Practical Optimization and Uncertainty Analysis for Permeable Reactive Barrier Systems

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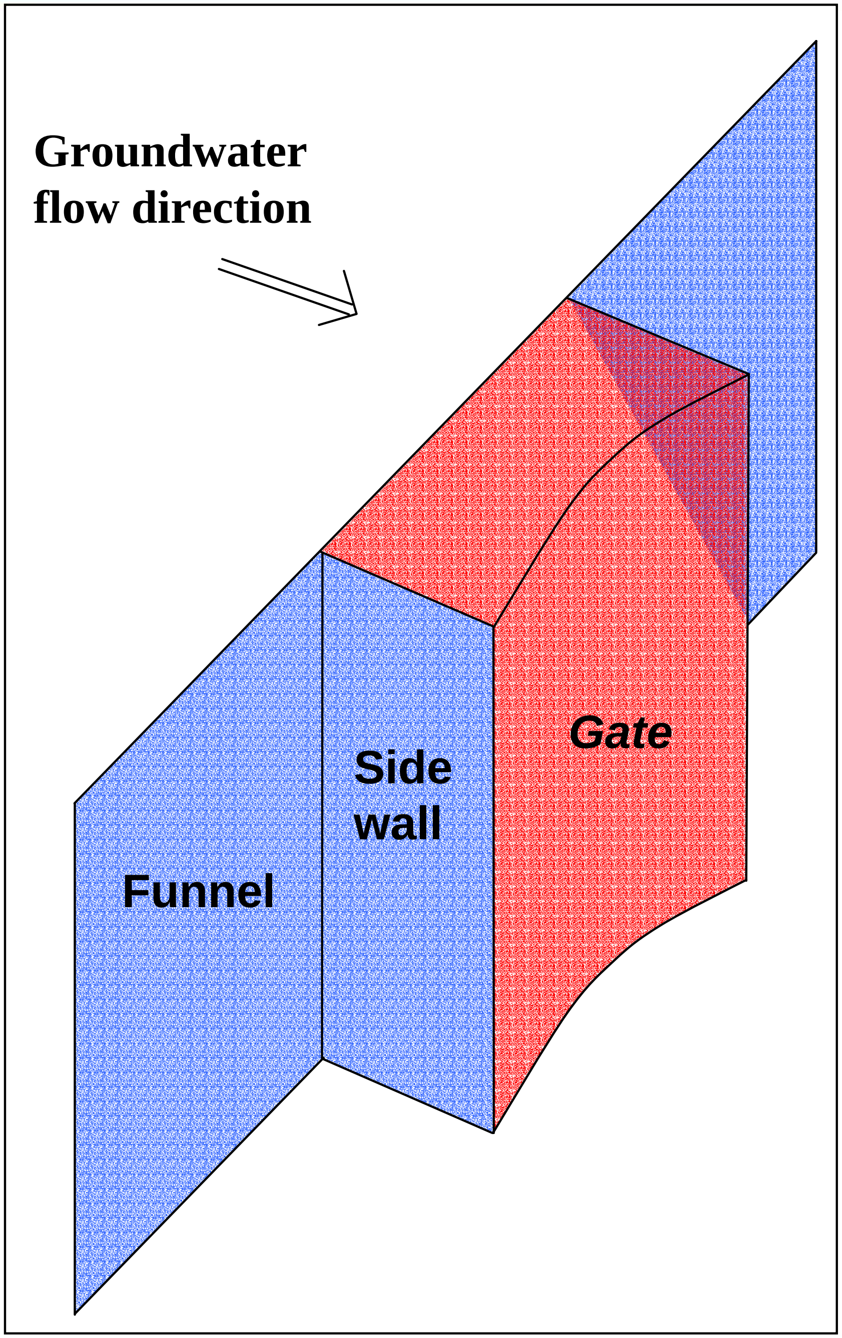
Permeable Reactive Barrier (PRB)

"An emplacement of reactive materials in the subsurface designed to intercept a contaminant plume, provide a flow path through the reactive media, and transform the contaminant(s) into environmentally acceptable forms to attain remediation goals down-gradient of the barrier" (U.S. EPA, 1998).


Groundwater
flow direction
Gate
Side
wall
Funnel

Project Aim

Create an optimal PRB design methodology of practical use to decision-makers, enabling them to explore design options and the effects of user input uncertainty with minimal processing time.

PRB Design Methodology

- Hydraulic Simulation
- Design Optimization
- Uncertainty Analysis

Hydraulic Simulation Aim

Determine functional relationships between PRB design variables and performance measures for fully penetrating PRBs.

