No longer in Flux: *Why Volumetric and Mass Flux Are Your Secret Weapons for Achieving Remediation End States*

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Session: Achieving Remediation End States: Turning Vision into Reality

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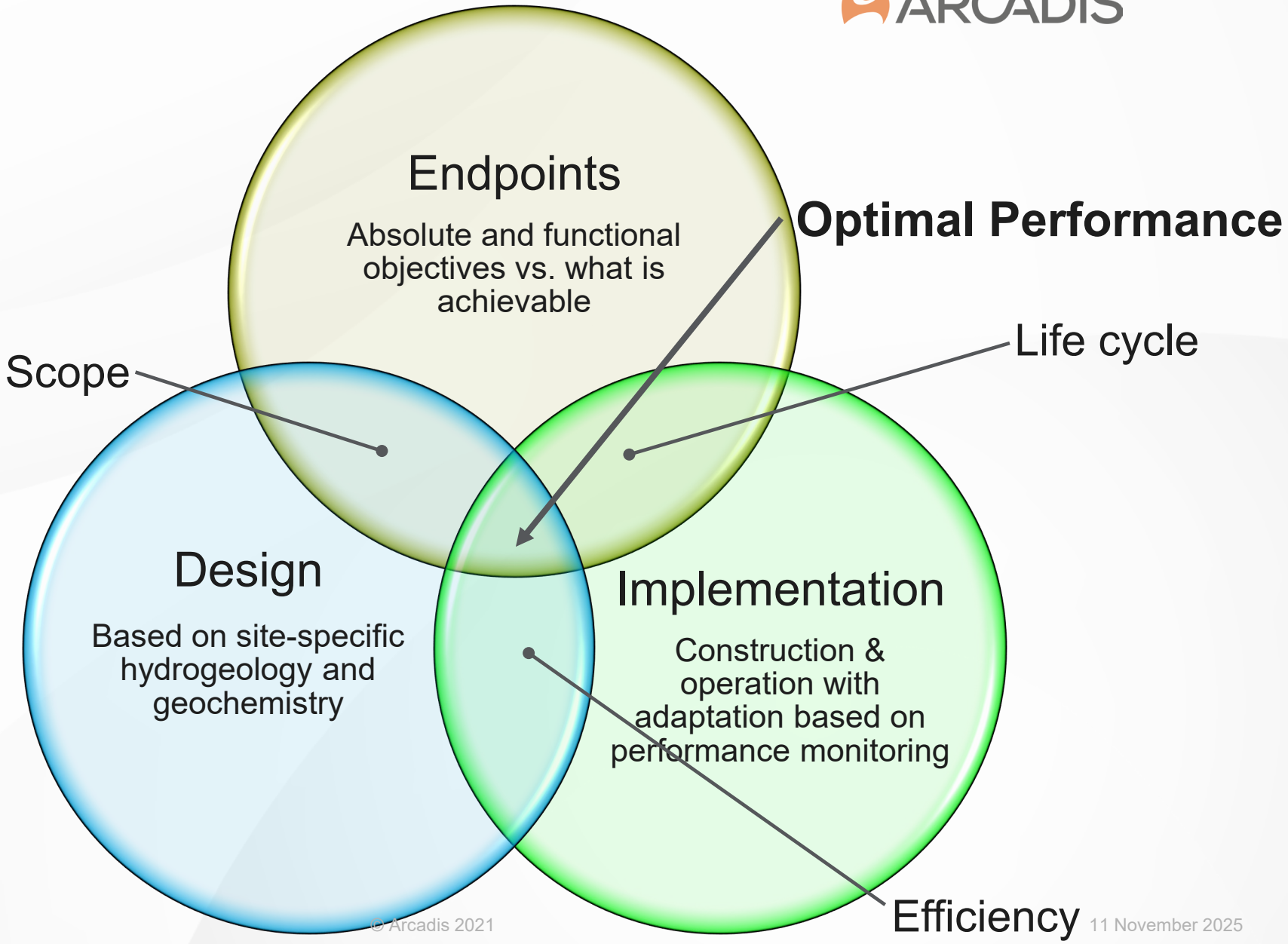
Successful Remediation

Successful outcomes are based on a combination of factors

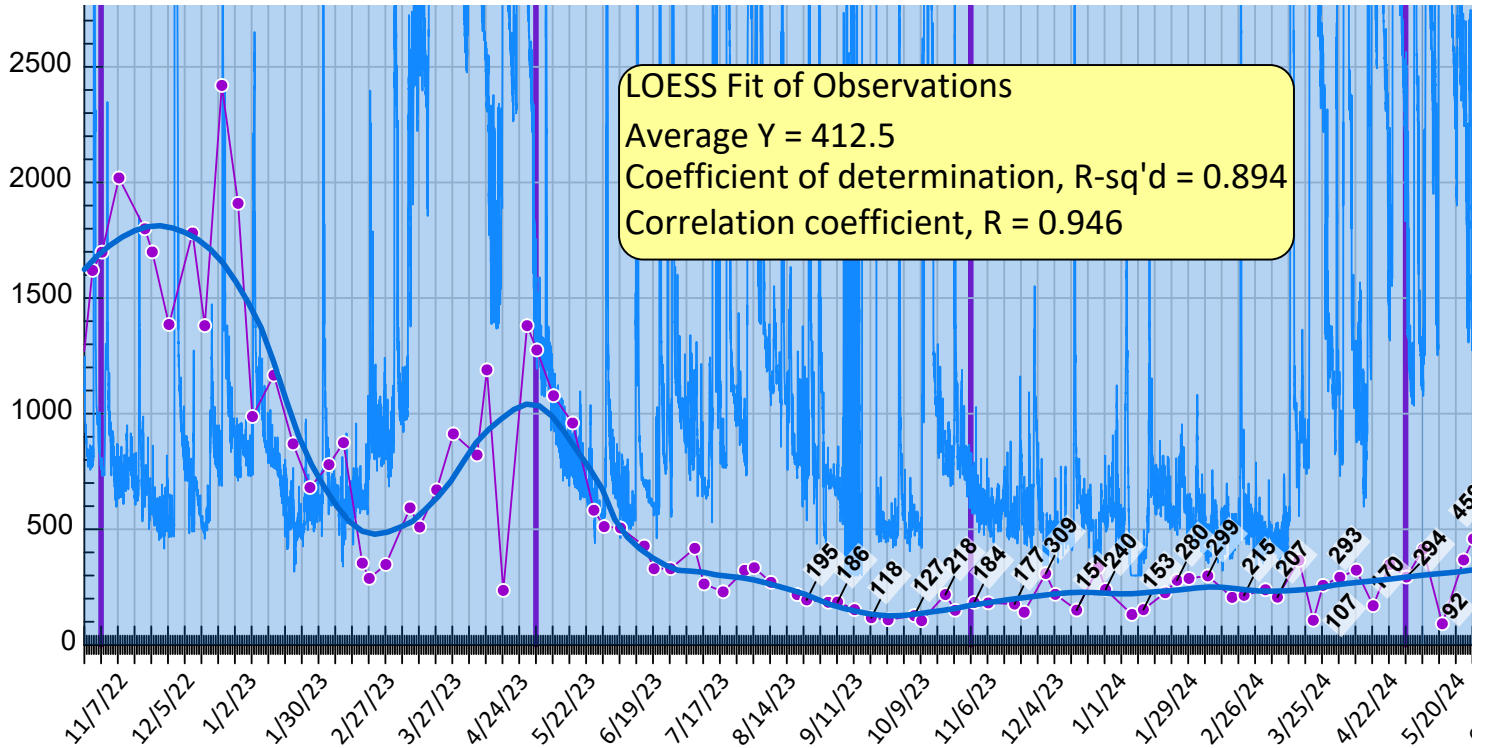
- Constraints
- Data/Findings
- Interpretation
- Regulations
- Risks
- Technologies



