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Long Term Performance of a Colloidal Activated Carbon Barrier – a Ten-Year Review Supported by Aspect Ratio Analysis, Flux Measurement and Modelling

Jeremy Birnstingl BSc, PhD, FRSC. CEnv. – VP Environmental Technology

Chris Lee – Senior Design Hydrogeologist

Craig Sandefur – VP Applications Design

Capsule Summary – what this presentation is about

- Long term performance of a **PlumeStop barrier** (9 years and counting)

- Integrated use of **three tools** to aid performance interpretation:
  - Modelling
  - Aspect ratio analysis
  - Passive flux measurement devices

The interest lies in the use of the tools themselves
in addition to the barrier concept and its performance.

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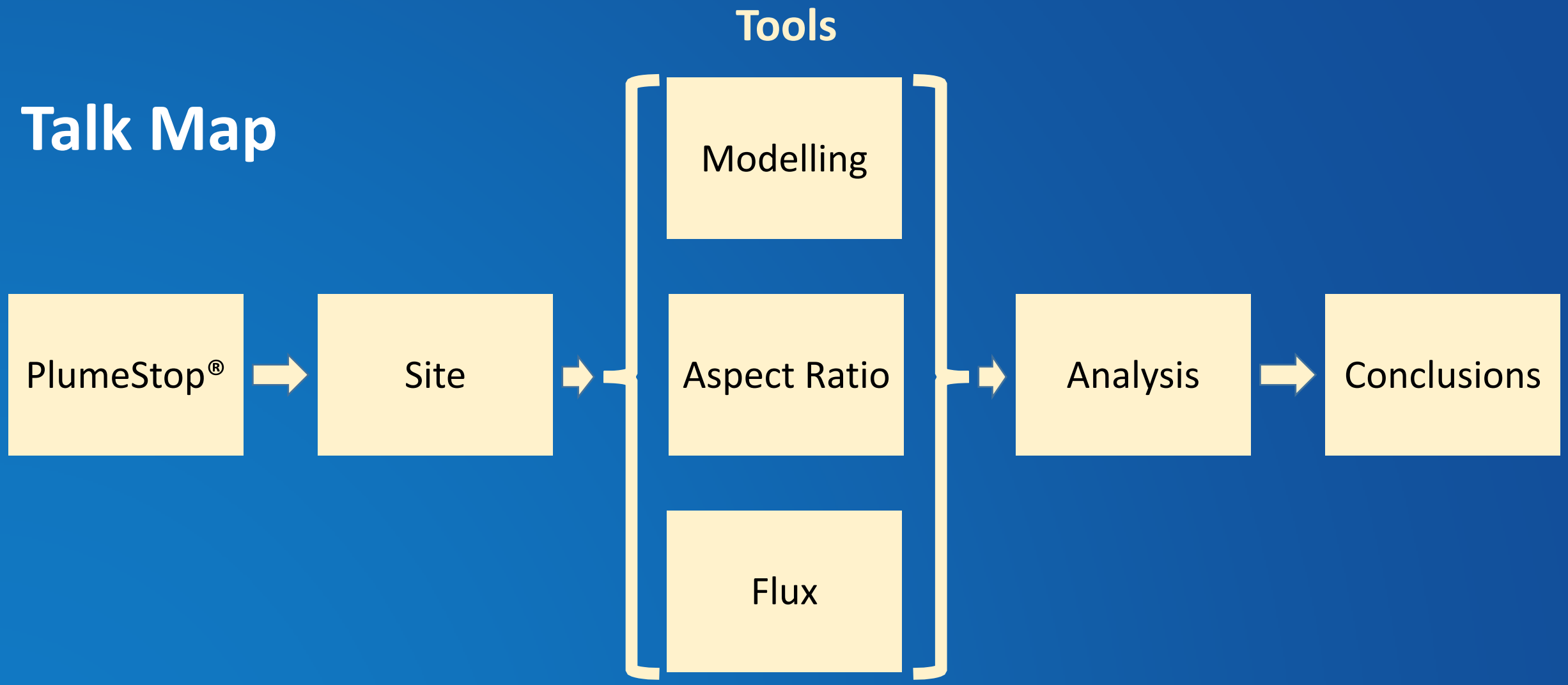
Talk Map



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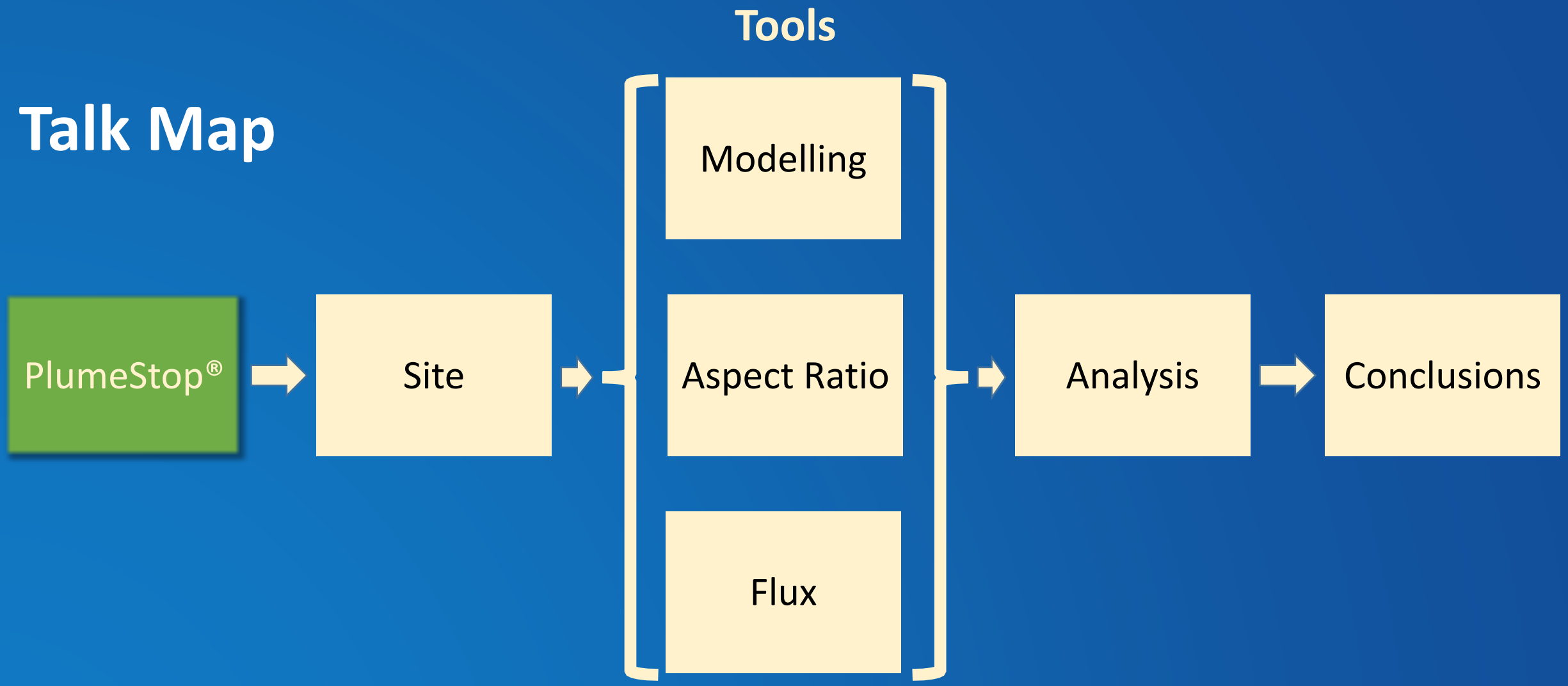

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Injectable activated carbon – fundamentals

PLUME STOP™
Liquid Activated Carbon

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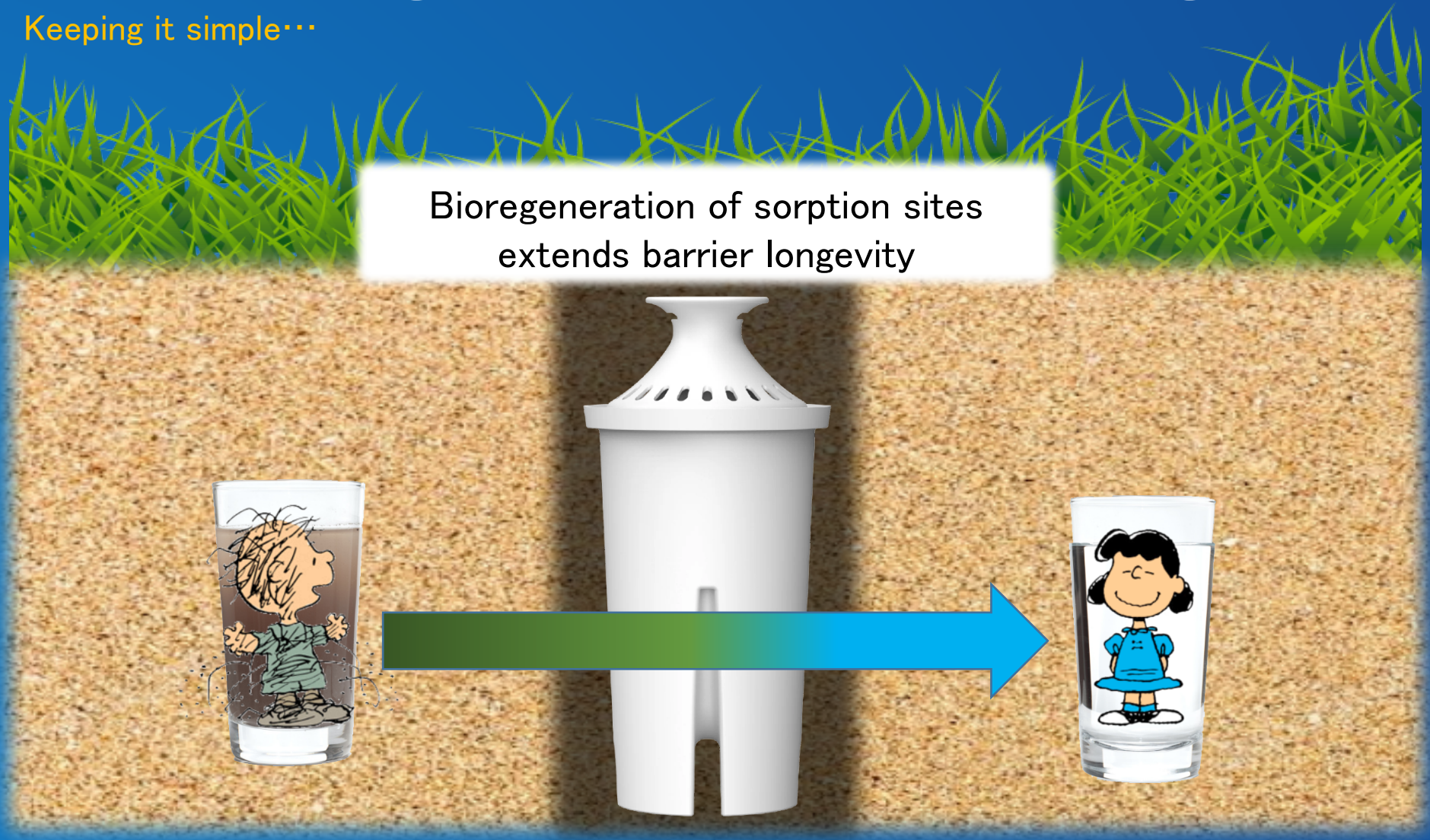
Booth # 225

