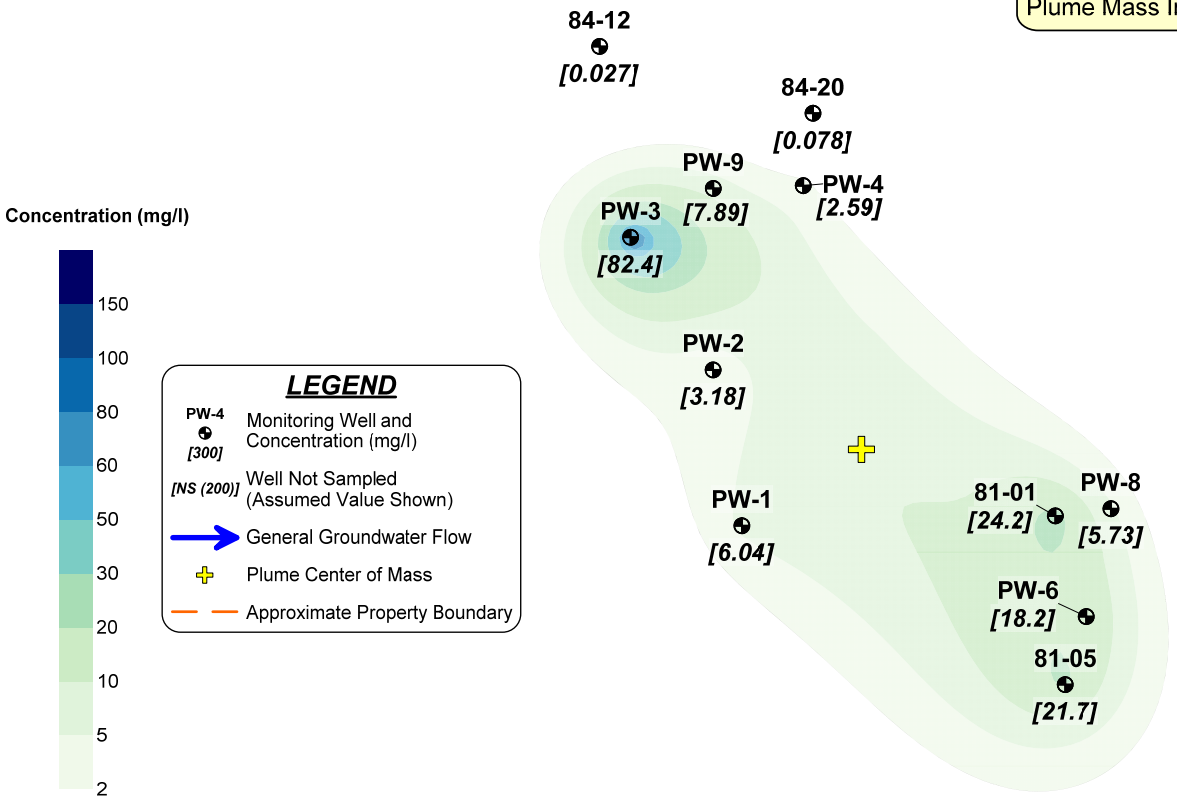
Plume Characteristics

Plume Area: 7.31 hectares
Plume Average Concentration: 8.36mg/l
Plume Mass Indicator: 1283 kg



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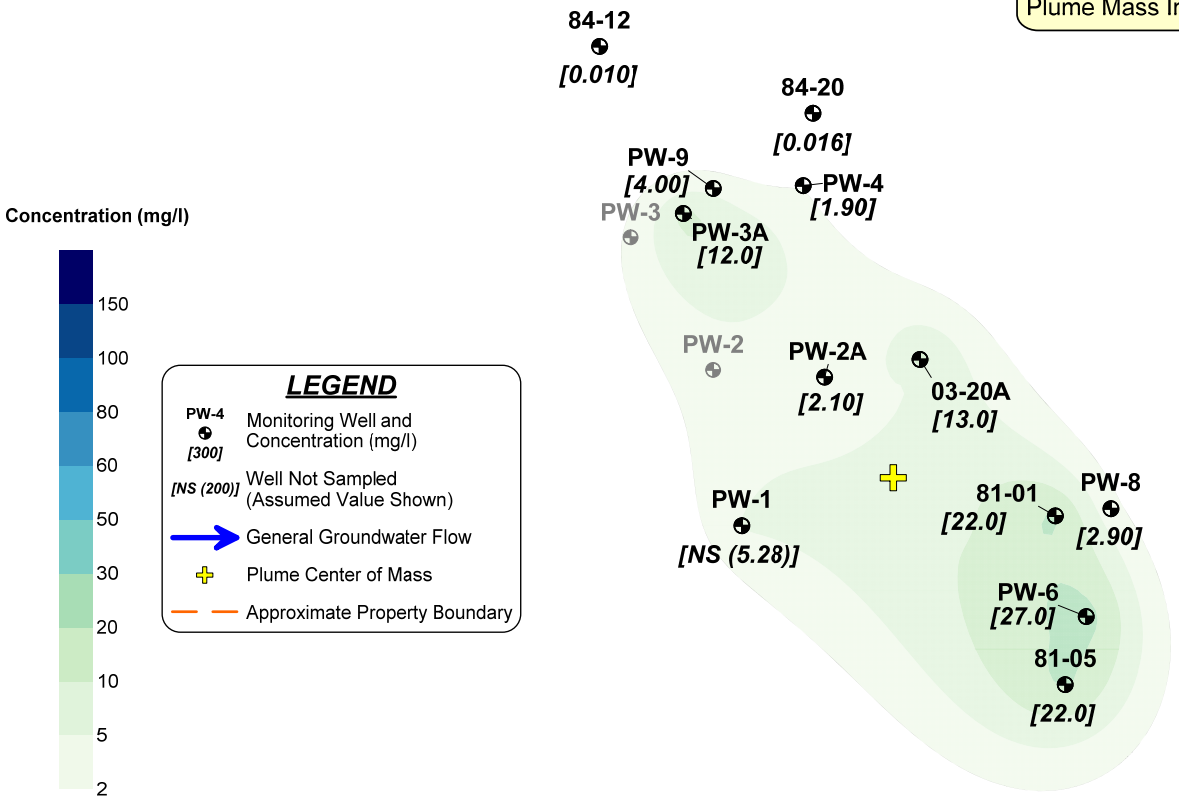
Phenol Plume
May 2011

Plume Characteristics

Plume Area: 6.51 hectares
Plume Average Concentration: 6.39 mg/l
Plume Mass Indicator: 873 kg



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Phenol Plume
April 2013

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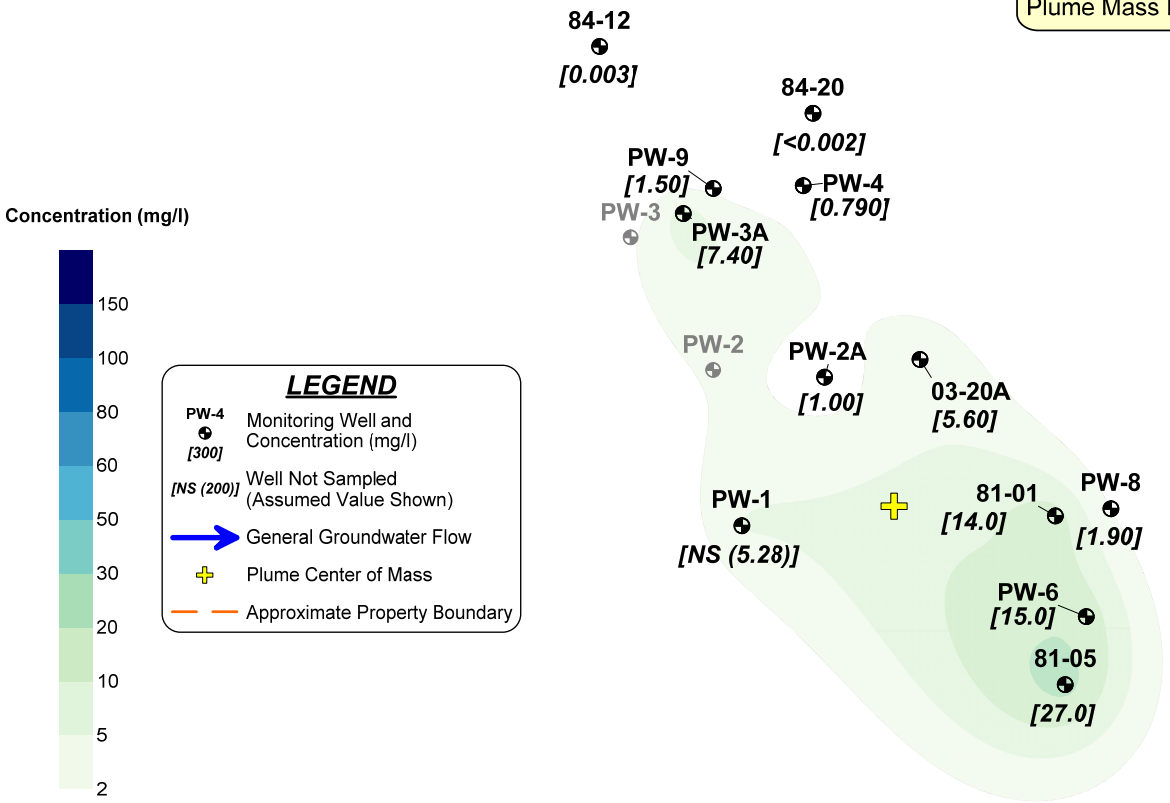
Plume Characteristics

Plume Area: 5.54 hectares
Plume Average Concentration: 5.99 mg/l
Plume Mass Indicator: 697 kg



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Phenol Plume Stability Analysis Summary