Hypothesis to categorize remedial decisions

There exists a representative general metric based on our decisions varying from 0.0 to 1.0, where a value of 1.0 is a great idea and 0.0 would never work

An example would be a *LOESS Fit* to measured data, a generalized incremental relationship based on multiple decision variables



Methodology to develop a framework

Balancing objectives to achieve outcomes

- *Hypothesis*
- *Conceptualization*
- *Testing*
- *Application / Outcomes*

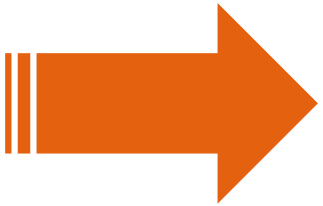
Conceptual approaches were evaluated

GROUNDWATER FLOW

- Hydraulic gradients between two wells
  - Flow toward extraction wells
- Groundwater Flow Directions
  - Particle Tracking
- Drawdown

SOLUTE TRANSPORT

- Contaminant Mass (extracted, degraded, sequestered)
- Plume Stability
- Period-of-Performance



A generalized relationship capturing these ideas

plus

Technologies

Thermal, Excavation, . . .

Mass Remediation Ratio

The *Mass Remediation Ratio* is the ratio of *The Mass Removed* to the *Total Contaminant Mass* before the remedy began.

$$\wp = \frac{Mass\ Removed}{Total\ Contaminant\ Mass}$$

This ratio conforms with our intended metric – it varies from 0.0 to 1.0.

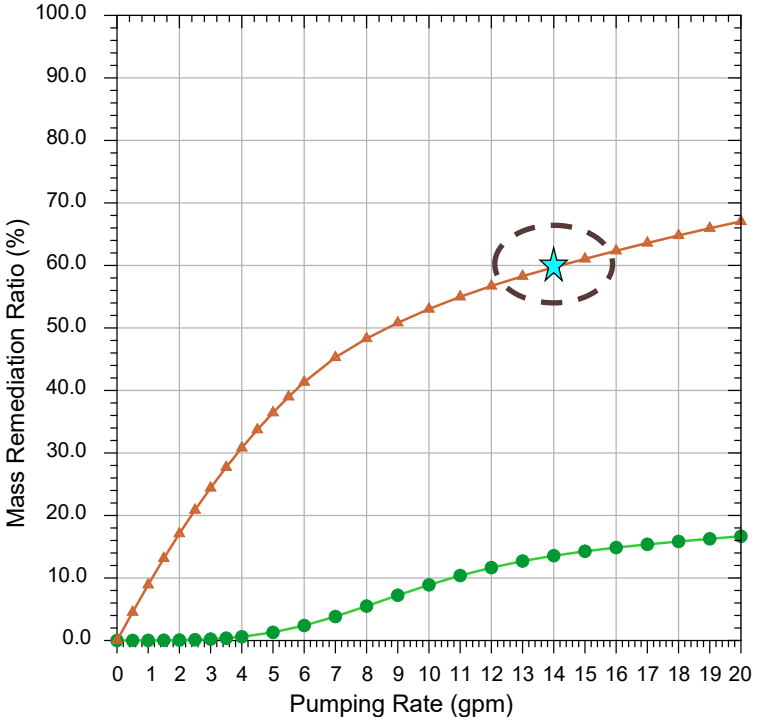
The **Mass Removed** is a general concept and can be from groundwater extraction, *in situ* sequestration, or *in situ* degradation. The **Total Contaminant Mass** is dissolved, sorbed, and diffused.

The relationship also needs to have specific mathematical properties to be useful

- Continuous
- Differentiable
- No local Minima or Maxima

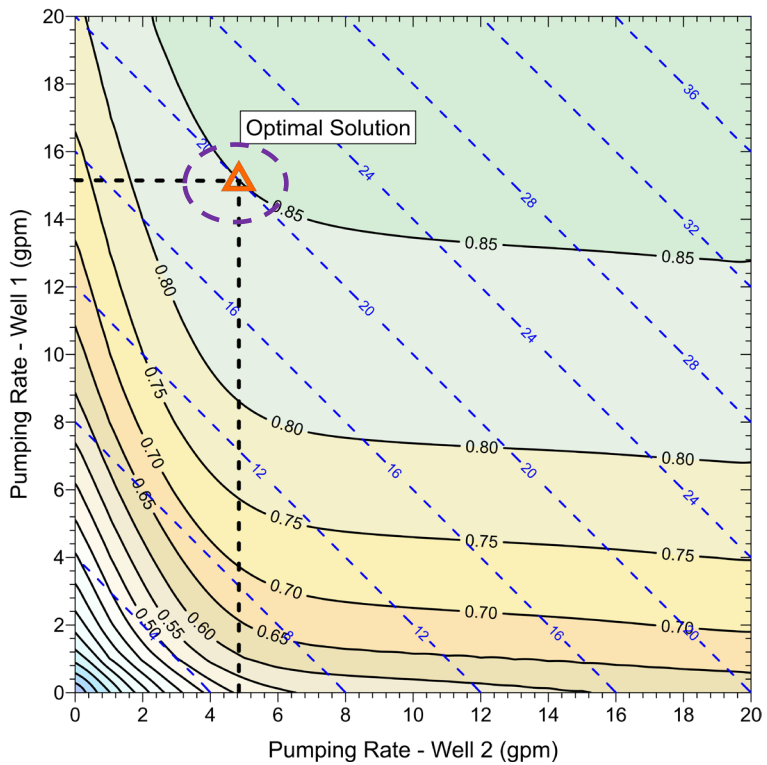
Pump & Treat: *The simplest Mass Remediation Ratio*