Plume Management – Barrier Configuration

Keeping it simple…



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Fundamentals

- **The carbon quantity is tiny**
  - Groundwater flow is not affected
- **The capture efficiency is high**
  - Contaminant advection is slowed significantly
- **The groundwater may flow through the barrier in days**
  - The contaminants may take years to pass through (if they come out at all)
- **Biodegradation in the barrier extends its performance**
  - If the rate is fast enough the extension is indefinite

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PlumeStop®

- **Deep tech webinar series** on modelling and processes (2023)
- Available at **regenesis.com** and on **YouTube**

Webinar #1

Modelling and Design

Webinar #2

Hidden Processes

Webinar #3

Performance Optimization

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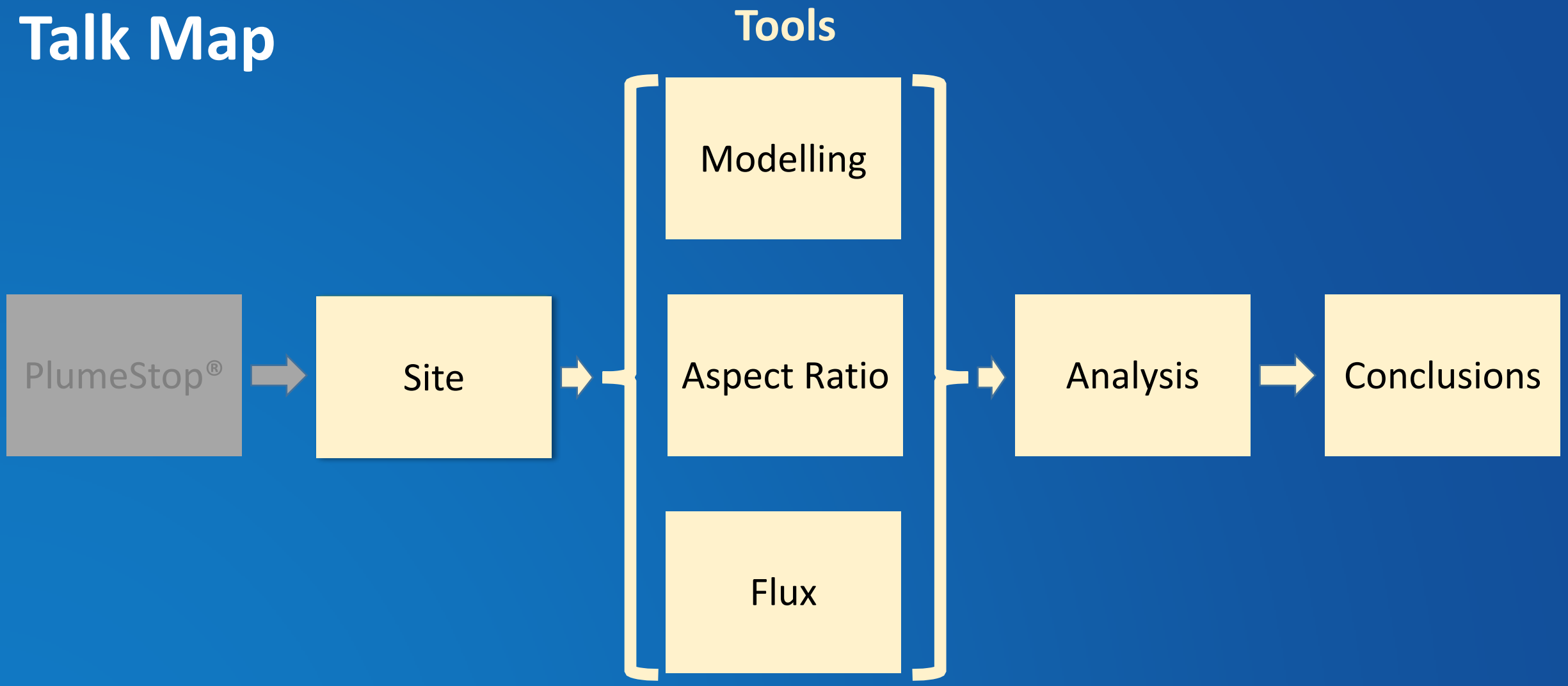
Talk Map



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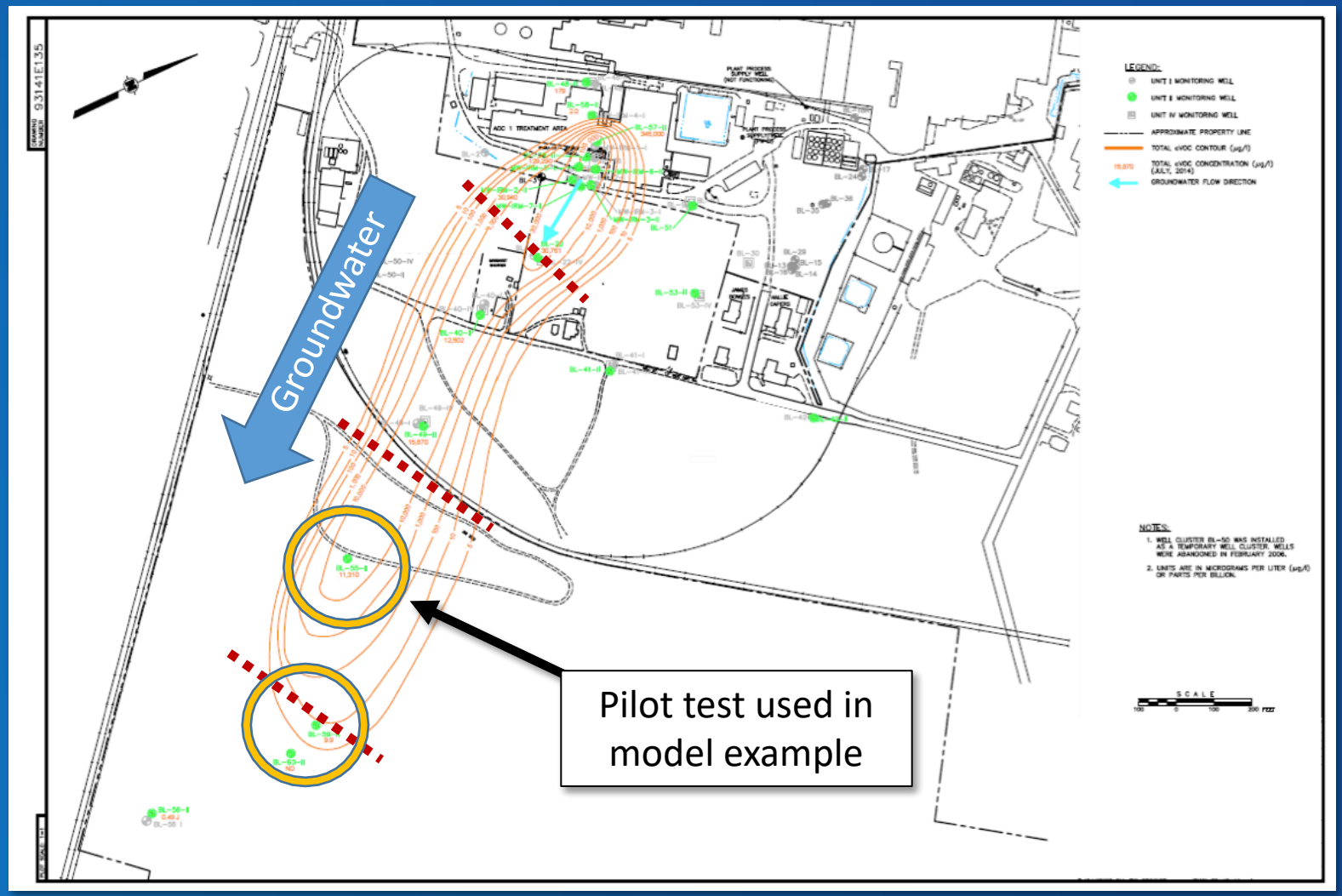
Eastern USA Site

- Industrial facility – established in 1950s
- Chlorinated solvent plume (TCE, daughters)
- RCRA Consent Order (1998)

Eastern USA Site

- **Plume > 1,700 ft** (500 m)
- **TCE 12,000 µg/L** (target 5 µg/L)
- **Source treatments 2011 and 2014**
- **Barrier pilot tests 2014 (data of this exercise)**
- **Three full scale barriers (winter 2015 – 2016)**
  - **Each barrier 400 ft** (122 m)
  - **25' – 45' below grade** (7.5 – 14 m)
  - **PlumeStop®, HRC®, BDi®**



Pick your season…

Pilots: Fall 2014

Full Scale: Winter 2015-16

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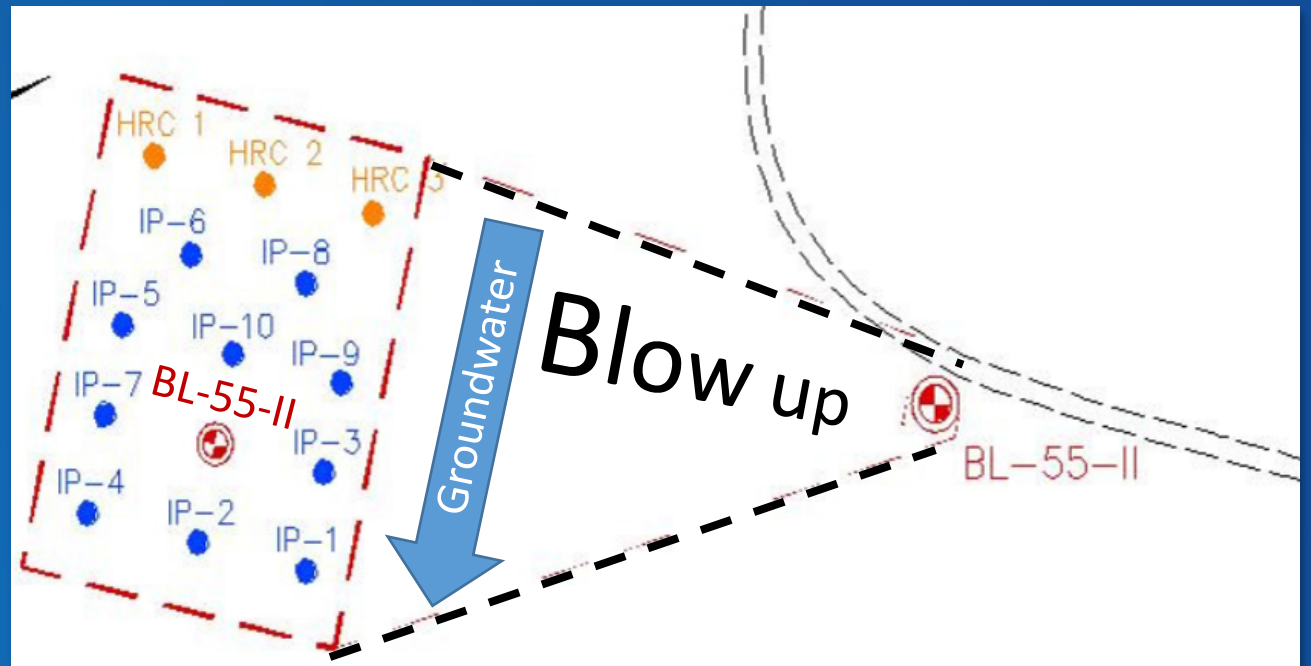
Eastern USA Site

- Reagent injections on 8 ft centers (2.5 m)
  - **PlumeStop®**
  - Electron donor (HRC®)
  - Inoculum (BDi®)
- Target unit 25 – 45 ft bgs (7.5 – 14 m)
  - Sandy clay with sand stringers
- The monitoring well is **within** the barrier
  - Window into processes – good data for modelling
- Monitored since 2014 installation
- Rare **"What happens over time if we just leave it?"** data set