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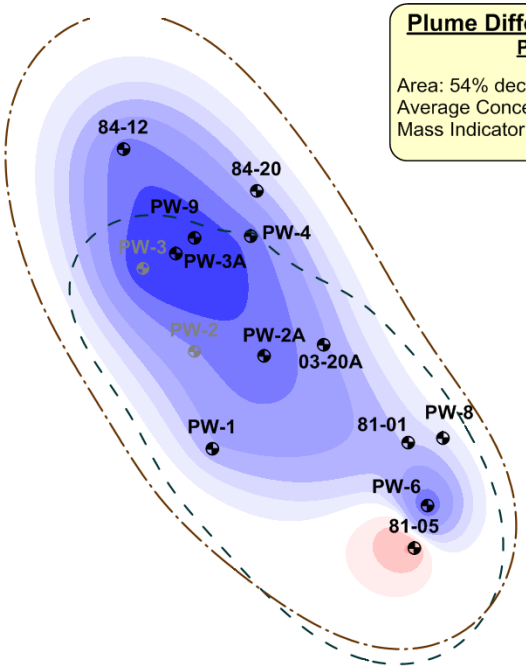
Plume Difference Map (1984 vs. 2013)



Plume Difference Characteristics
Percent Change

Area: 54% decrease
Average Concentration: 82% decrease
Mass Indicator: 92% decrease

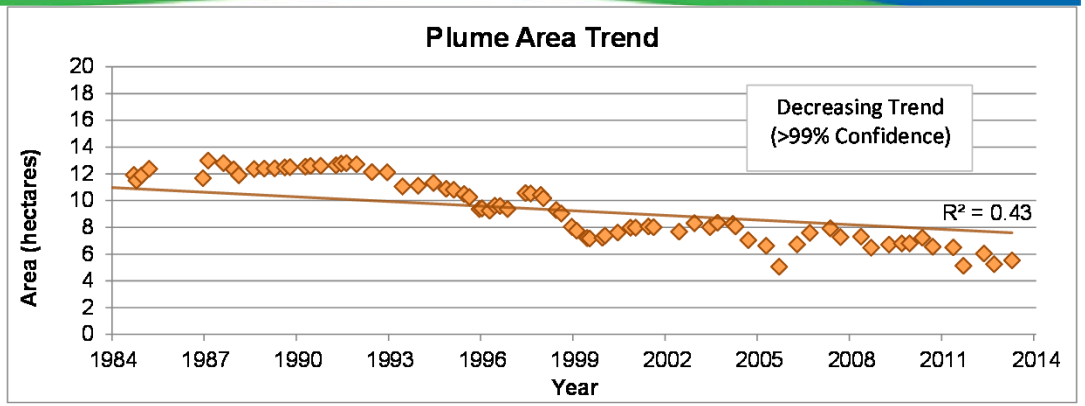
EXPLANATION

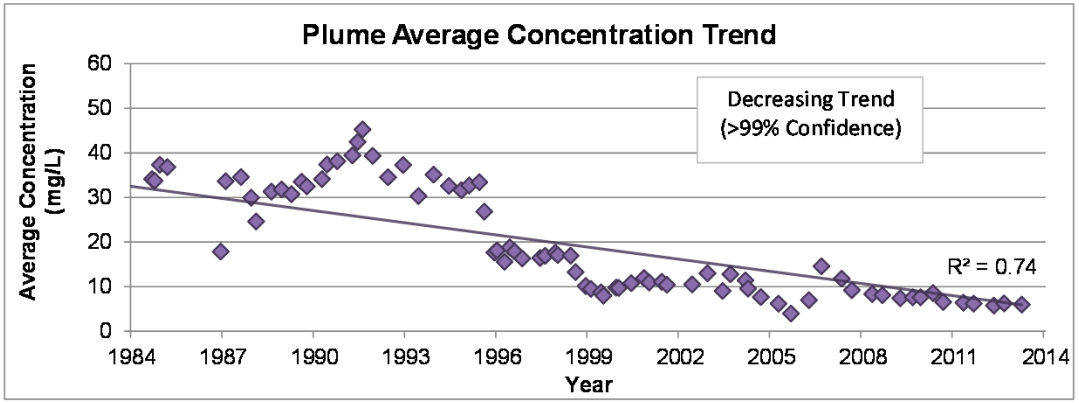
BLUE SHADING INDICATES AREAS OF CONCENTRATION DECREASE
RED SHADING INDICATES AREAS OF CONCENTRATION INCREASE

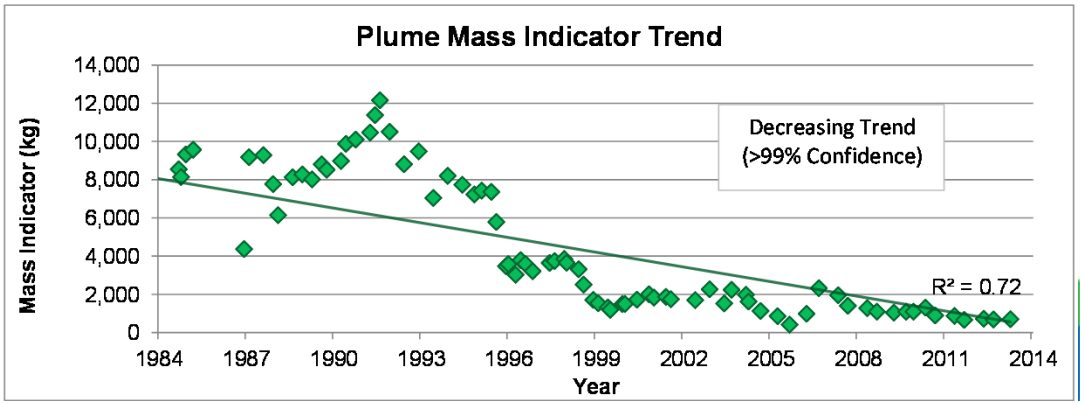
1984 Plume Boundary
2013 Plume Boundary
General Groundwater Flow Direction

Concentration Difference (mg/l)