1 Well (n=1)



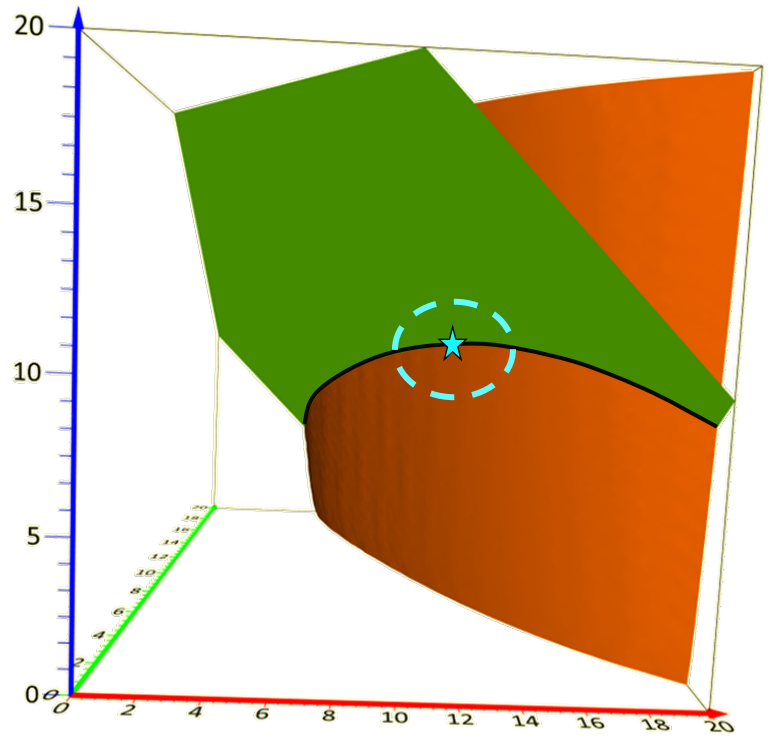
Points (n=0)

2 Wells (n=2)



Lines (n=1)

3 Wells (n=3)

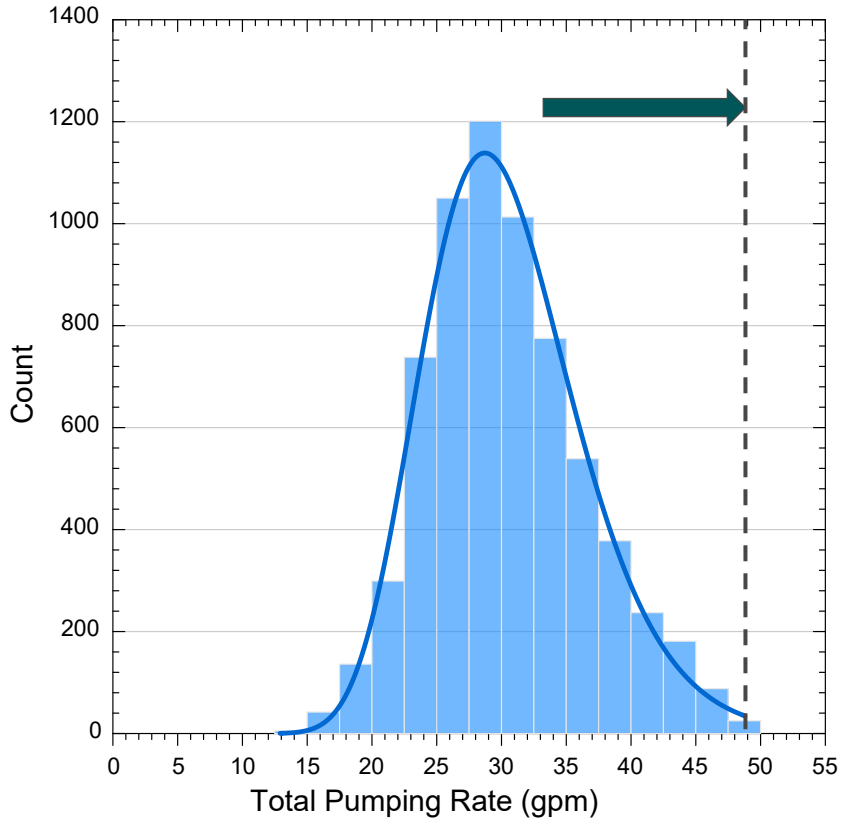


Planes (n=2)

Theorem: The roots of a polynomial with n degrees-of-freedom can be represented by families of independent polynomials with ≤ n-1 degrees-of-freedom. (Atkinson 1975)

Finding roots amongst the choices

- The key to sorting through the possibilities to evaluate decisions is recognizing that each combination of potential decisions has a unique statistical probability of success



The combination of the decisions with the highest likelihood of success is located at the right extreme of the distribution of possibilities – where the cumulative area under the curve approaches 100% of the distribution

It represents the decision doing the maximum level of remediation with the least effort