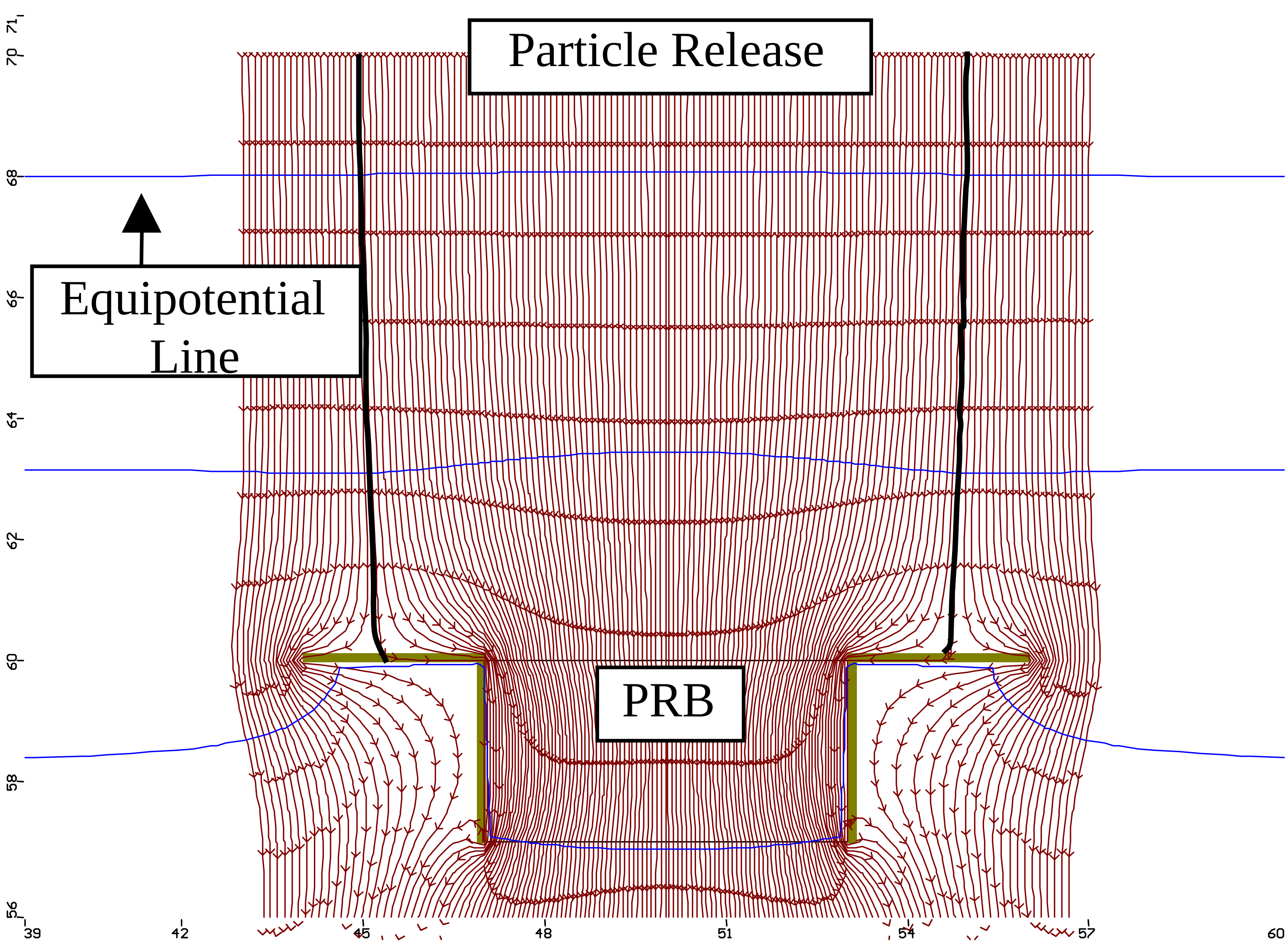
Design Variables:

- Gate width
- Gate length
- Funnel width
- Hydraulic conductivity ratio (gate/aquifer)

Performance Measures:

- Plume capture
- Residence time

Visual MODFLOW Output (Plan View)



Spreadsheet Optimization Model

User Inputs

- Site characteristics
- Costs
- Reactive material mixture characteristics

Output

- Minimum cost PRB design

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Design Optimization using Excel

	Lower		Amount		Upper
Design Variables					
Total funnel width in two equal sections (m)	0.00	<=	20.79	<=	60
Gate width (m)	3.00	<=	3.23	<=	18
Gate length at edge (m)	0.75	<=	3.18	<=	18
Reactive material proportion in gate (-)	0.01	<=	1.00	<=	1
Constraints					
Hydraulic conductivity ratio (PRB / Aquifer)	1.00	<=	1.00	<=	10.00
Gate length/gate width	0.00	<=	0.98	<=	2.00
(Funnel width +gate width)/gate width	0.00	<=	7.43	<=	10.00
Capture (m)	10.00	<=	10.00		
Ave final concentration (g/m^3)	0.00	<=	20.00	<=	20.00
Design Dependent Parameters					
Funnel depth (m)			6.50		
Side wall length (m)			3.18		
Gate depth (m)			6.00		
Gate length at centre (m)			2.64		
Reactive material volume (m^3)			50.150		
Non-reactive material volume (m^3)			6.334		
Objective: MIN PRB Cost =	$362,560.65				Formula

Post-Optimization Analysis

- Sensitivity analysis on optimal solution.
- Verification of chosen PRB design.
- Pilot-scale installation(s).