Pilot injection arrangement – 2014



The monitoring well is *within* the treatment zone

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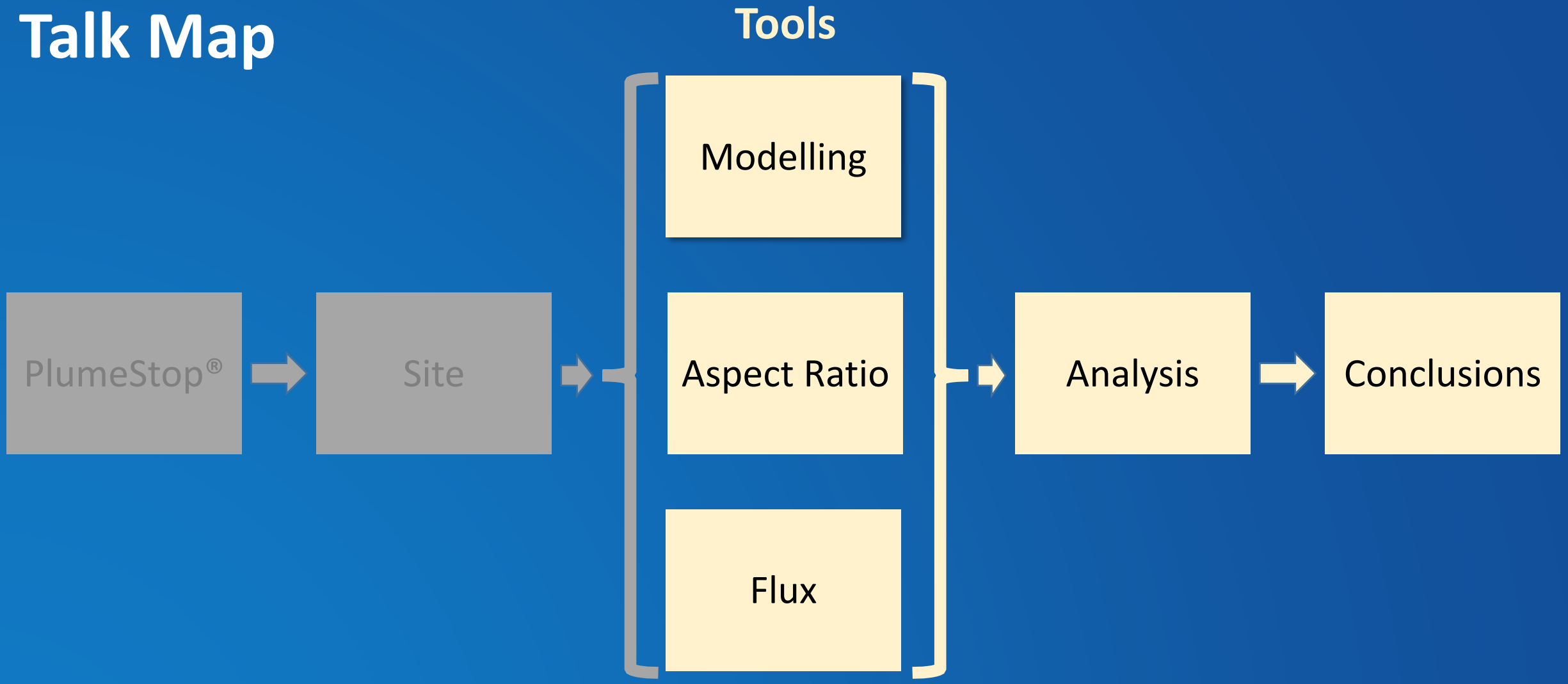

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What is a model?

A model is like a flight simulator

- Complex interacting calculations
- Scenario explorations
- Design optimization
- Visualized outcomes

understand better – design better – communicate better

PlumeForce™ Modeling Tool

Jeremy Birnstingl, BSc, PhD, FRSC, CEnv
VP Environmental Technology, REGENESIS

- Exploration
- Design
- Interpretation
- Communication

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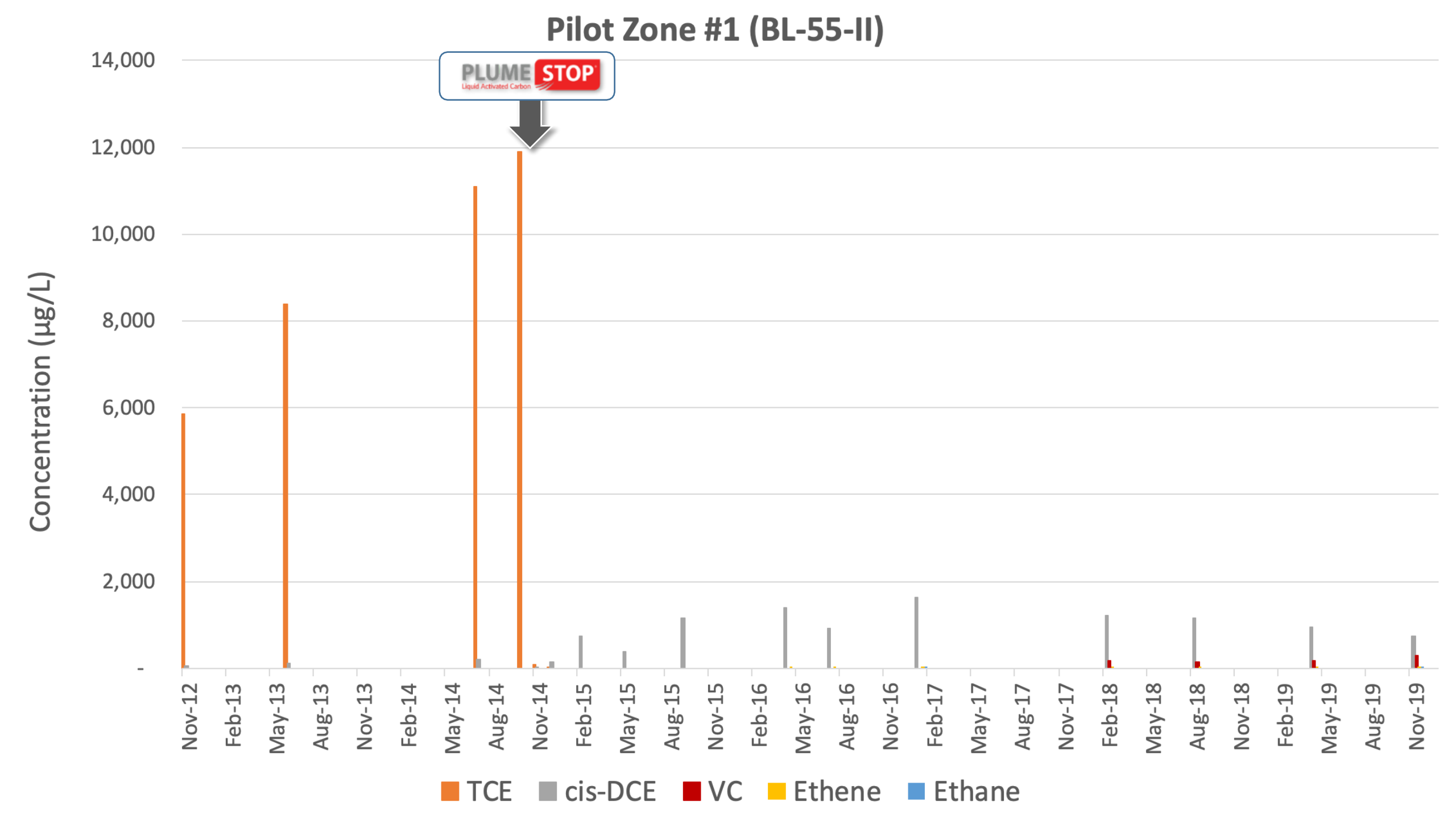
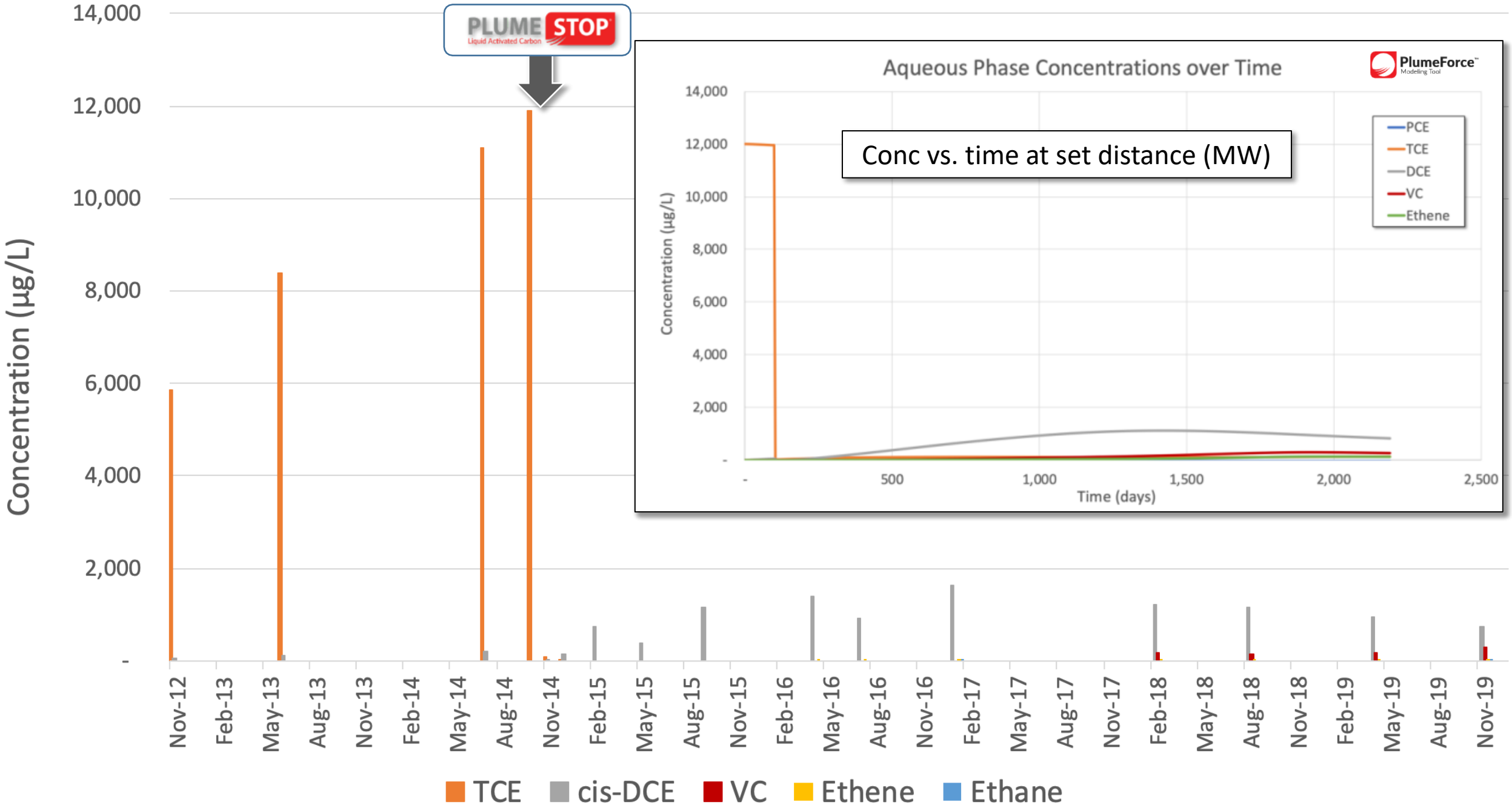
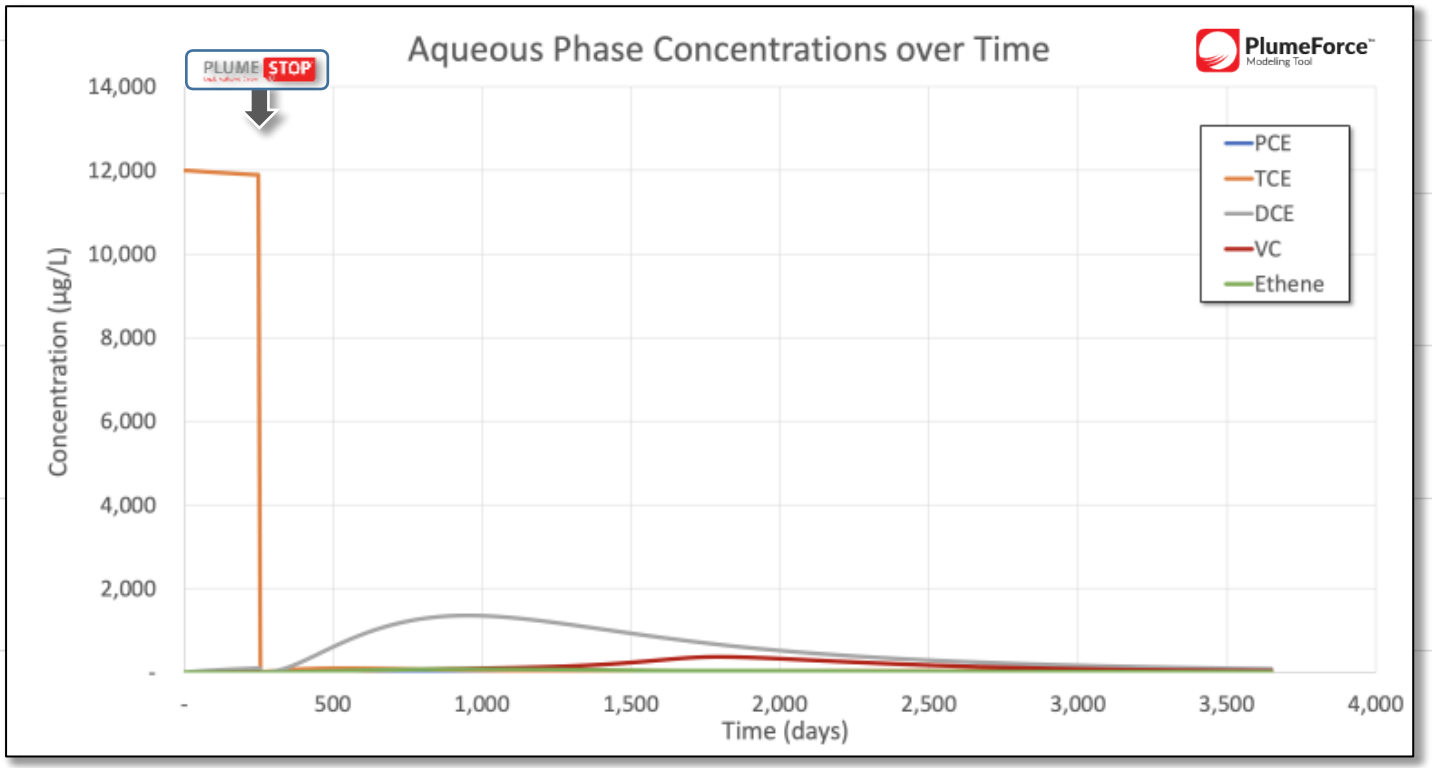