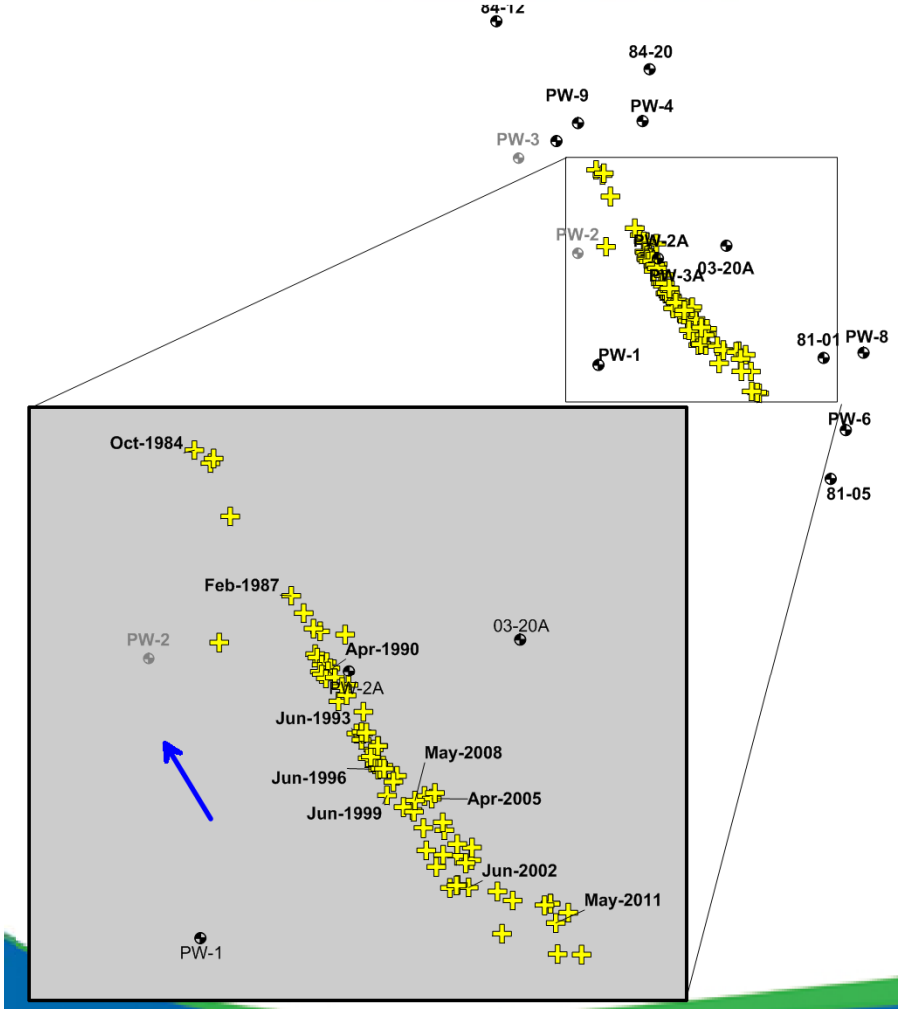
-100 -50 -20 -10 -5 -2 2 5 10 20 50 100

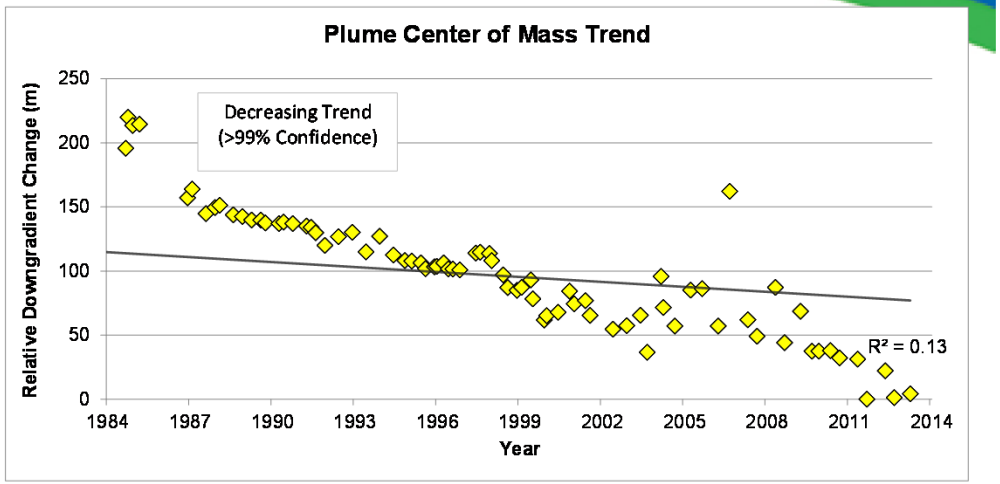


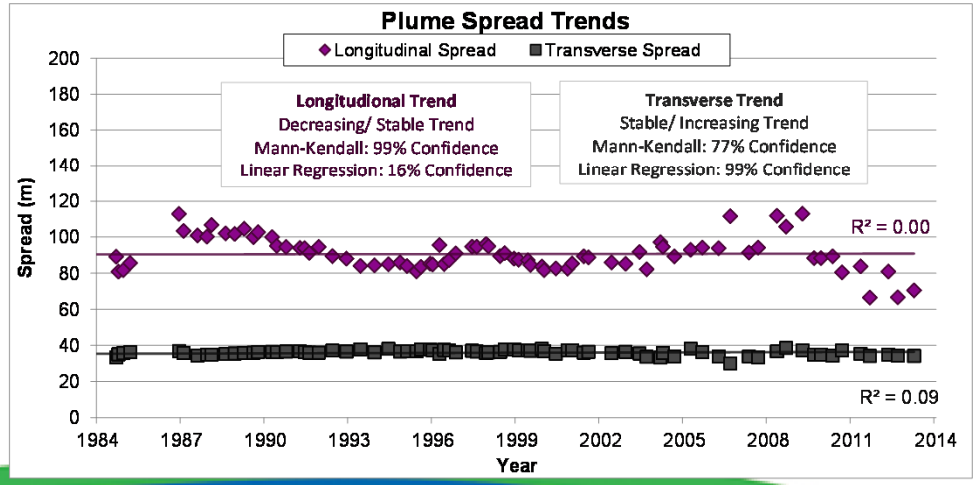




Phenol Plume Center of Mass Summary







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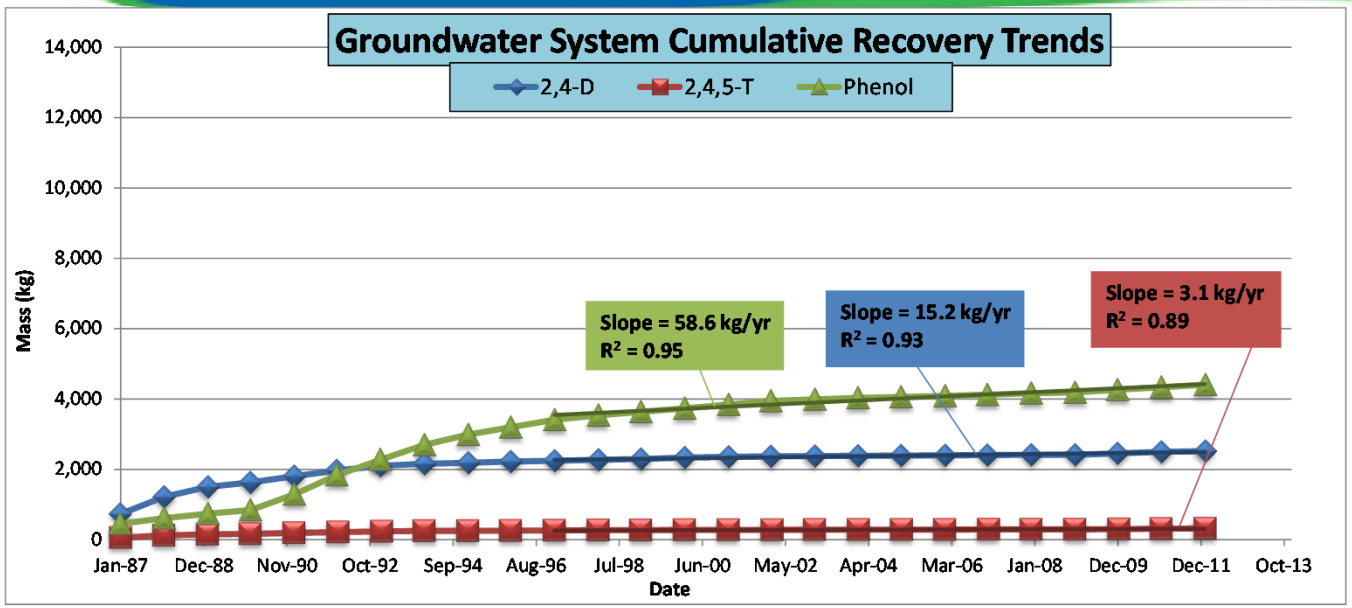
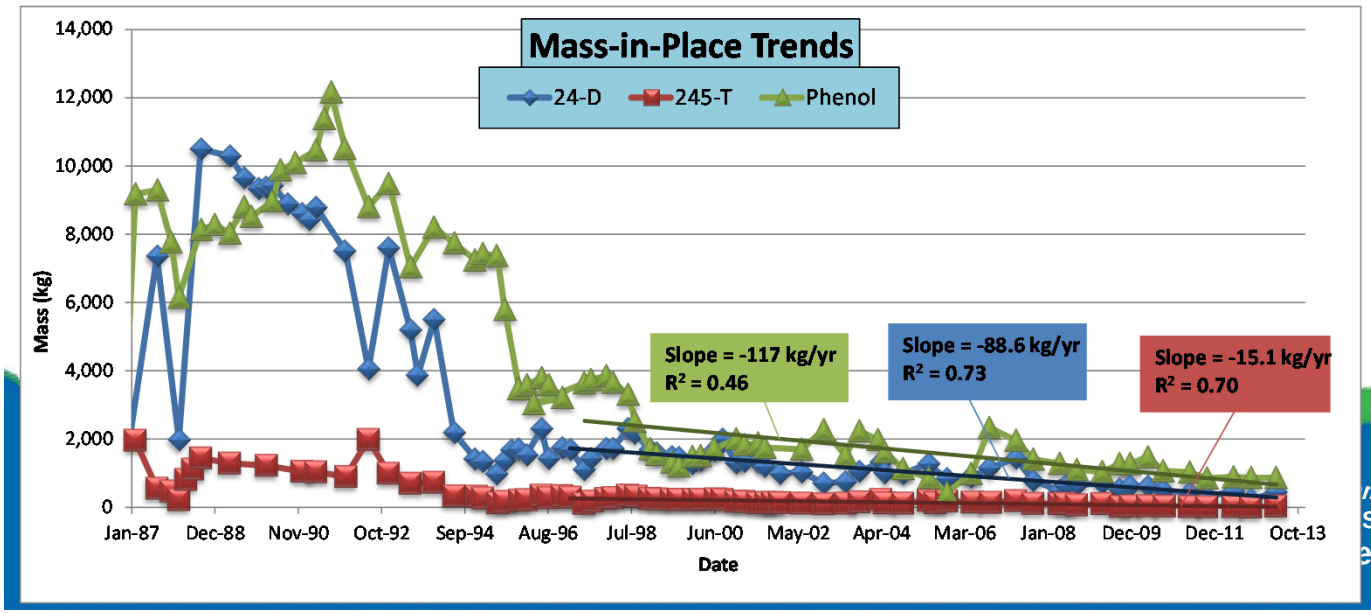
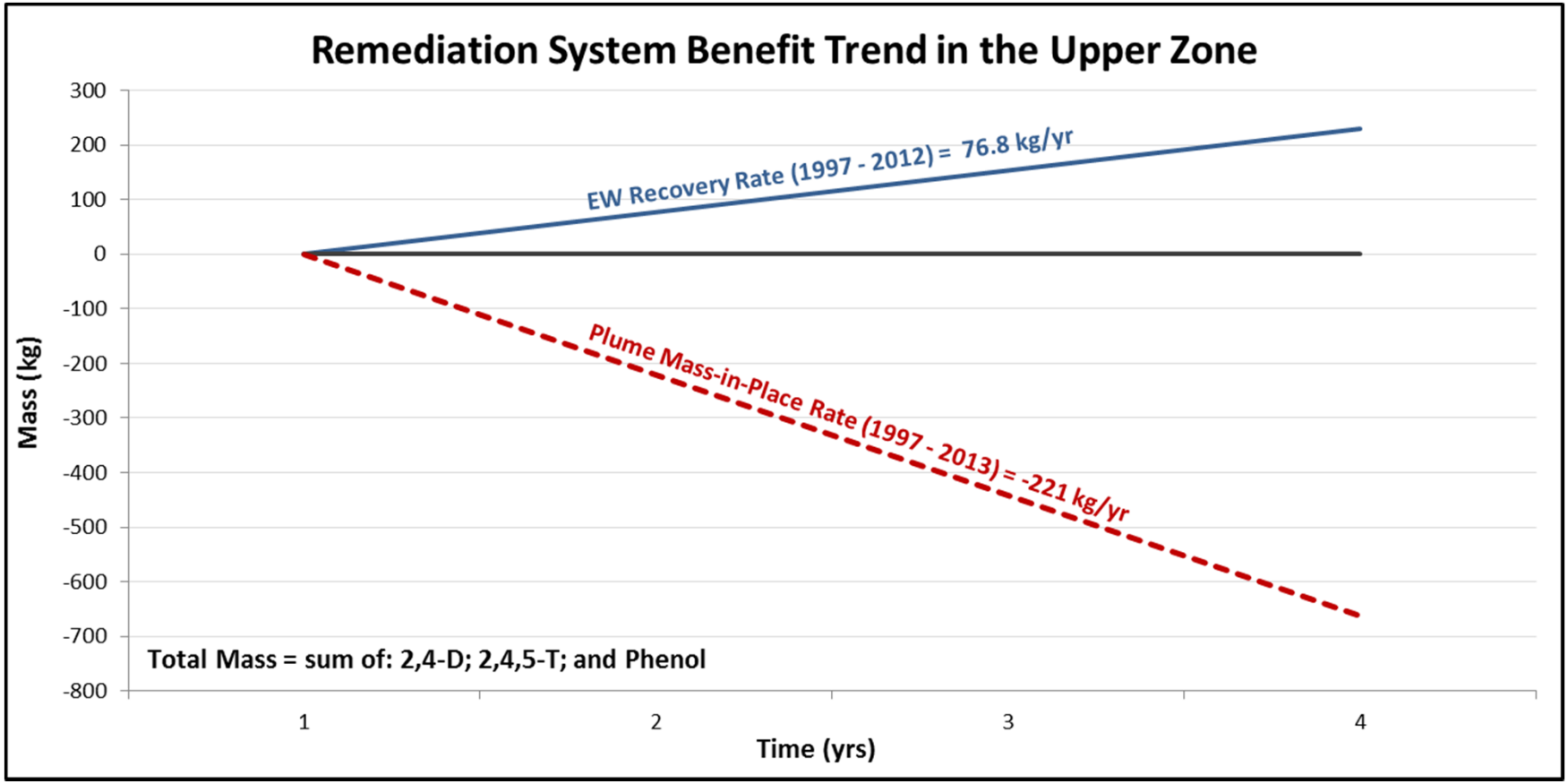
Remediation System Evaluation