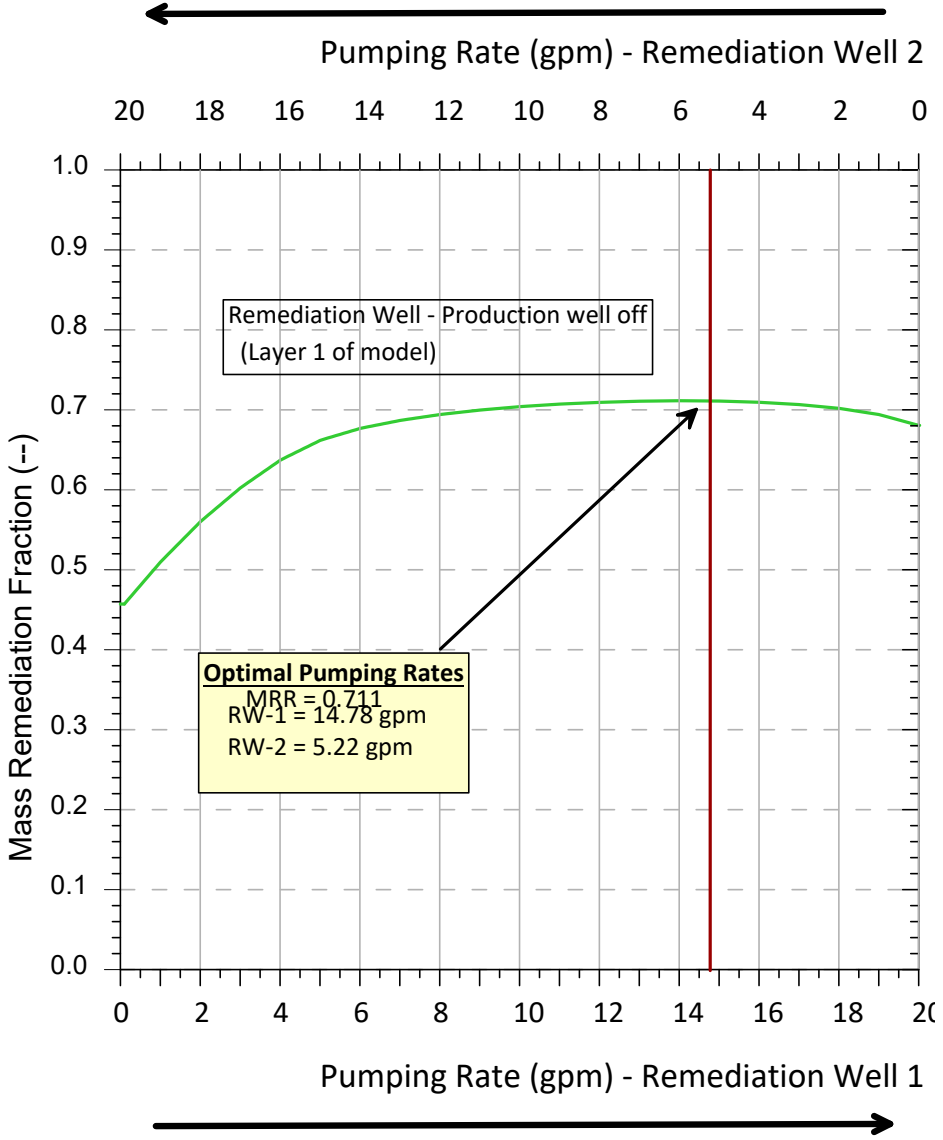
Solution Algorithm

Adaptive Simulated Annealing (ASA); (Ingber 2011)

Finding the maximum MRR by testing combinations of pumping rates to estimate the distribution of possibilities

Maximize mass remediation ratio bounded by a set of constraints

- *Range of pumping rates (0 < Q < Max)*
- *Locations (A set of Possibilities)*
- *A maximum number of wells*
- *Cost relationships*
- *Technology*



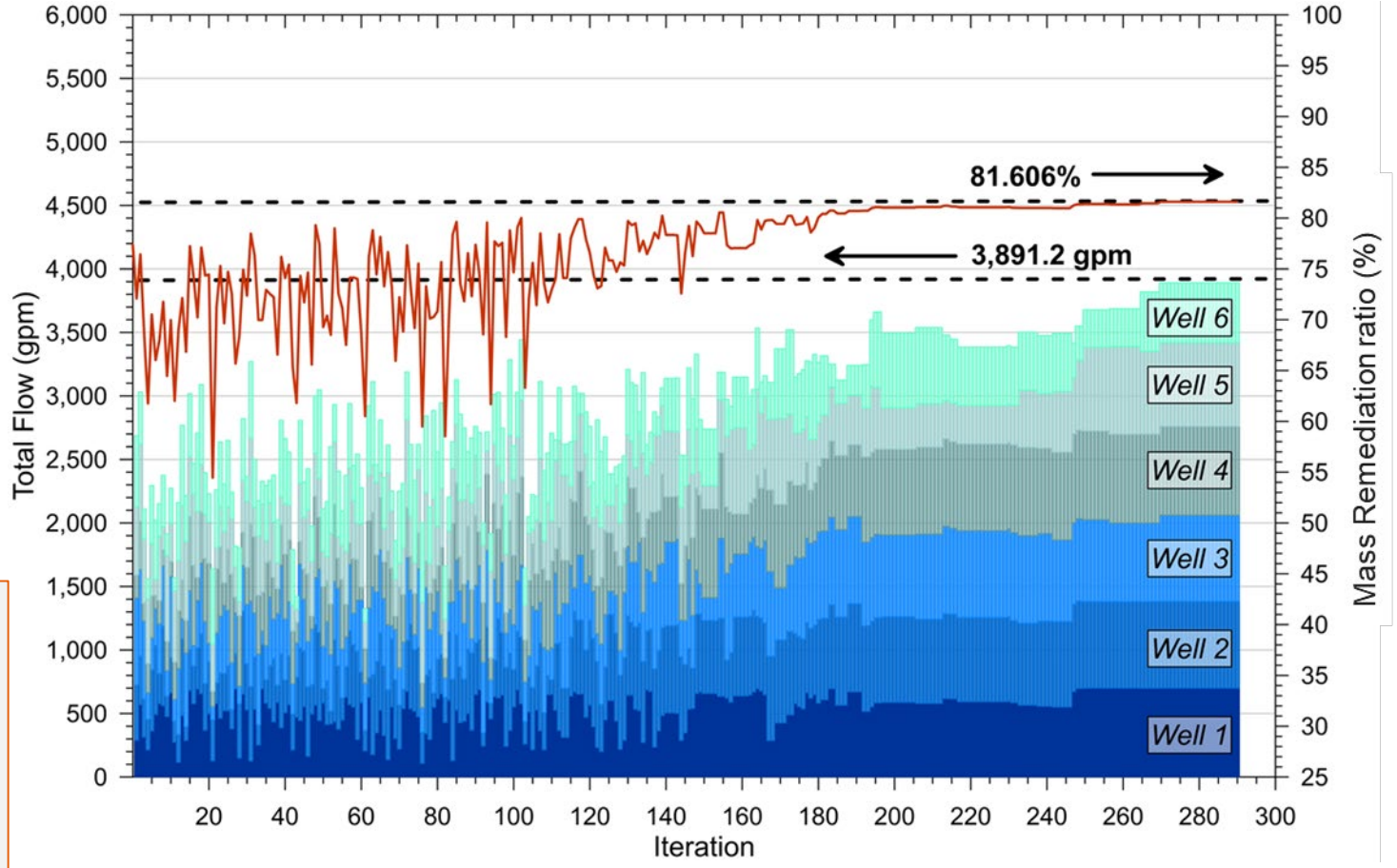
Assessment of extraction wells in “Zone A”