Pilot Zone #1 (BL-55-II)
PLUME STOP
Liquid Activated Carbon
Concentration (µg/L)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
Nov-12
Feb-13
May-13
Aug-13
Nov-13
Feb-14
May-14
Aug-14
Nov-14
Feb-15
May-15
Aug-15
Nov-15
Feb-16
May-16
Aug-16
Nov-16
Feb-17
May-17
Aug-17
Nov-17
Feb-18
May-18
Aug-18
Nov-18
Feb-19
May-19
Aug-19
Nov-19
TCE
cis-DCE
VC
Ethene
Ethane

Pilot Zone #1 (BL-55-II)



Pilot Zone #1 (BL-55-II)

(3,300 days = 9 years)



Concentration (µg/L)

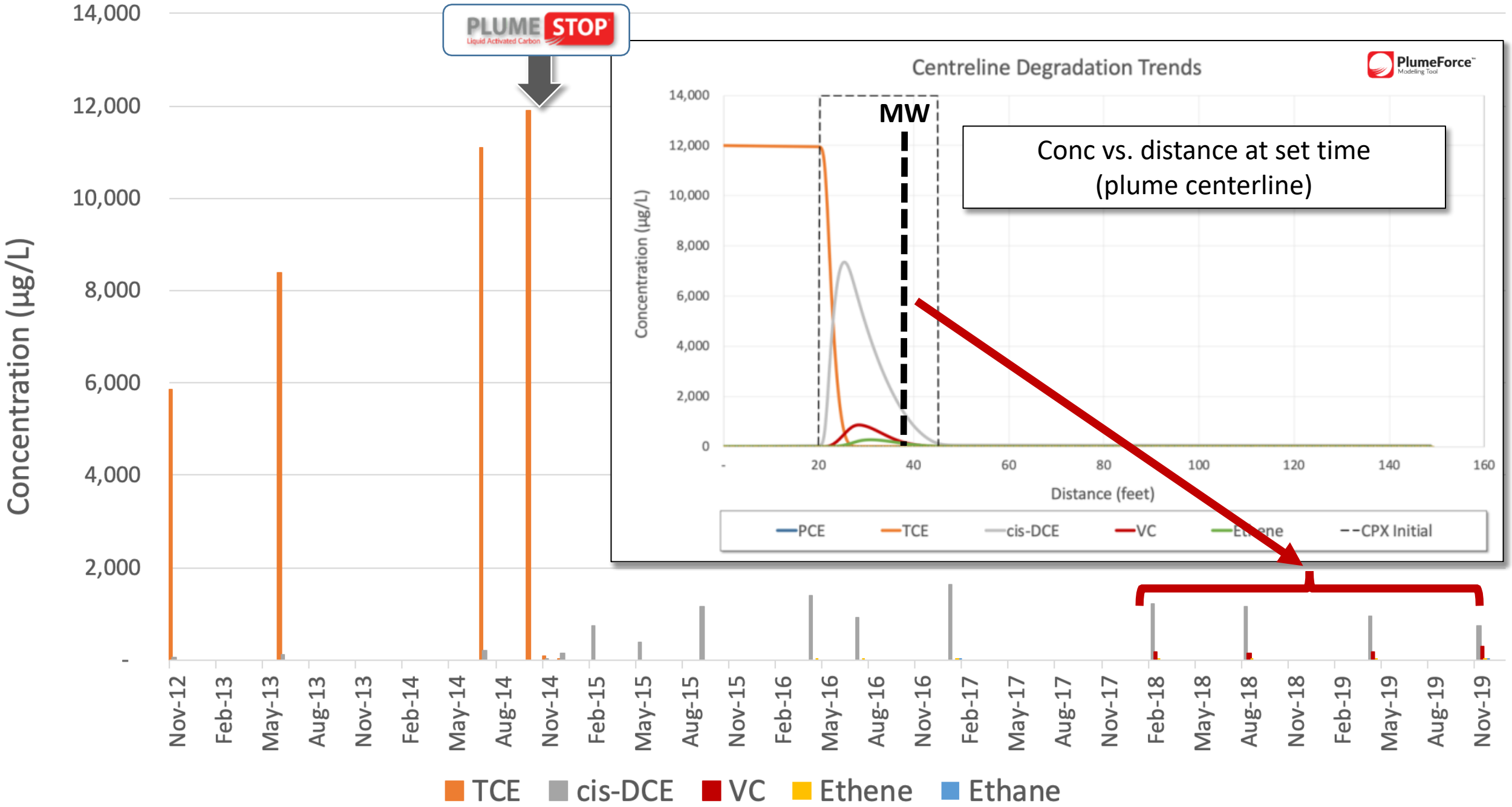
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-

PLUME STOP Liquid Activated Carbon

Mar-14 Jul-14 Nov-14 Mar-15 Jul-15 Nov-15 Mar-16 Jul-16 Nov-16 Mar-17 Jul-17 Nov-17 Mar-18 Jul-18 Nov-18 Mar-19 Jul-19 Nov-19 Mar-20 Jul-20 Nov-20 Mar-21 Jul-21 Nov-21 Mar-22 Jul-22 Nov-22 Mar-23 Jul-23 Nov-23

TCE cis-DCE VC Ethene

Pilot Zone #1 (BL-55-II)



Modelling

- The **optimum model fit** suggests:
  - a seepage velocity **faster** than 60 ft/year (18 m/yr)
  - **significant mass contribution** from organic matter desorption and matrix diffusion
    - approximately **10 – 20x** the mass in the mobile aqueous phase

A plume **retardation factor of ≈ 11 - 21** can therefore be inferred from sorption and forward diffusion into these compartments.

- The **known rate** of plume advance is 1,700 feet (500 m) in ca. 60 years ≈ 28 ft/year (8.6 m/yr)
- The **groundwater velocity** can therefore be estimated at **300 - 600 ft/year** (90 - 180 m/year)
- This is in **sharp contrast** with the design estimate of 60 ft/year (18 m/year)

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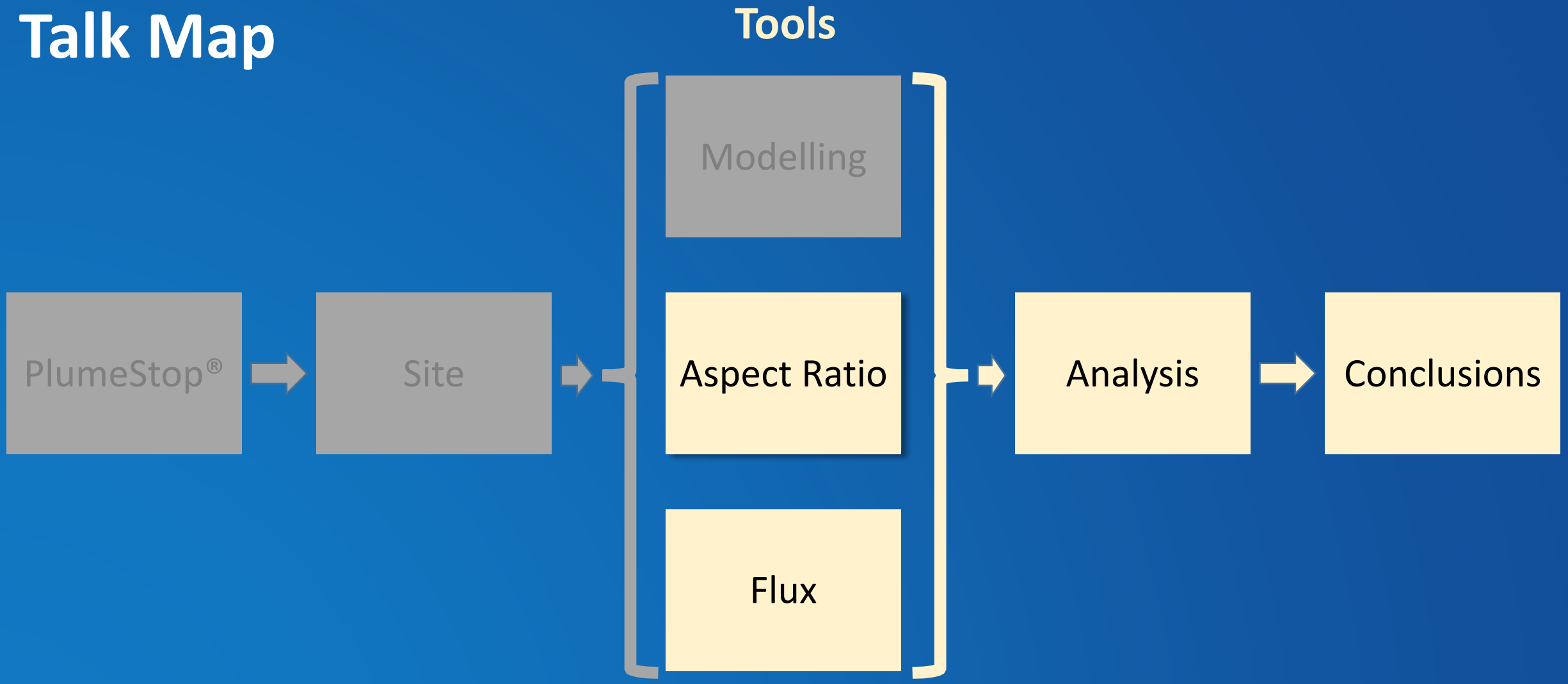
Talk Map