Remediation System Evaluation



Example Site Outcome

- **Based on plume stability analysis, client is currently in negotiations with Alberta Environment for complete cessation of remediation system.**

- **Annual savings >$200k**

Example Site
Plume Stability Analysis

- **Example site analysis for operating industrial site in Ontario**

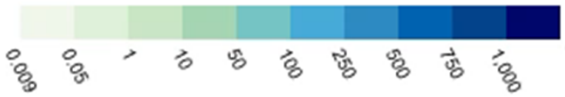
- **Ricker Method® used evaluate plume dynamics**
  - Existing remediation system at 15 years of operation
  - Remediation at <30% (based on plume areal extent)

- **CVOCs evaluated**
  - N-Nitrosodimethylamine (NDMA)
  - Chlorobenzene

NDMA
Upper Municipal Aquifer

NDMA
UPPER MUNICIPAL AQUIFER

Concentration (µg/l)



Note:
This analysis requires fixed data points within a fixed area for the purposes of assessing relative changes of area, average concentration, and mass indicator over time. Therefore, any created isopleth maps are not intended to be a depiction or model of the actual plume but rather is meant to show conceptual behavior of the aforementioned metrics over time.

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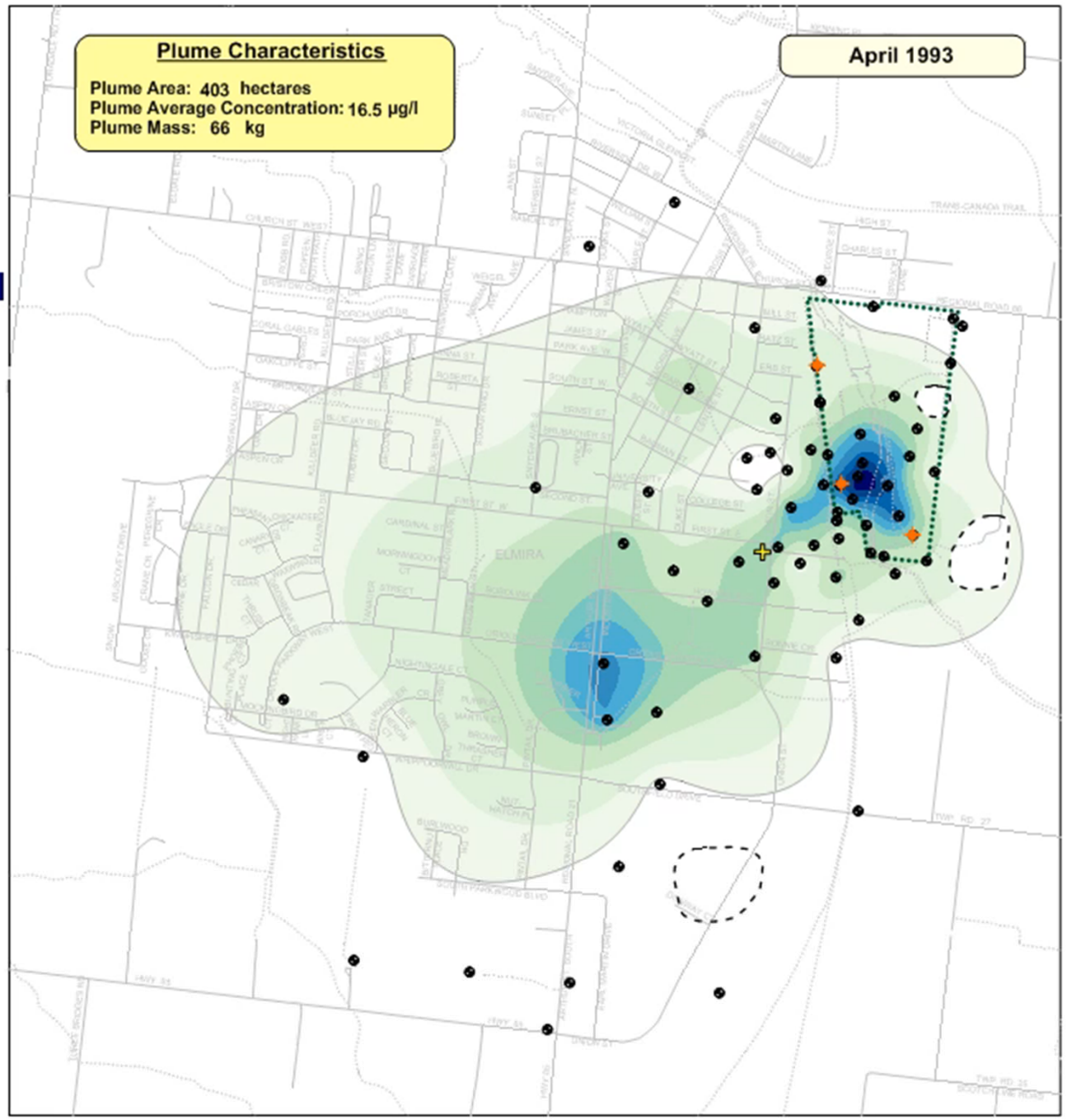
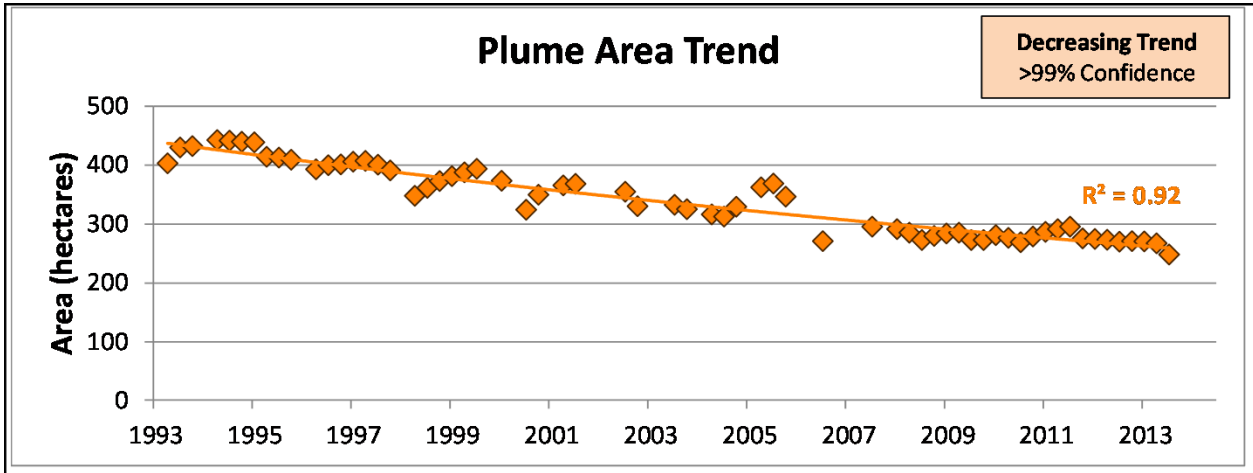
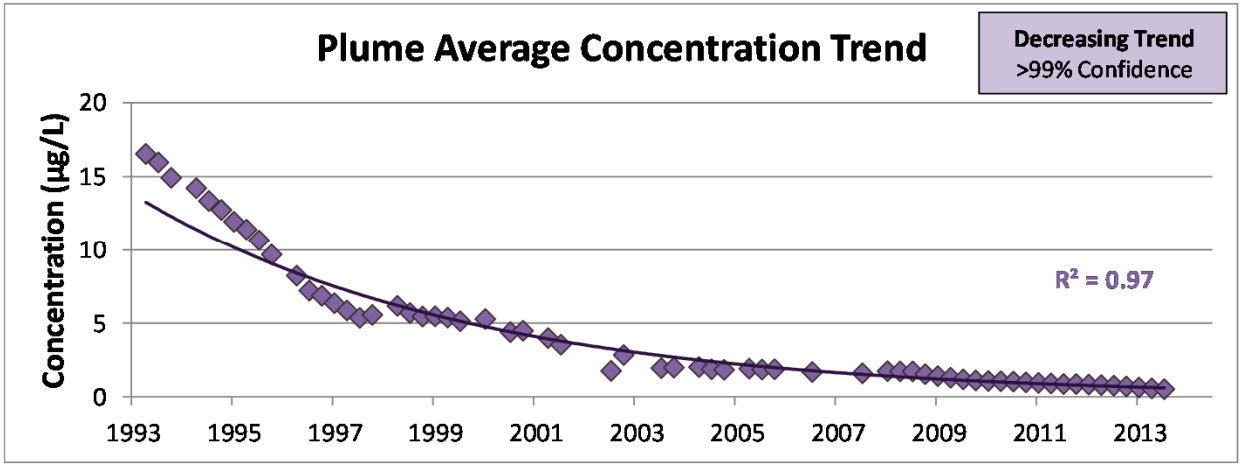