- 6 Well system
- Each well can operate
  0 < Q < 750 gpm
- The treatment capacity is 5,000 gpm
- Infiltration of treated water

You can’t capture more than 81.6 % of the plume,

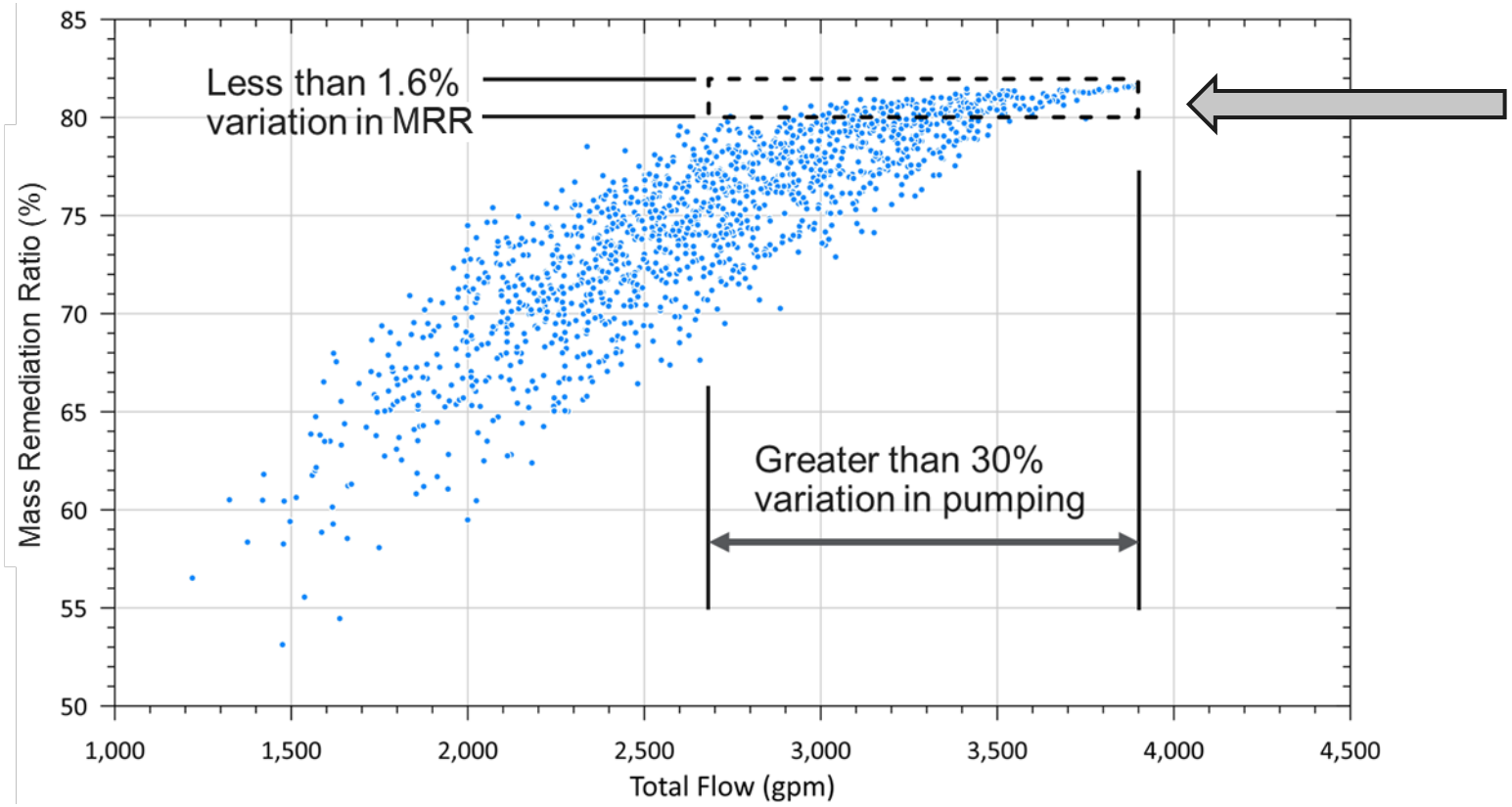
and

Pumping more than 3,900 gpm is not beneficial

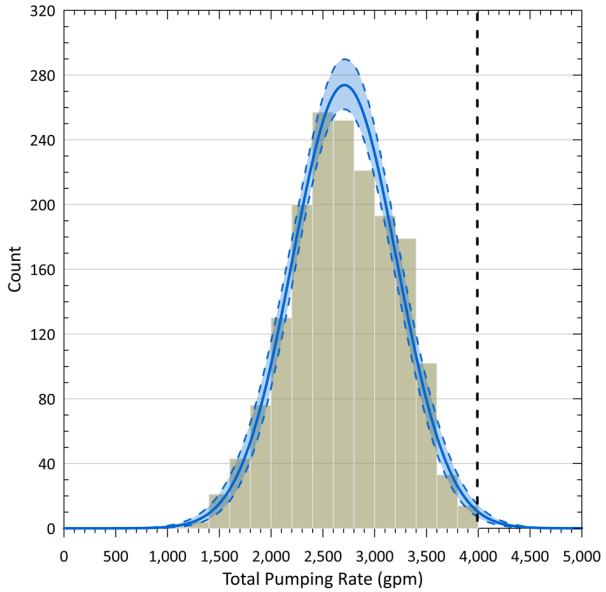


Maximizing of Mass Remediation Ratio

Operational options to pump water from Zone A . . . .