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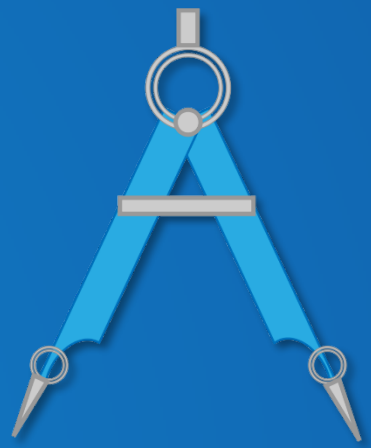
Aspect Ratio



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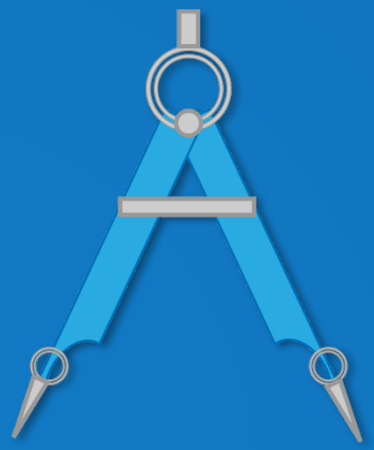
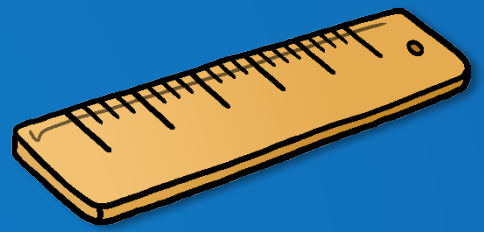
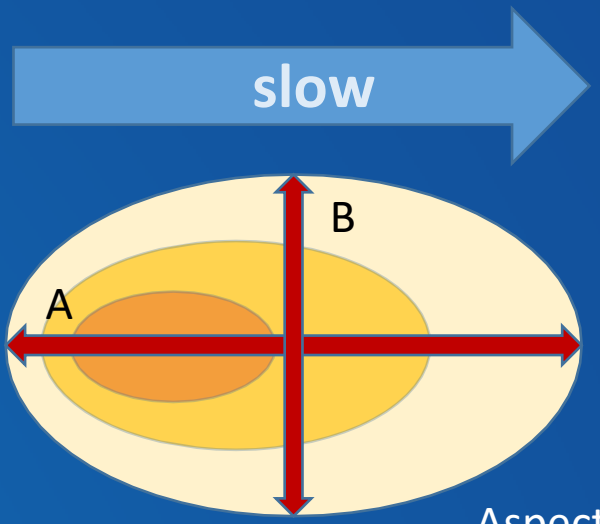
Aspect Ratio

- The aspect ratio (AR) of a plume (length/width) is a function of the groundwater velocity.
- Correlation analysis of AR with measured groundwater velocity from multiple plumes provides a regression function and measure of statistical confidence.
- **Using this, AR can be used to estimate groundwater velocity from plume isopleth maps.**

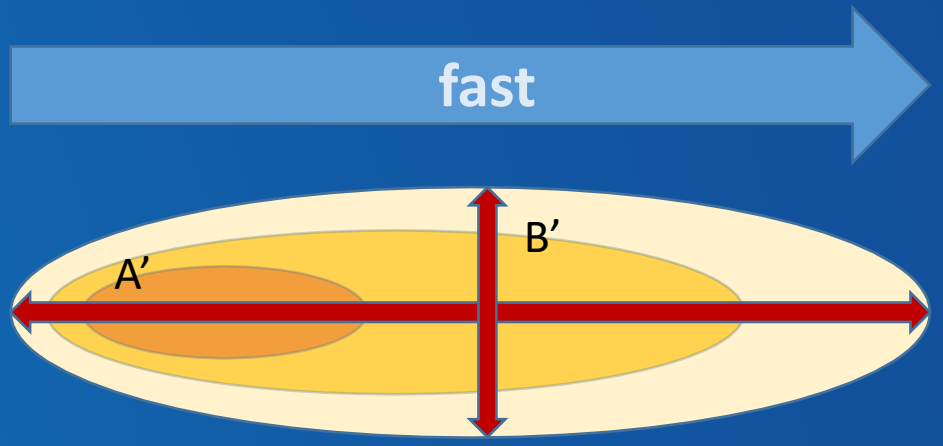




(Publication in preparation)



Aspect Ratio A/B = small ‘blob’



Aspect Ratio A’/B’ = large ‘cigar’

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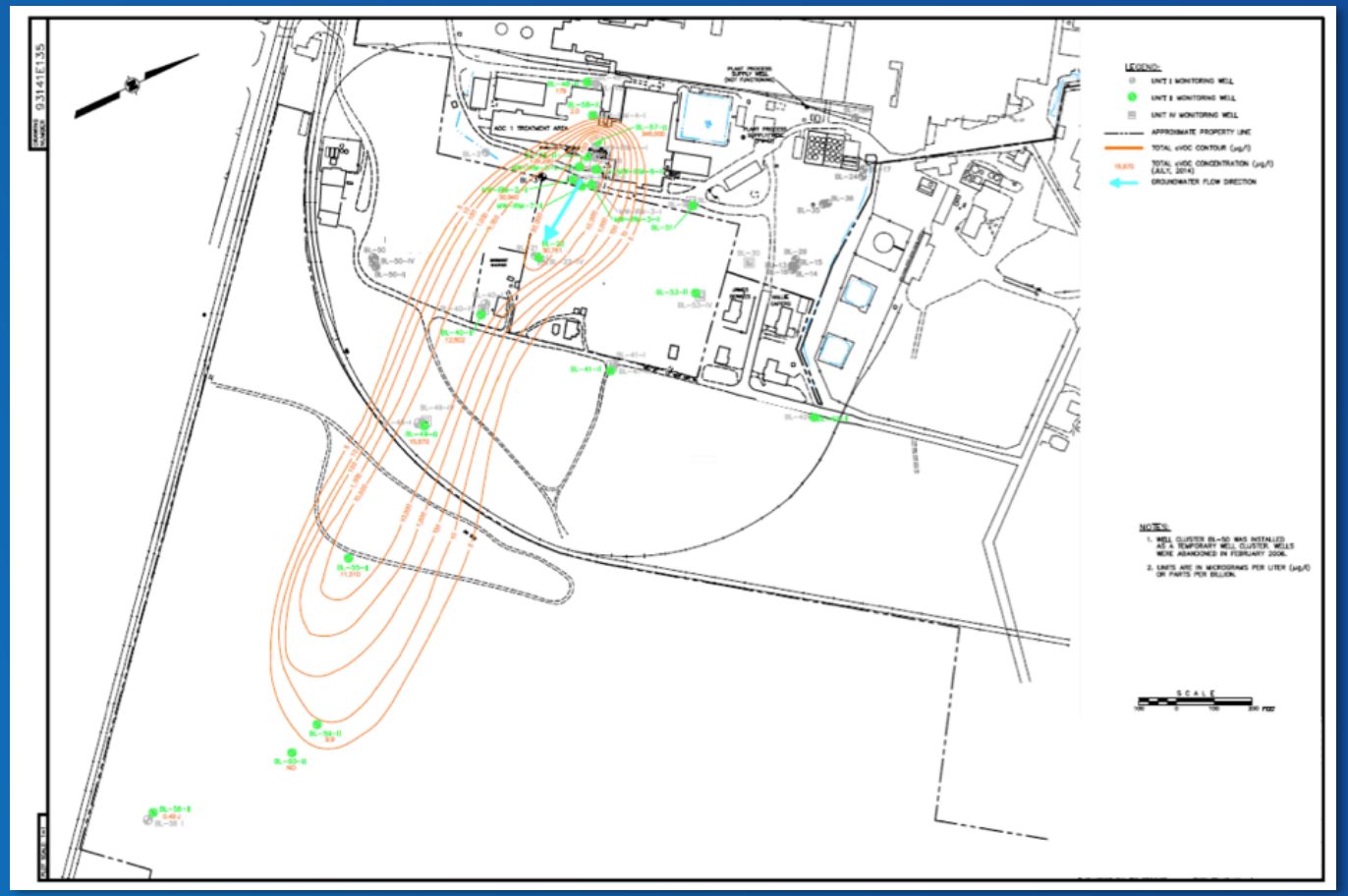
Aspect Ratio Analysis

- Plume shape suggests groundwater is fast-moving
  - ‘cigar’ not ‘blob’
- GW Velocity calculated from AR at different points (sensitive to effective porosity)
  - Minimum *V* = 320 ft/year
  - Maximum *V* = 610 ft/year
  - **Estimate 350 – 500 ft/year**
  - Pilot location *V* = 480 ft/year



Encouraging agreement – but is it true?

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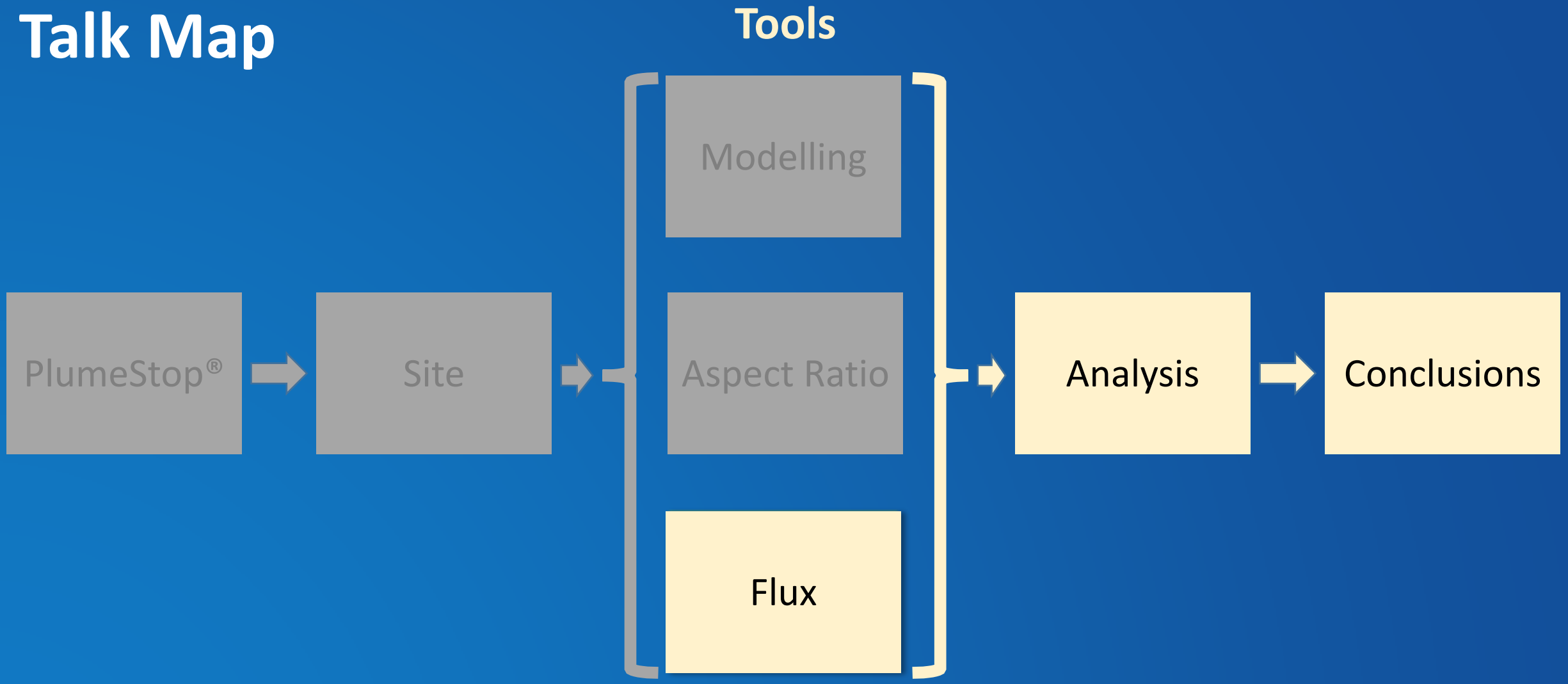