NDMA
UPPER MUNICIPAL AQUIFER
PSA Summary

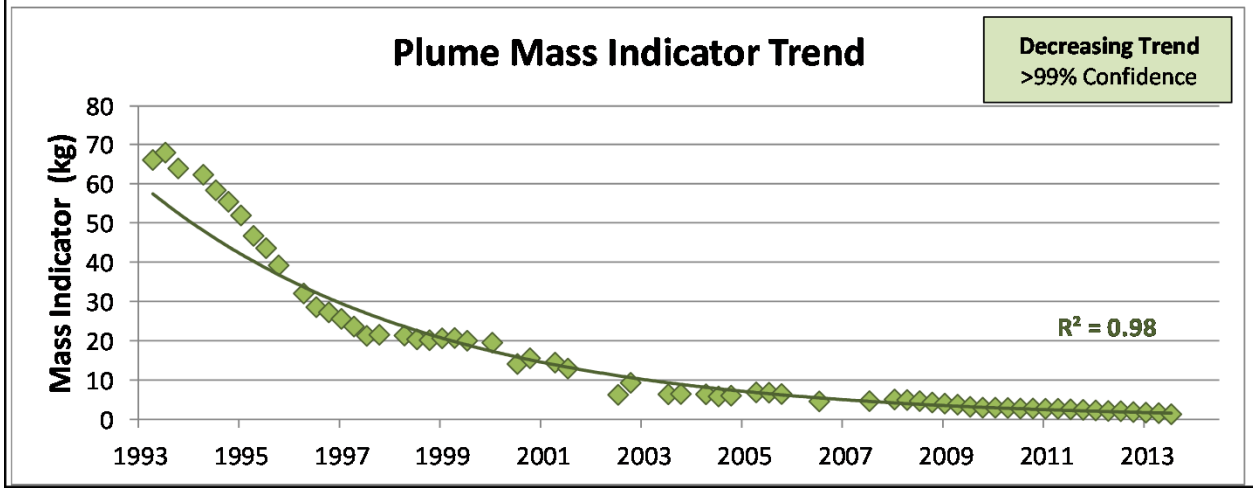
Plume Area Trend



Plume Average Concentration Trend



Plume Mass Indicator Trend



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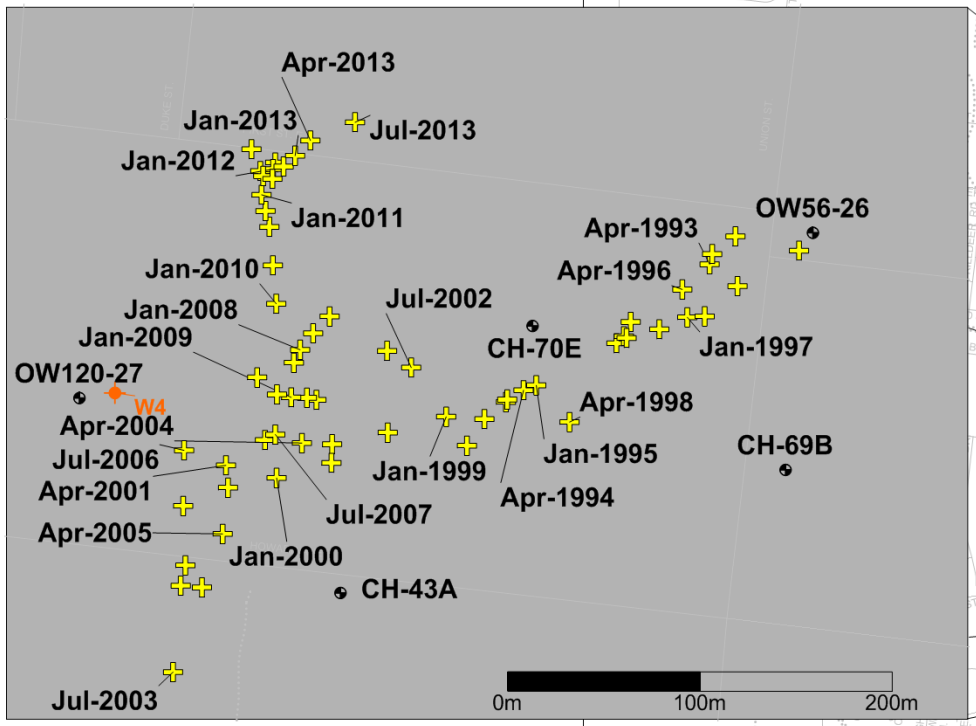
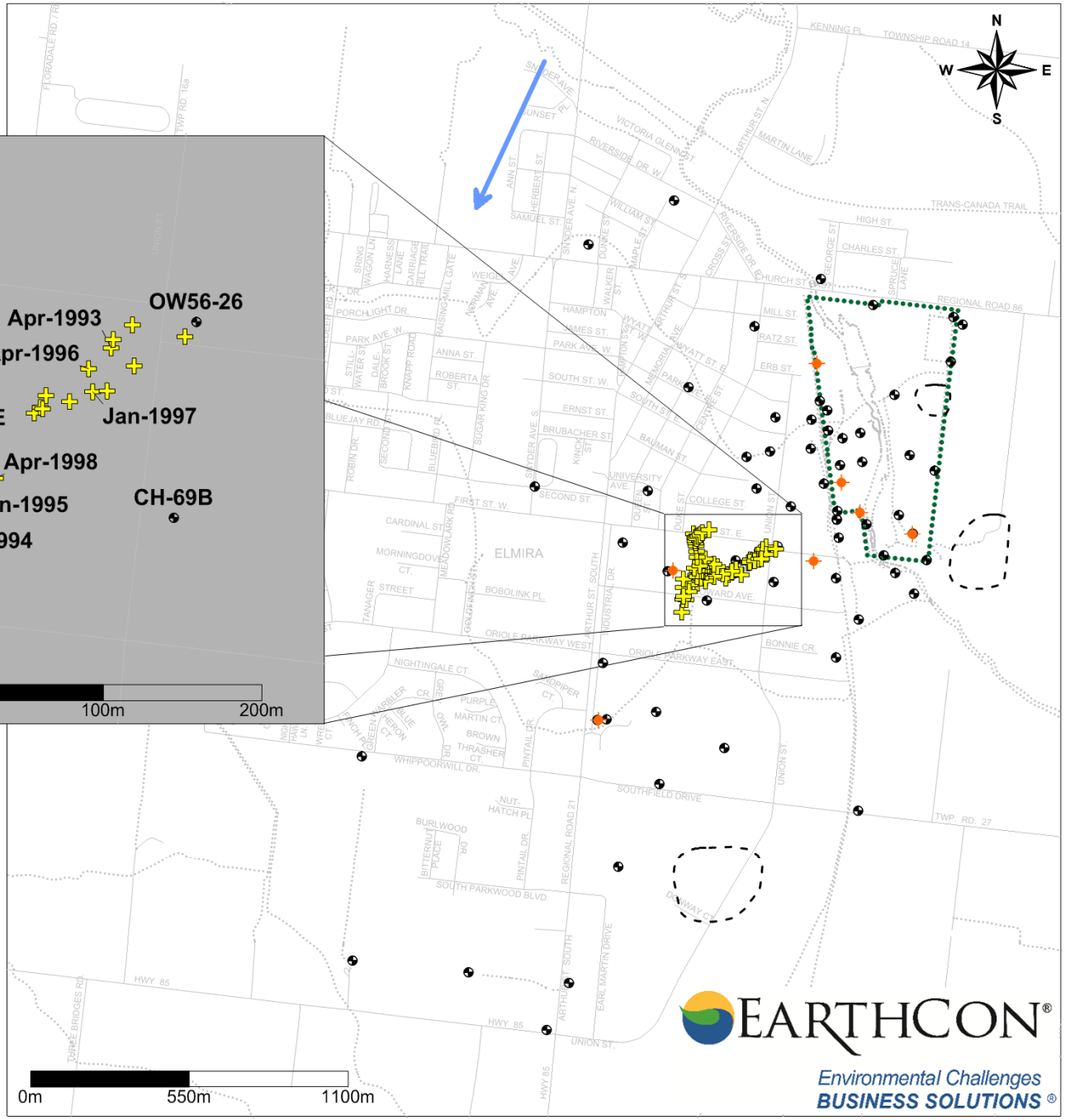
UPPER MUNICIPAL AQUIFER
Center Of Mass Summary