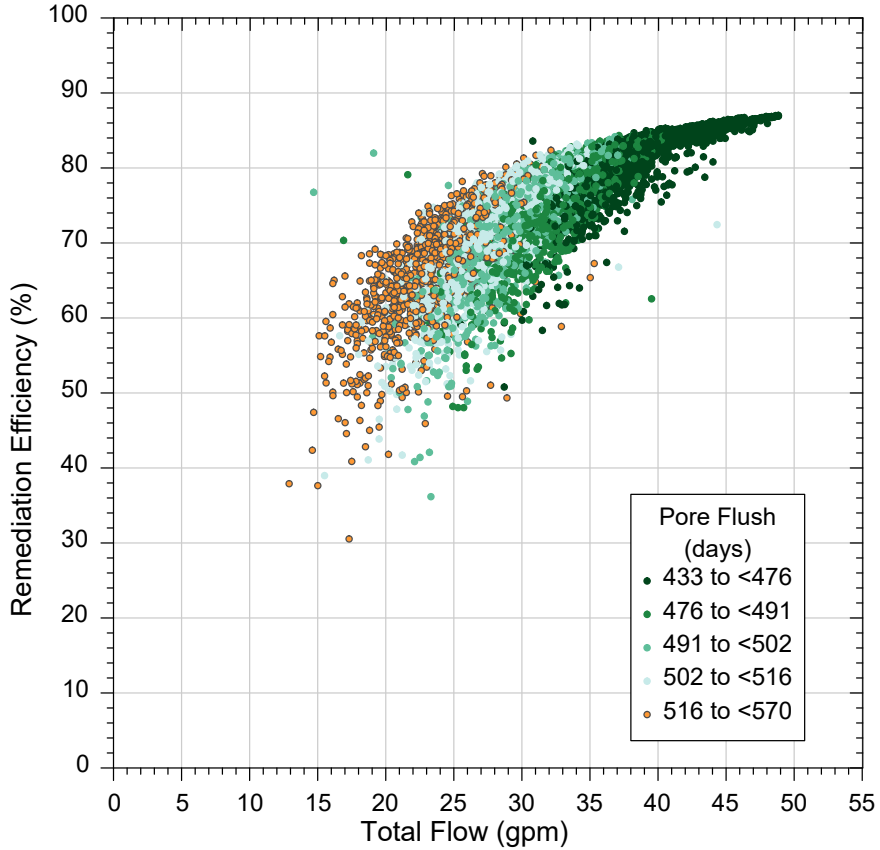


There is a range in outcomes which provide similar levels of performance



Scatter Plot of All Flow Estimates vs. Mass Remediation Ratio

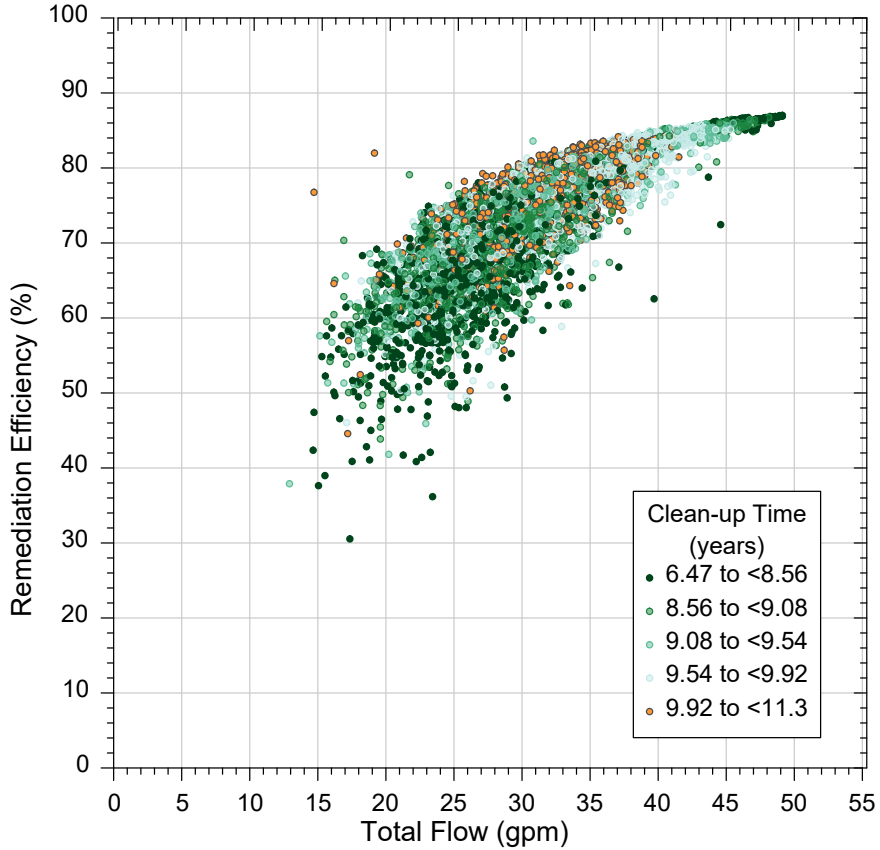
Secondary Performance Metrics



How fast does water move through the plume?

Average Pore Flush (days)