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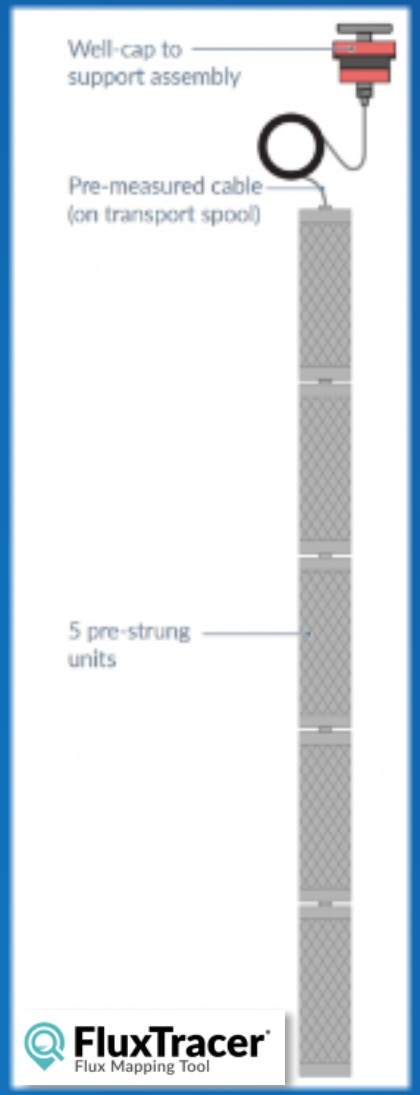
Passive Flux Measurement Devices

- Cannisters of sorbent (activated carbon)
- Pre-loaded with alcohols
- Suspend in monitoring wells (2 – 3 weeks)
- Alcohols wash out
  → **groundwater flux**
- Contaminants load up
  → **contaminant flux**



Field-Scale Evaluation of the Passive Flux Meter for Simultaneous Measurement of Groundwater and Contaminant Fluxes

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ES&T 39(**18**) 2005 pp 7194-7201

Mike Annable

UF UNIVERSITY of FLORIDA

Europe

iFLUX

www.ifluxsampling.com

USA (Florida)

ENVIROFLUX

www.enviroflux.com

USA (California)

FluxTracer Flux Mapping Tool

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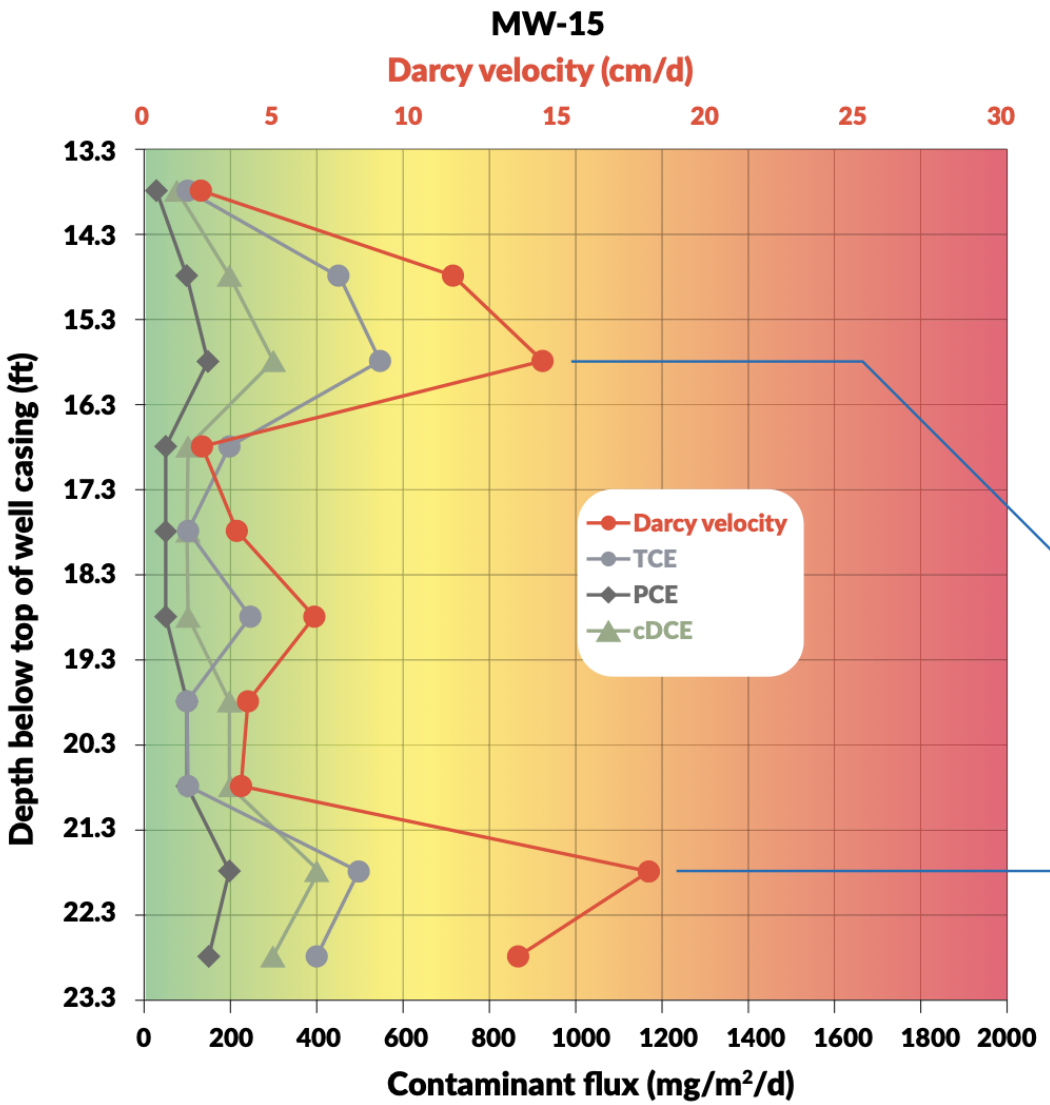
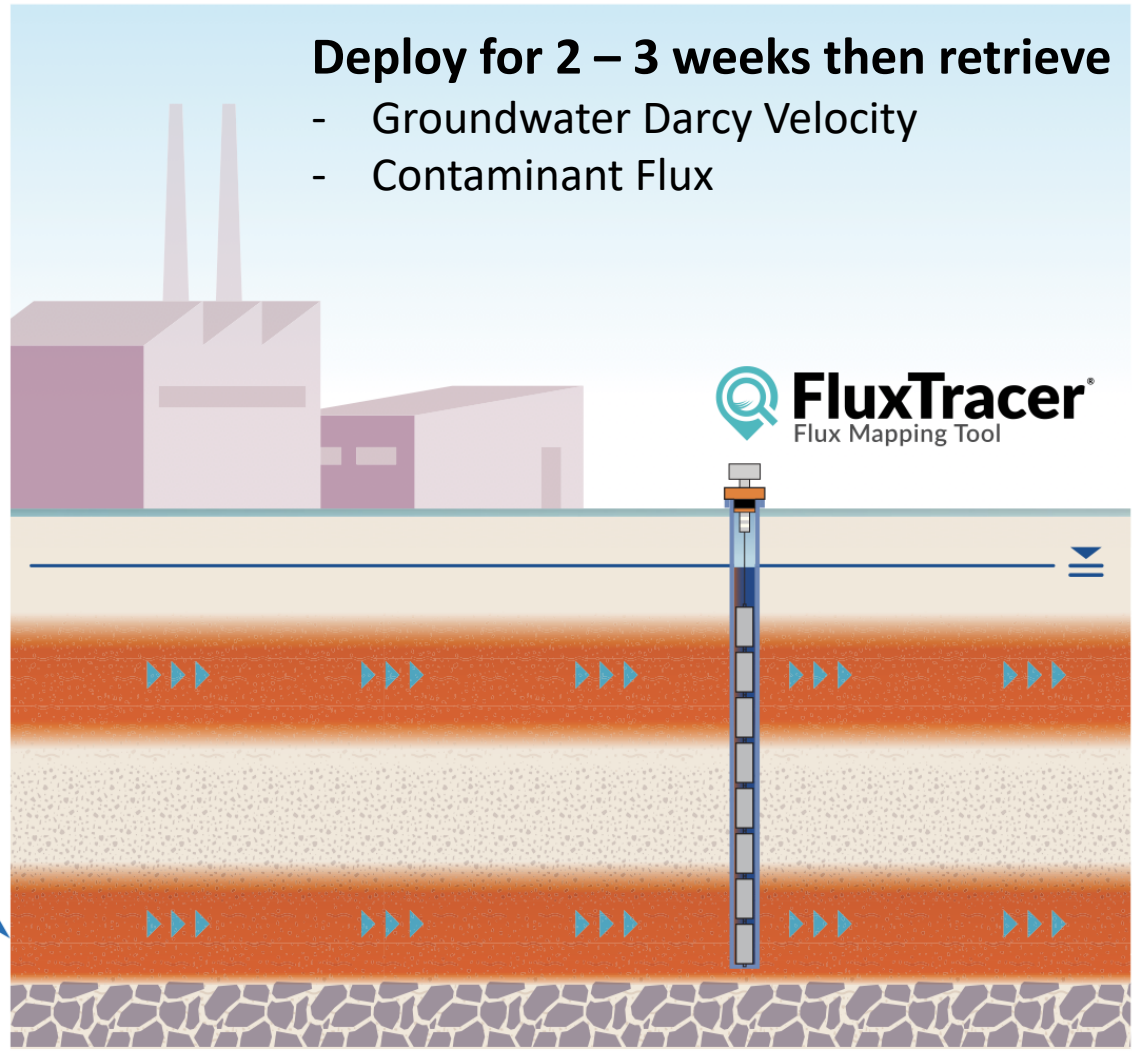
Passive Flux Measurement

quantitative vertical flux profiling – ideal for PlumeStop® designs



Deploy for 2 – 3 weeks then retrieve

- Groundwater Darcy Velocity
- Contaminant Flux



More permeable zone

More permeable zone

FluxTracer™ - Results

- Darcy velocity 9.6 cm/day
  → **Seepage velocity** ≈ **500 ft/year** (150 m/year)
  (Effective porosity estimate ≈ 23%)