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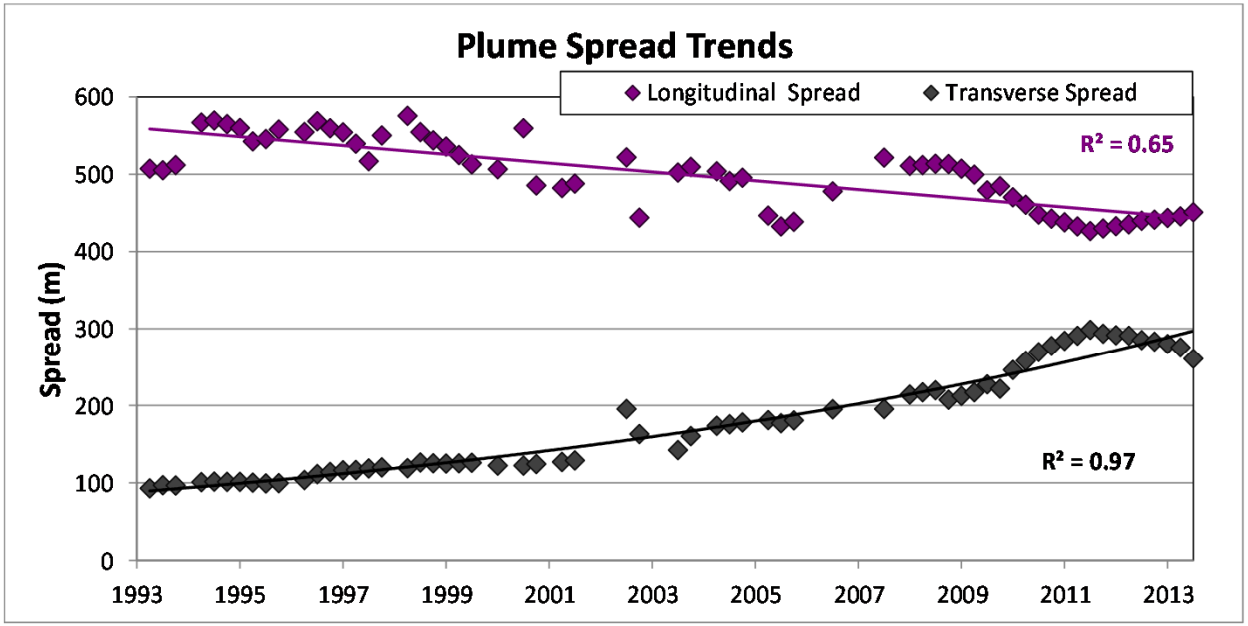
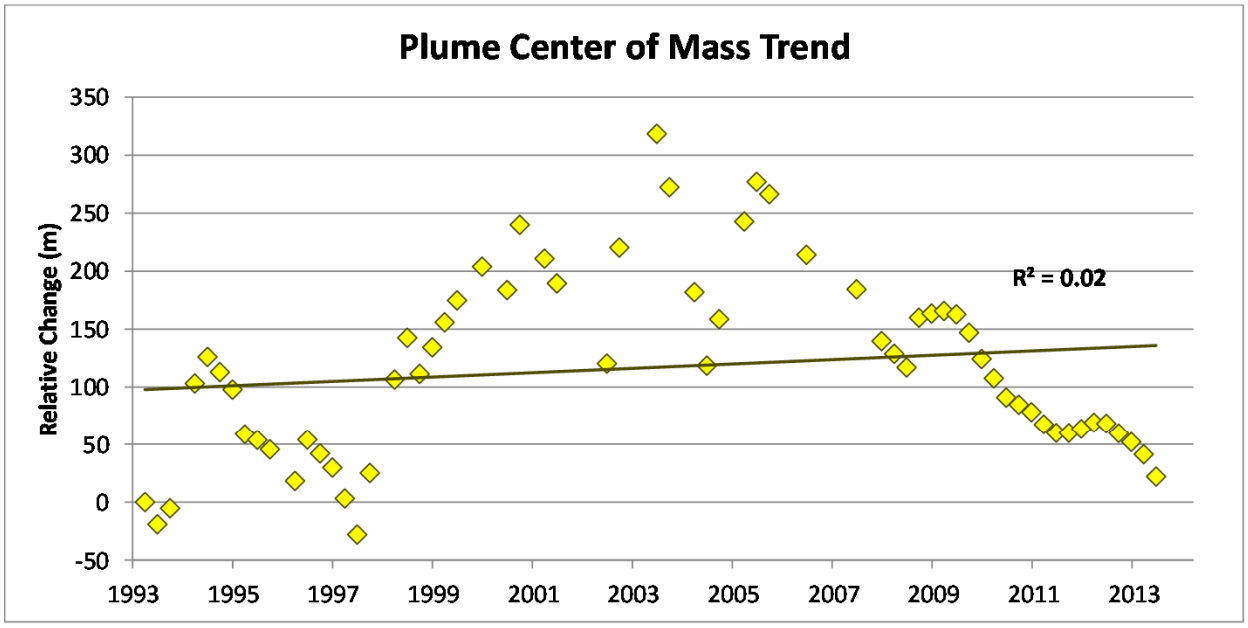
UPPER MUNICIPAL AQUIFER
CoM & Spread Summary





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UPPER MUNICIPAL AQUIFER

N
W E
S

Concentration Difference (µg/l)

Decrease — Increase

-2,000 -1,000 -200 -100 -70 -10 -0.009 0.009 10 70 100 200 1,000

0m 550m 1100m

Total Plume Difference Characteristics
Percent Change

Area: 38% decrease
Average Concentration: 97% decrease
Mass Indicator: 98% decrease

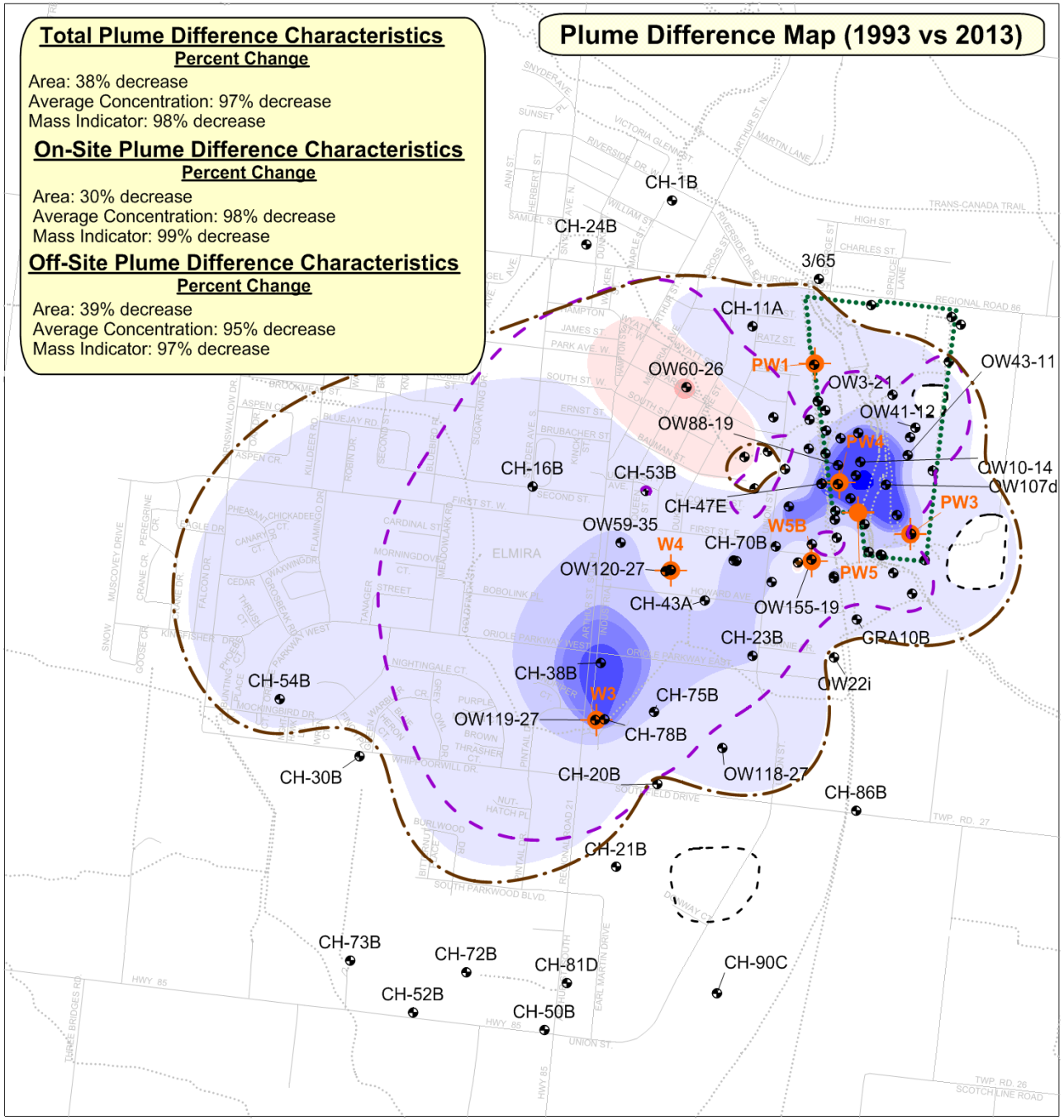
On-Site Plume Difference Characteristics
Percent Change

Area: 30% decrease
Average Concentration: 98% decrease
Mass Indicator: 99% decrease

Off-Site Plume Difference Characteristics
Percent Change

Area: 39% decrease
Average Concentration: 95% decrease
Mass Indicator: 97% decrease

Plume Difference Map (1993 vs 2013)



Note:
This analysis requires fixed data points within a fixed area for the purposes of assessing relative changes of area, average concentration, and mass indicator over time. Therefore, any created isopleth maps are not intended to be a depiction or model of the actual plume but rather is meant to show conceptual behavior of the aforementioned metrics over time.

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Lower Municipal Aquifer

NDMA
LOWER MUNICIPAL AQUIFER

N
W E
S

Plume Characteristics

Plume Area: 302 hectares
Plume Average Concentration: 17 µg/l
Plume Mass: 72.4 kg

May 1993

Concentration (µg/l)

0.009 0.05 1 10 50 100 250 500 750 1,000

0m 550m 1100m

LEGEND

- Monitoring Well
- Plume Center of Mass
- Approximate Property Boundary
- Approximate Area Where Aquifer Does Not Exist
- Pumping/Extraction Wells (Not included in analysis)

Note:
This analysis requires fixed data points within a fixed area for the purposes of assessing relative changes of area, average concentration, and mass indicator over time. Therefore, any created isopleth maps are not intended to be a depiction or model of the actual plume but rather is meant to show conceptual behavior of the aforementioned metrics over time.