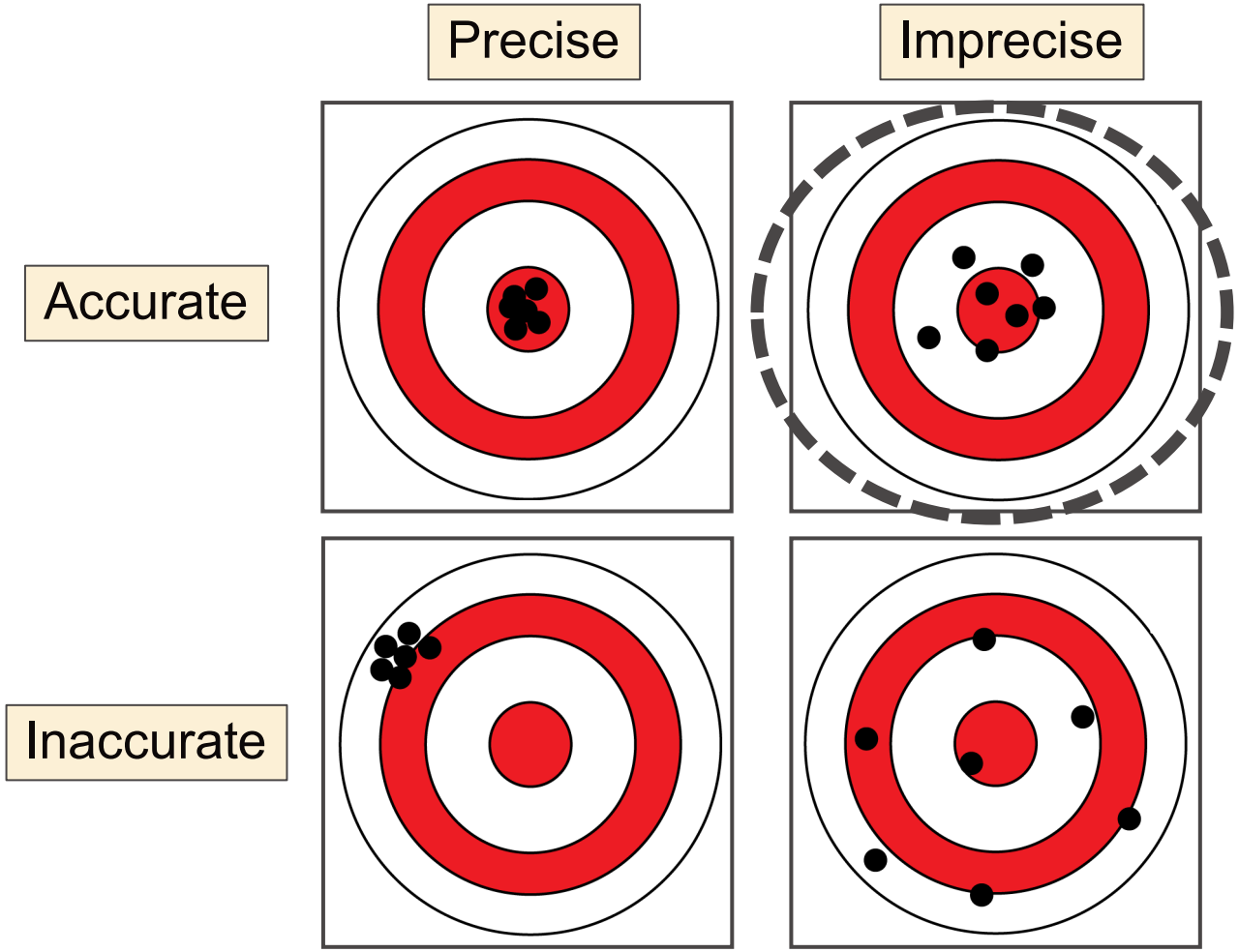
Darker is better



How long will a remedy be effective?

Clean-up Time (years)

Our data will be accurate but imprecise

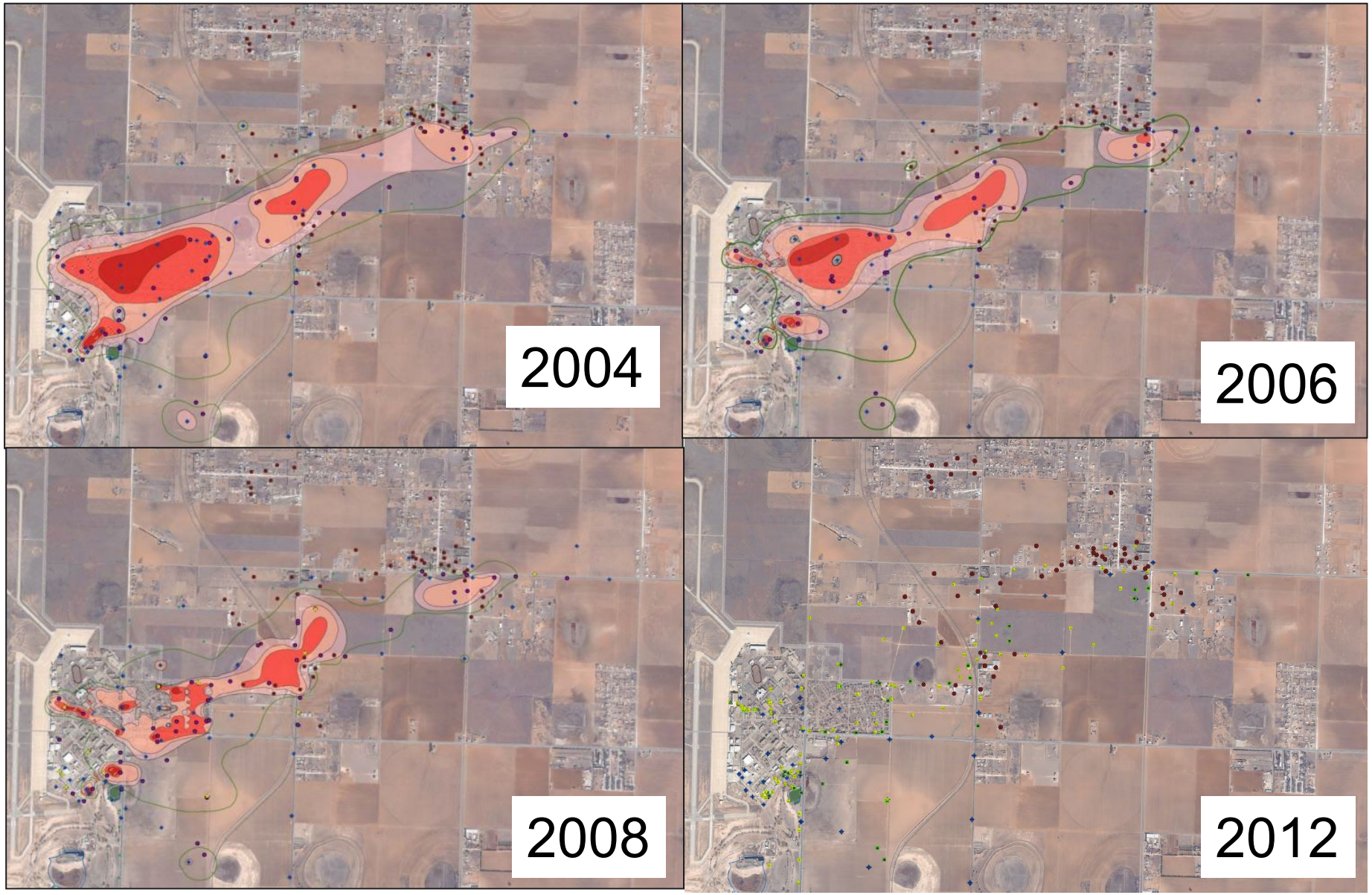


Accuracy refers to how close a measurement is to the actual or correct data value