- Good agreement:
  - **Aspect ratio** derived estimate of **400 to 500 ft/year** (120 – 150 m/year)
    - **480 ft/year** (146 m/year) at the monitoring well location
      (Effective porosity estimate ≈ 23%)
  - **Model-inferred** velocity range of **300 to 600 ft/year** (90- 180 m/year)
    - Optimum fit at ≈ **535 ft/year** (163 m/year)

- **Order of magnitude greater** than the **initial estimate** of **60 ft/year** (18 m/year)
  - used at the design stage

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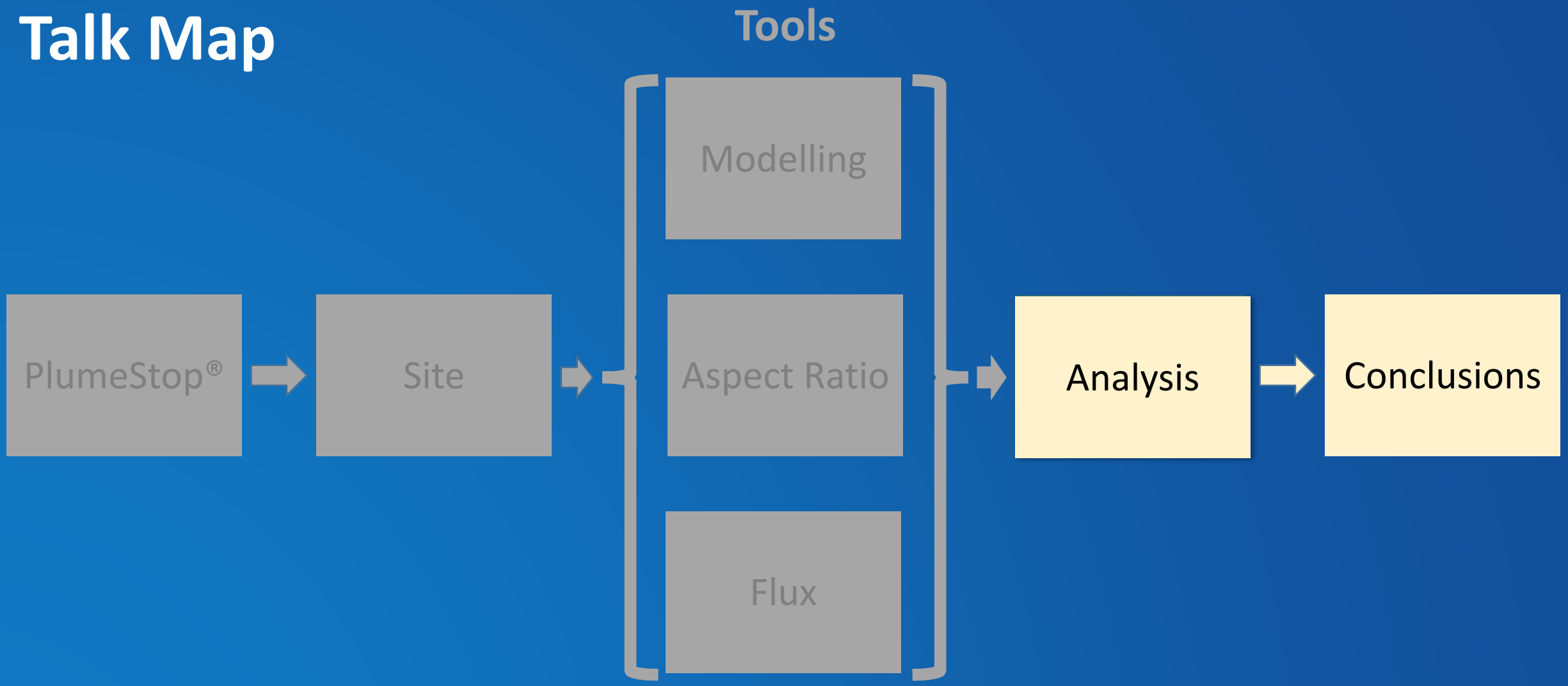
Talk Map



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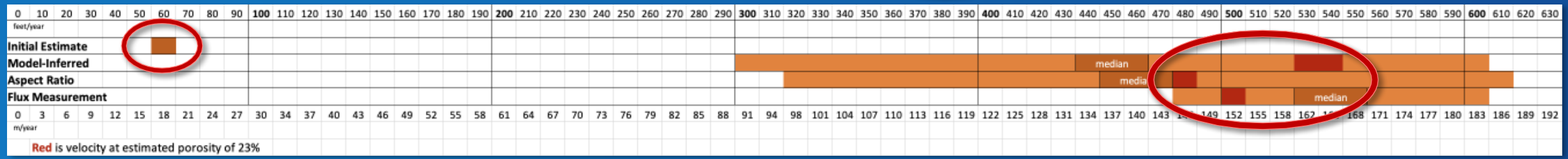
Data Agreement

Seepage Velocity Method	Range (feet/year)	Estimate (feet/year)	Range (m/year)	Estimate (m/year)
Initial Estimate	60	**60**	18	**18**
Model-inferred	300 - 600	**540**	91 - 183	**165**
Aspect Ratio	320 - 610	**480**	98 - 186	**146**
Flux Measurement	480 - 600	**500**	146 - 183	**152**



- **Broad agreement** of the **new techniques** ≈ 500 ft/year (150 m/year)
- Consultant's initial estimate an **order of magnitude** lower – 60 ft/year (18 m)
- Significant **design implications** as faster groundwater requires a higher carbon dose

So how did the barrier perform?

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Barrier Performance

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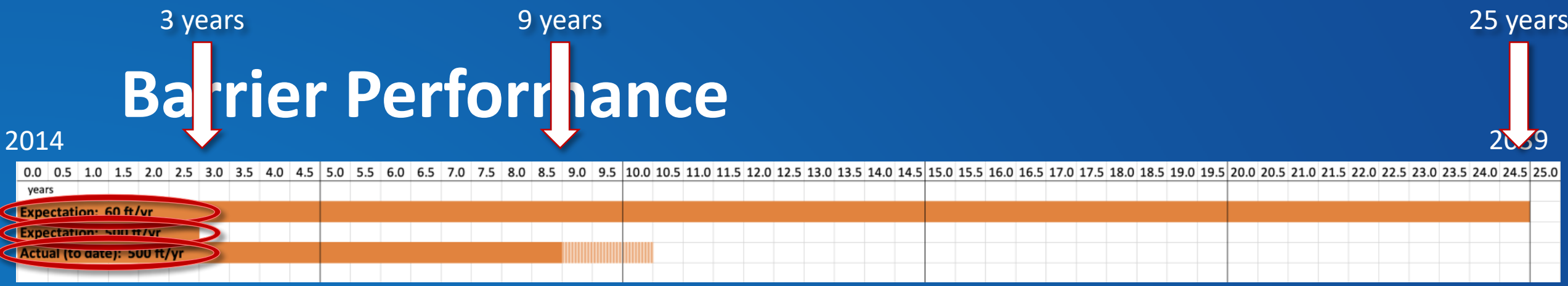
Barrier Performance



- **60 ft/year** (18 m/yr) – TCE expected to arrive at pilot MW in **25 years** (based on retardation only)
- **500 ft/year** (150 m/yr) – this reduces to **3 years**
- Not yet arrived at **9 years**
- Extension attributed to the **combination** of **biodegradation** with **retardation**
  - Possible **bio-regeneration** of carbon sorption sites

Performance is therefore **triple** the sorption-only expectation at the measured flux
This suggests the initial 25-year design would be met / exceeded under the design conditions

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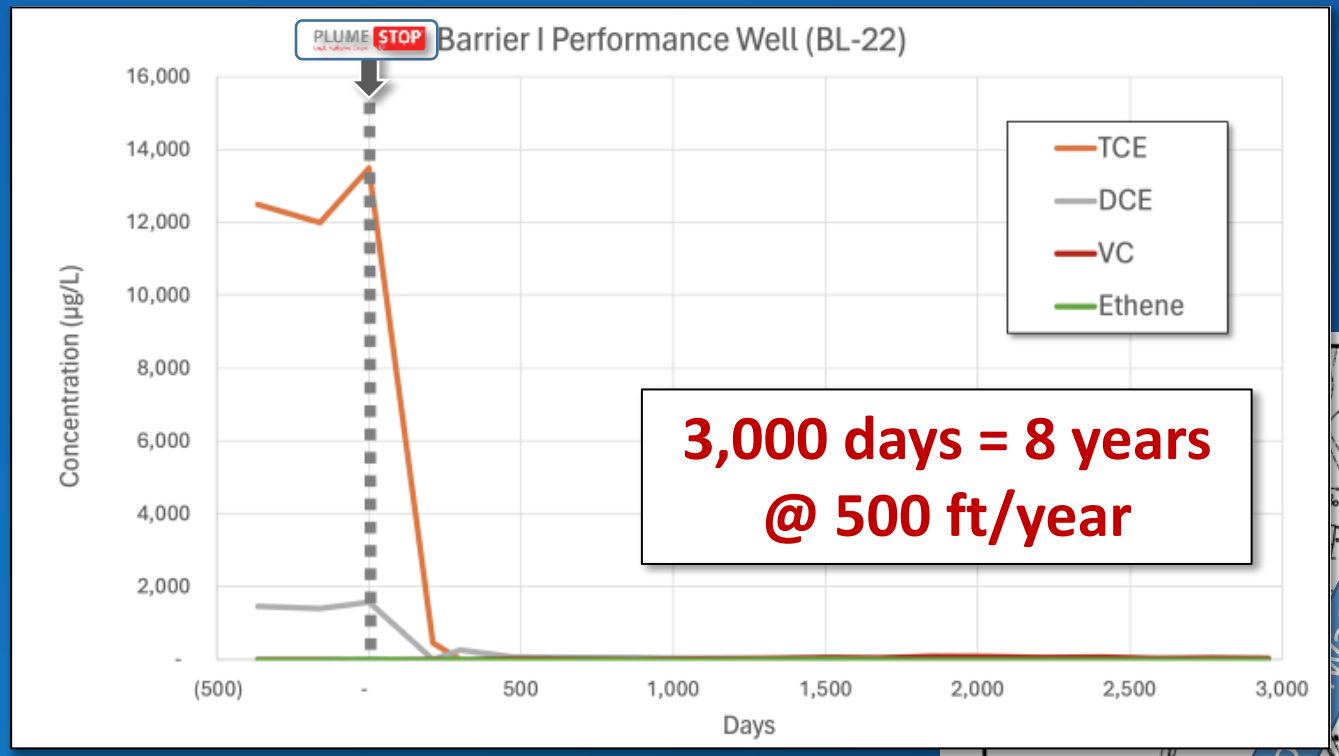
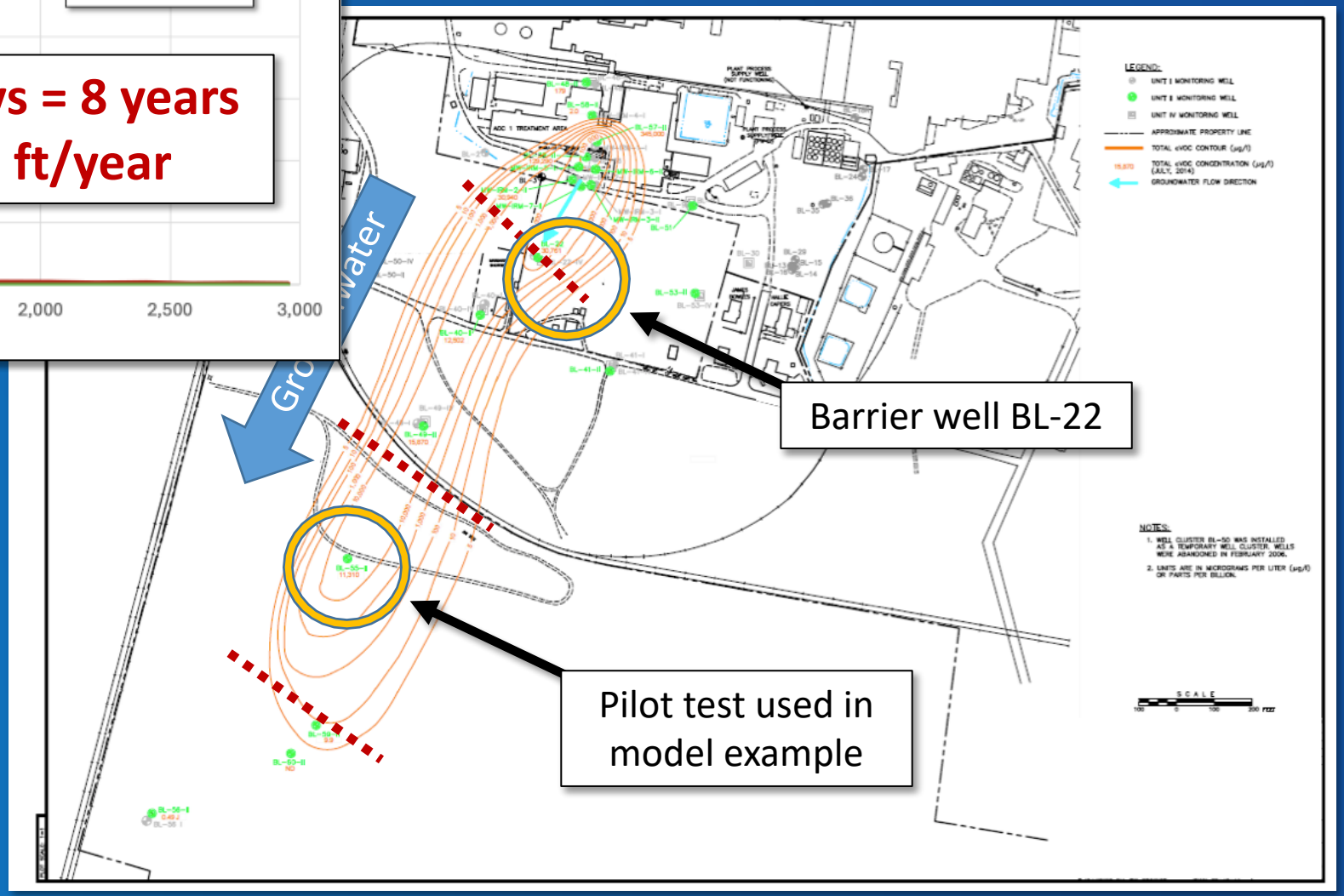
Up-Gradient Barrier