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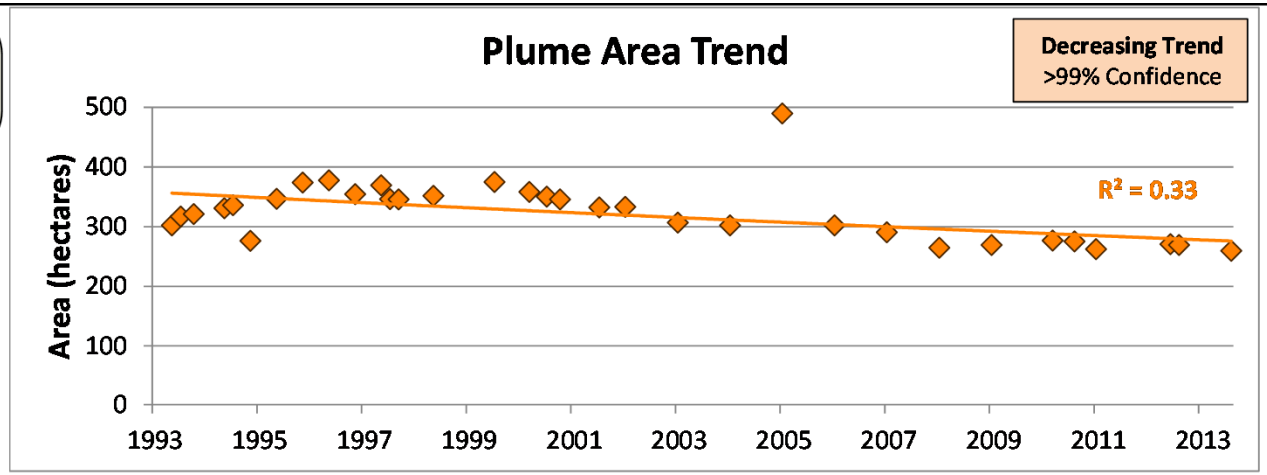
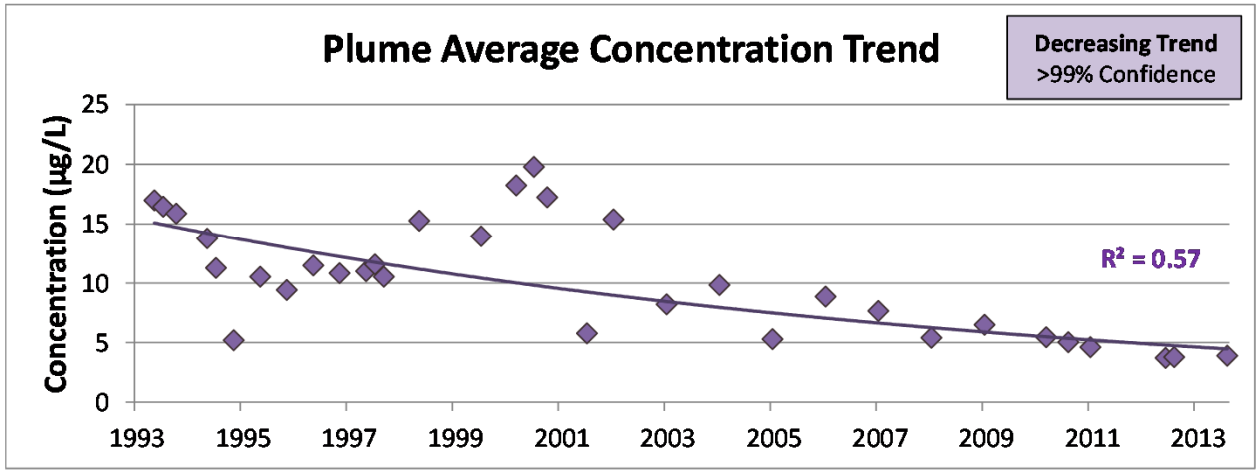
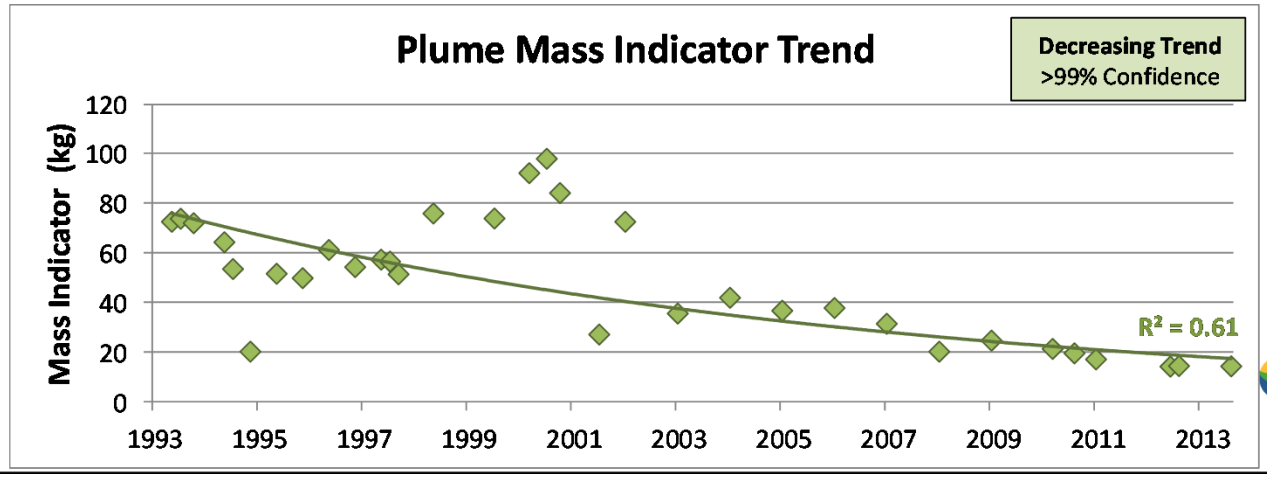
LOWER MUNICIPAL AQUIFER
Plume Stability Summary







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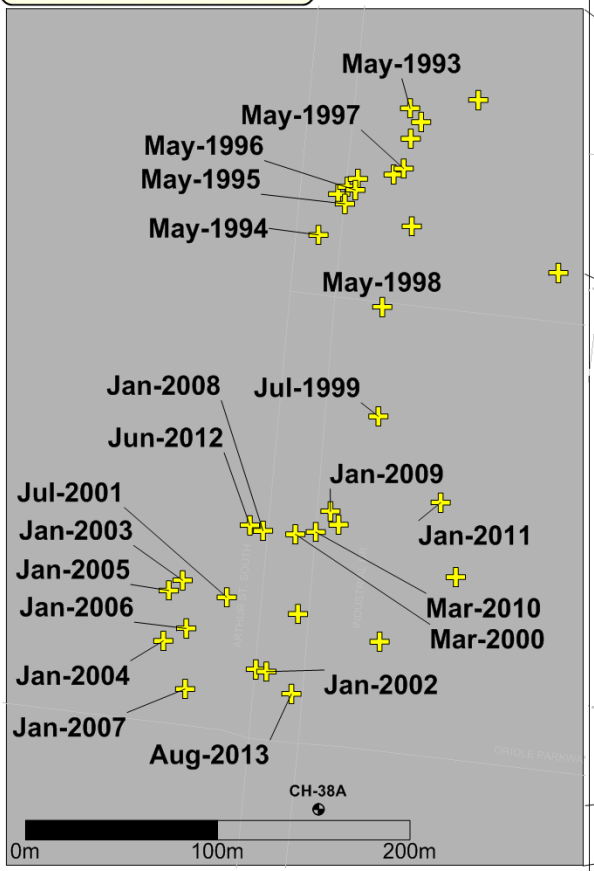
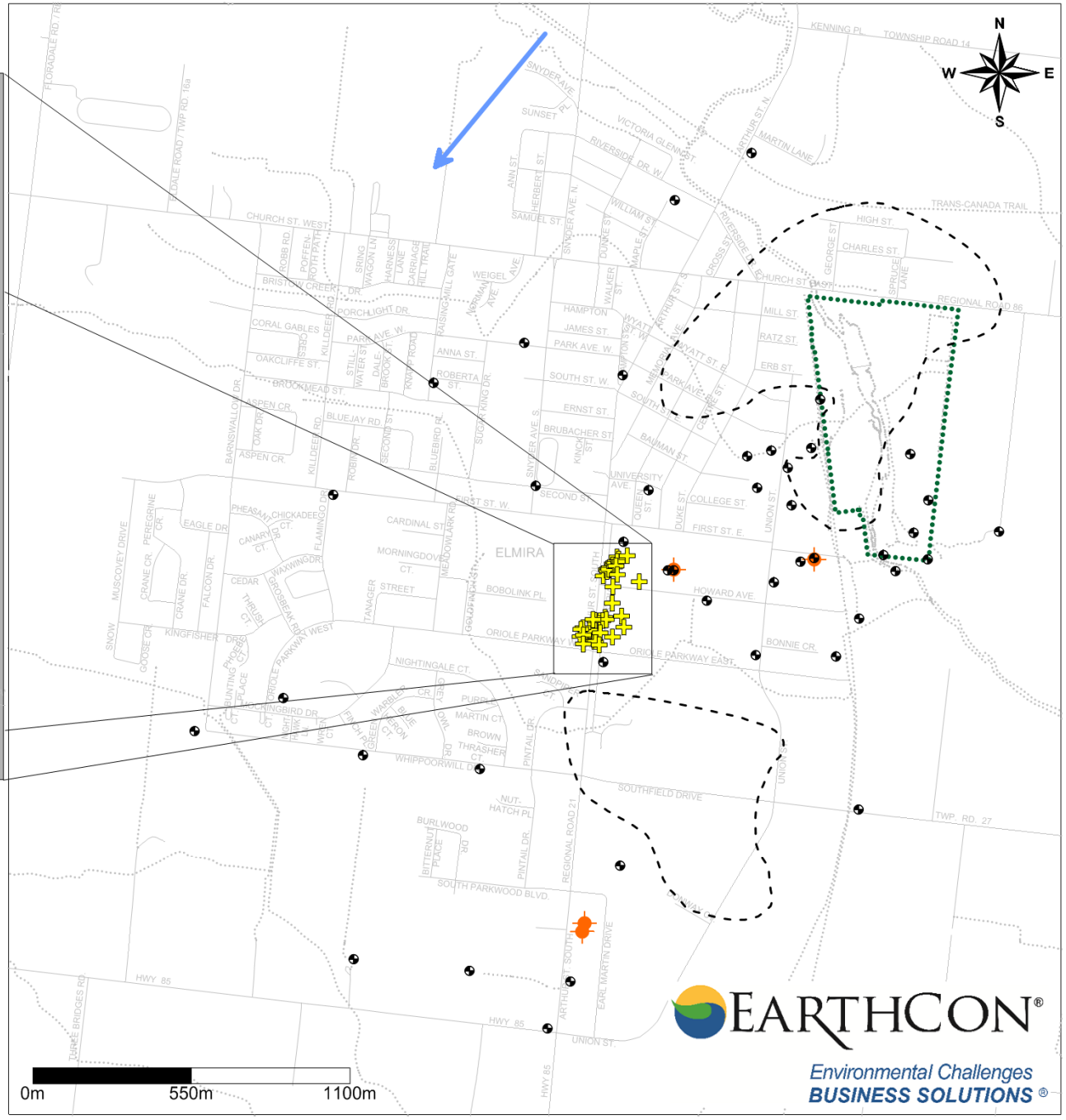
LOWER MUNICIPAL AQUIFER
Center Of Mass Summary