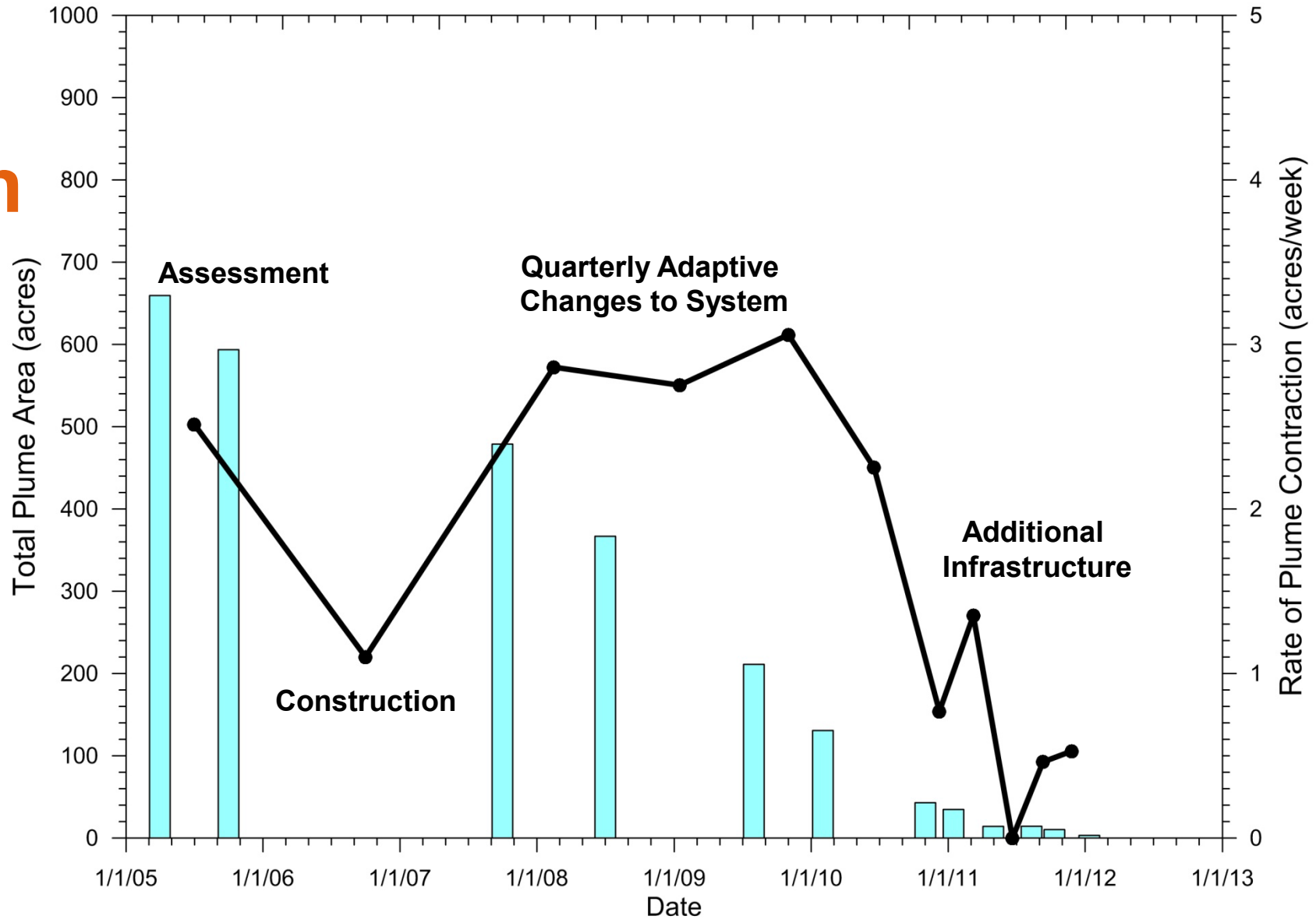
Precision describes how close repeated measurements of data values are to one another

Adapted from *http://www.antarcticglaciers.org/glacial-geology/dating-glacial-sediments-2/precision-and-accuracy-glacial-geology/*

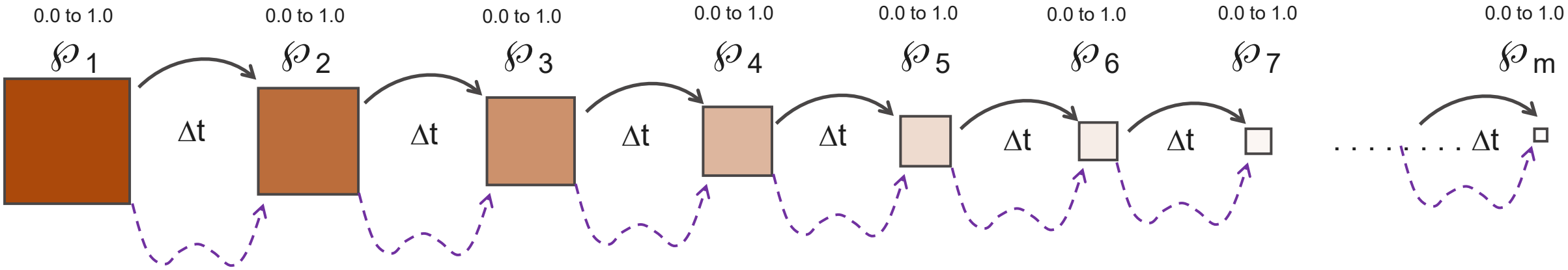
former Reese AFB



Velocity of Remediation



Uncertainty is managed through adaptive change



Successful remediation is a repetitive process of assessment and adjustment

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Thank you

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