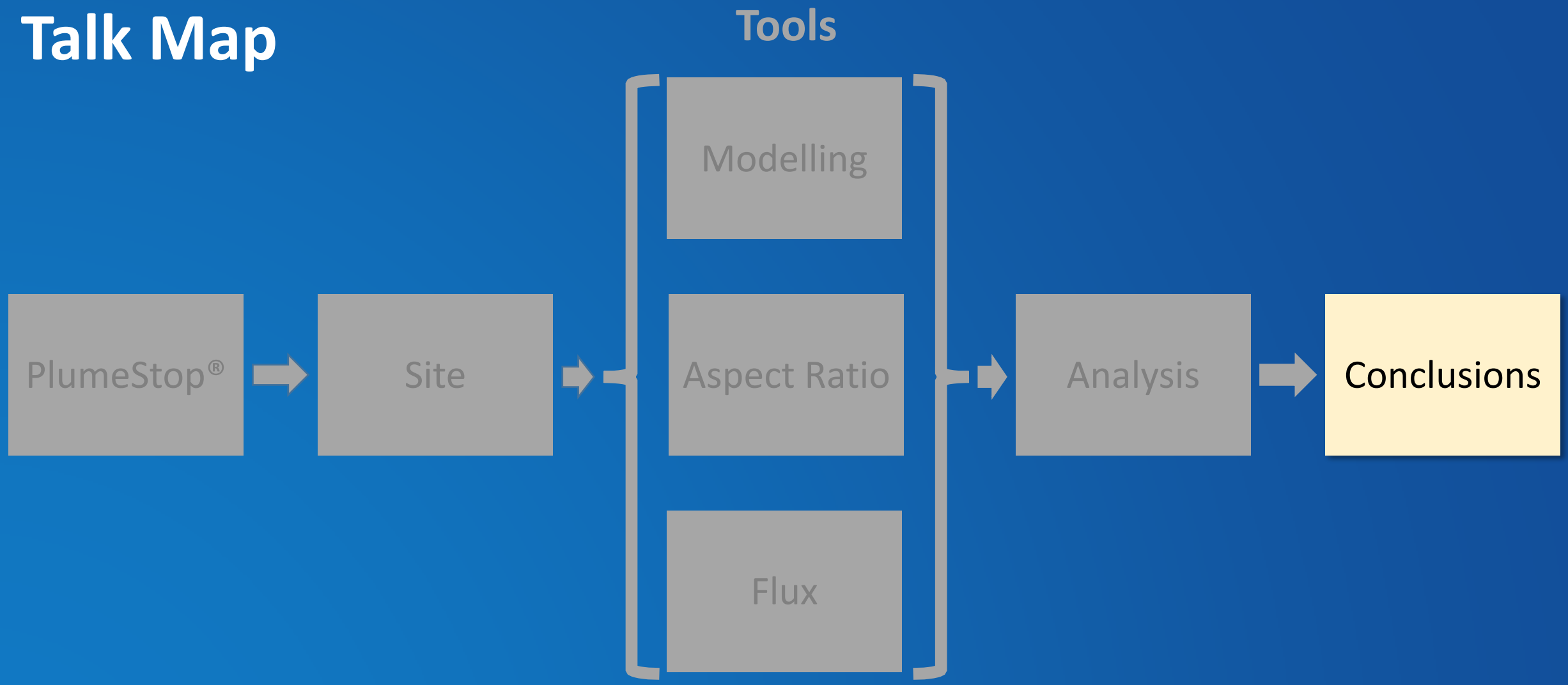
Overall Plume Remediation

- Objectives are being met (2016 to date)
  - Plume is **contained**
  - Mass is **depleting**

Barrier Performance – bonus ball

- Modelling suggests TCE and daughter **biodegradation has remained ongoing**
  - long after the **depletion** of the HRC® donor
    - Pre-treatment aquifer was **aerobic** – minimal TCE degradation
    - HRC® electron-donor longevity **<1 year** at 500 ft/year seepage velocity
    - Rate has reduced but **has not reverted** to pre-treatment rate
- Analysis of chemical and geochemical data supports the modelled inference.
- The mechanism behind this is intriguing but beyond the scope of the present study.
- (That's a story for another time.)

Talk Map


Tools
Modelling
PlumeStop®
Site
Aspect Ratio
Analysis
Conclusions
Flux

Conclusions – tools

- The three approaches offer **good agreement**.
- **Order of magnitude higher** than the estimate made without these tools.
- **Convergence** supports **confidence** in their individual use.

Conclusions – application

- An understanding of **flux** is **critical** to PlumeStop® barrier designs
- Conventional approaches can significantly **underestimate** flux
- These three approaches provide the necessary flux basis for designs
  - **Aspect ratio** and **modelling** tools allow rapid **desktop** analysis
  - **Passive flux measurement** provides powerful **field** corroboration

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Conclusions – barrier

- The barrier pilot has remained functional to date
  - **9 years** at latest available data set
- Correcting for flux, performance is **triple** the retardation-only expectation
  - This **duration is extending** as the barrier continues to perform
- Solvent **biodegradation** remains **on-going** in the barrier zone long after donor expiry
  - Wider aquifer is aerobic – negligible background TCE degradation – intriguing but beyond present study

REGENESIS®
Technology-Based Solutions for the Environment

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Thank You

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PlumeForce™ Modeling Tool

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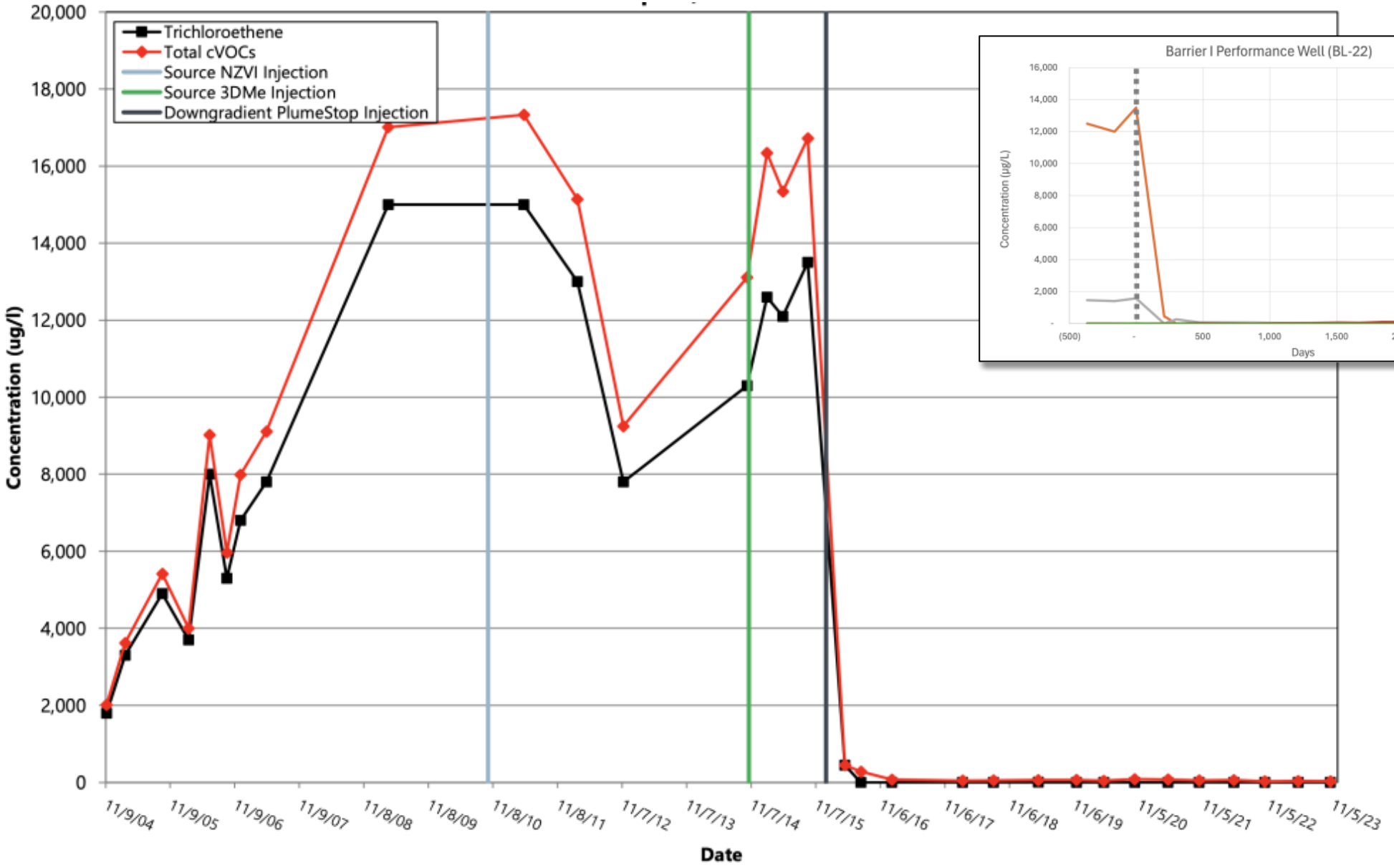
Time-Concentration Trend Chart
Unit II Monitoring Well BL-22



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