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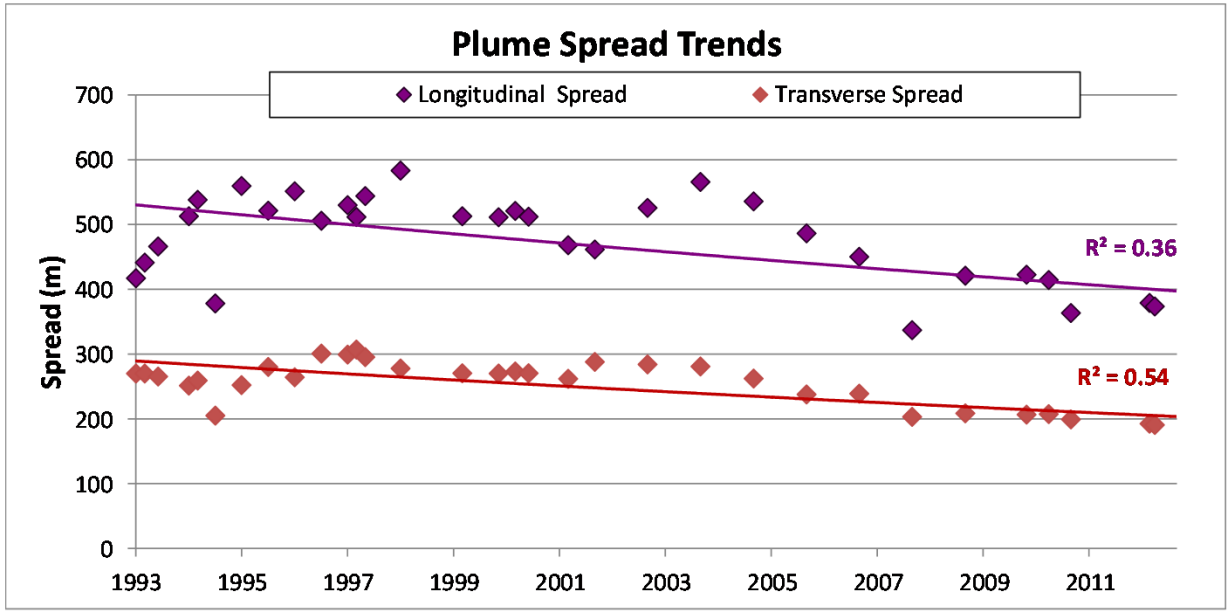
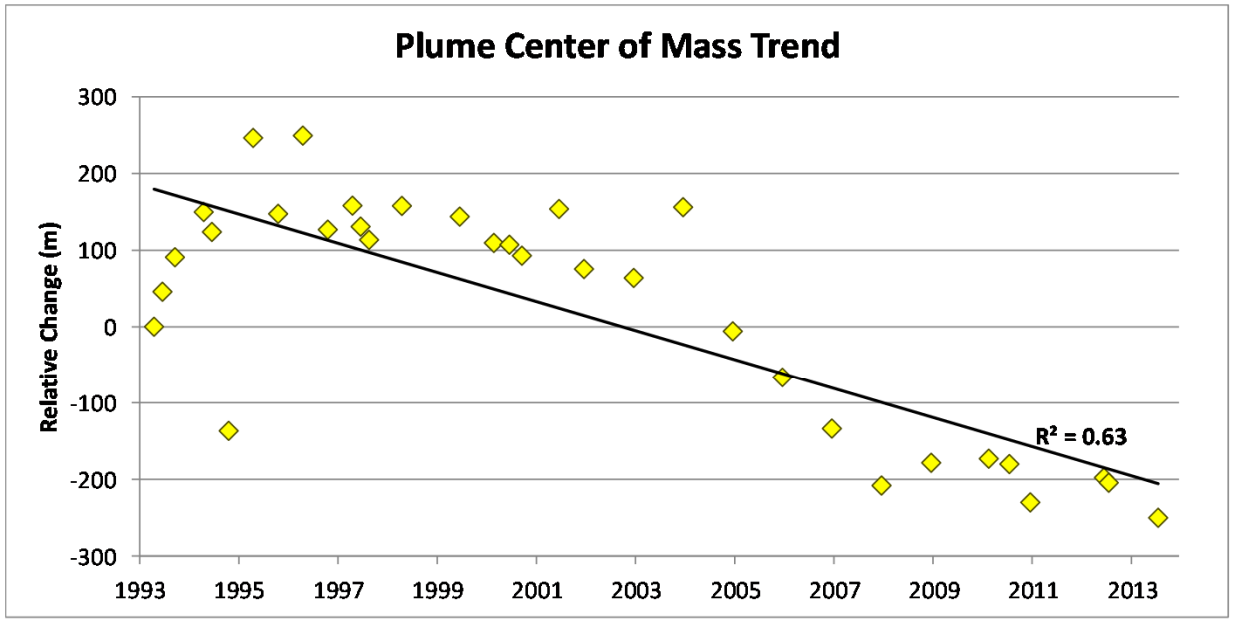
LOWER MUNICIPAL AQUIFER
CoM & Spread Summary





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LOWER MUNICIPAL AQUIFER

N
W E
S

Concentration Difference (µg/l)

Decrease — Increase

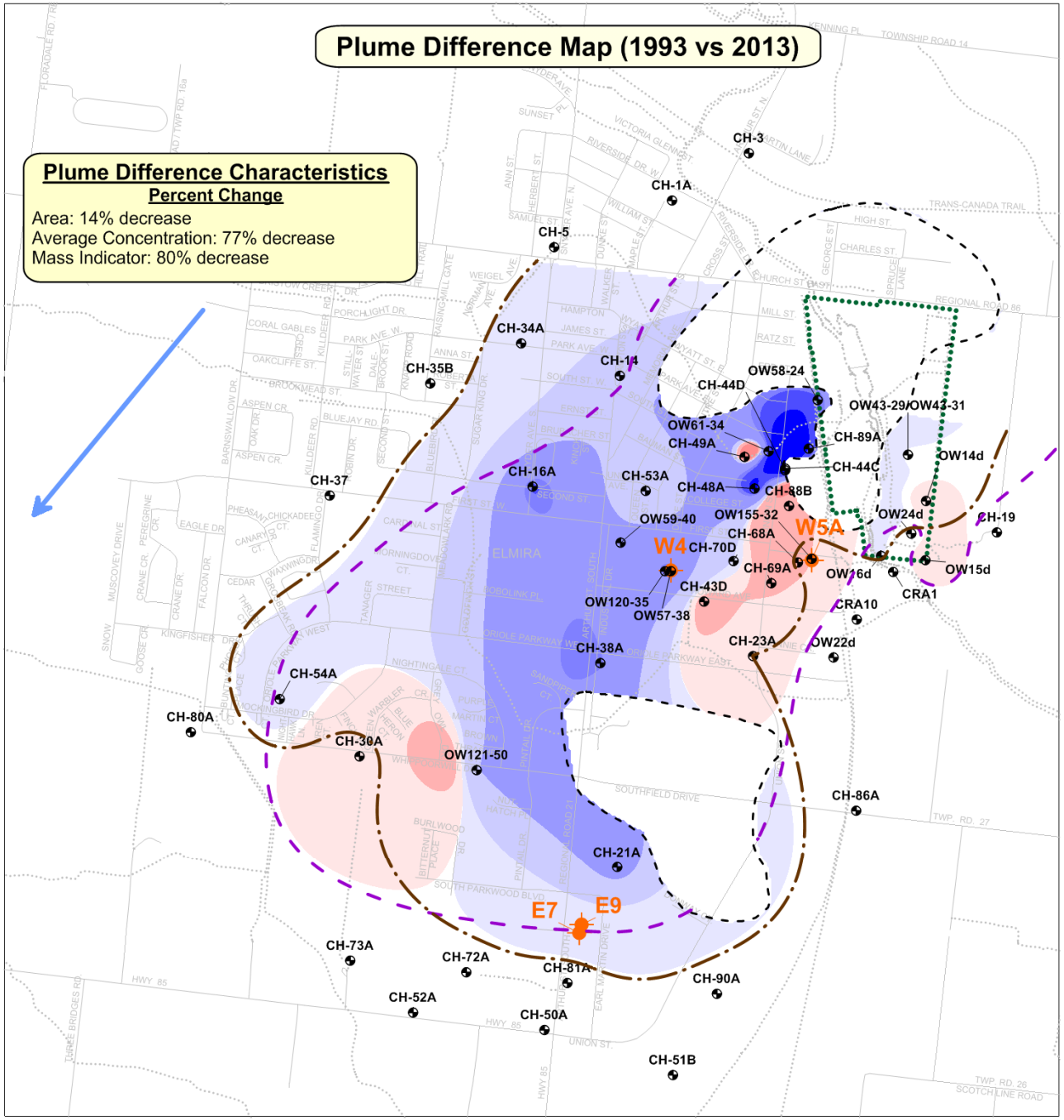
-200 -100 -70 -10 -1 -0.009 0.009 1 10 50 100 200

0m 550m 1100m

Plume Difference Map (1993 vs 2013)

Plume Difference Characteristics
Percent Change

Area: 14% decrease
Average Concentration: 77% decrease
Mass Indicator: 80% decrease



Note:
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Note:
1994 detection result for OW121-50 was extrapolated backward to 1993.
2011 detection result for OW61-34 was extrapolated forward to 2013.

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Thank you for the opportunity to present this information to you!

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