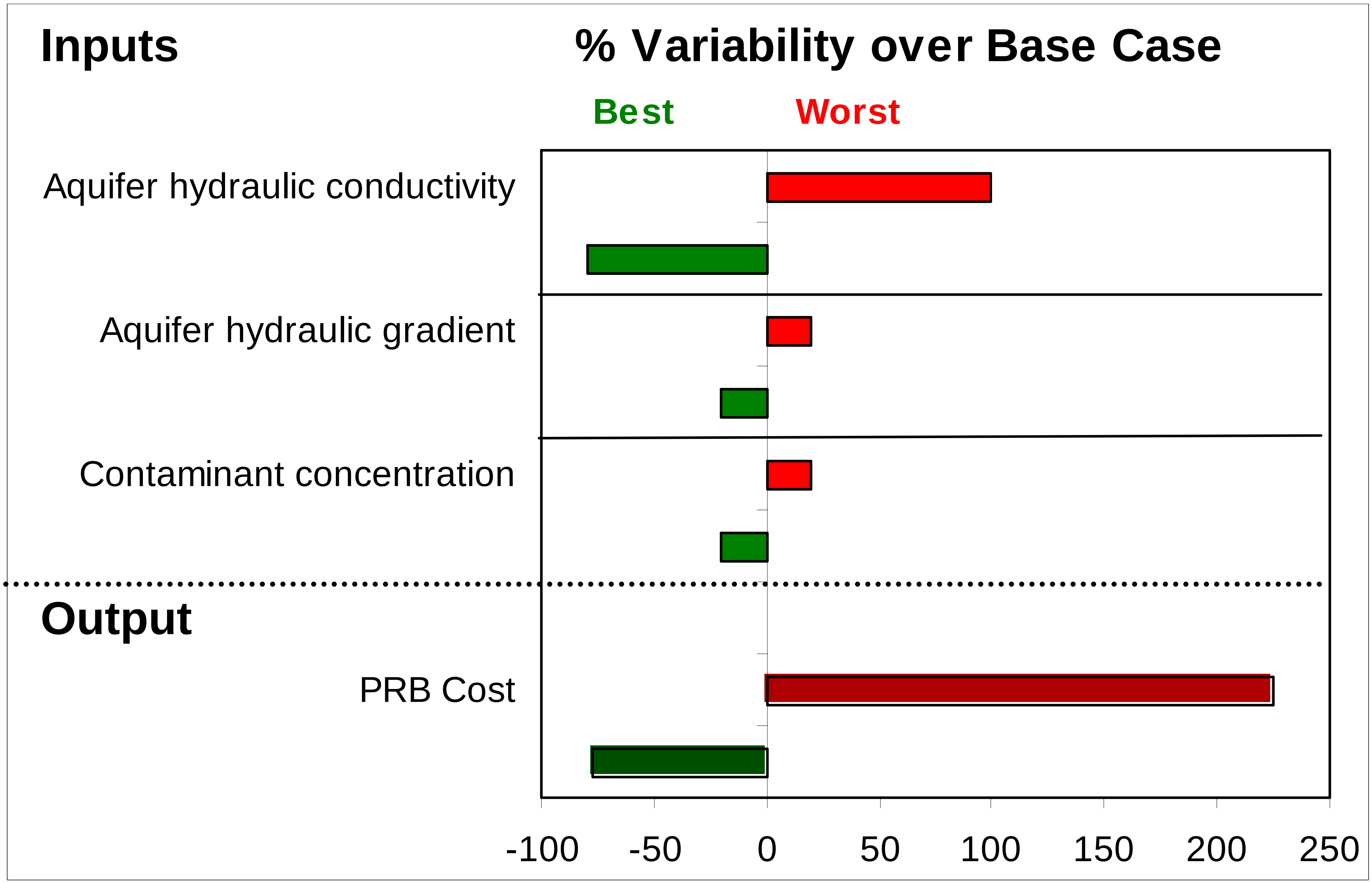
Uncertainty Analysis

Significant natural variation is expected in PRB design, particularly in aquifer and plume characteristics.

1. Scenario Analysis

2. Factorial Analysis

Scenario Analysis Example



Scenario Analysis Conclusions

Advantages

- Can incorporate non-linear effects and interactions between chosen inputs.
- Can be included in cost/benefit analysis regarding further expenditure on site characterization/analysis.

Disadvantage

- The effects of all chosen inputs under investigation are lumped together.

Uncertainty Analysis Options:

2. Factorial Analysis

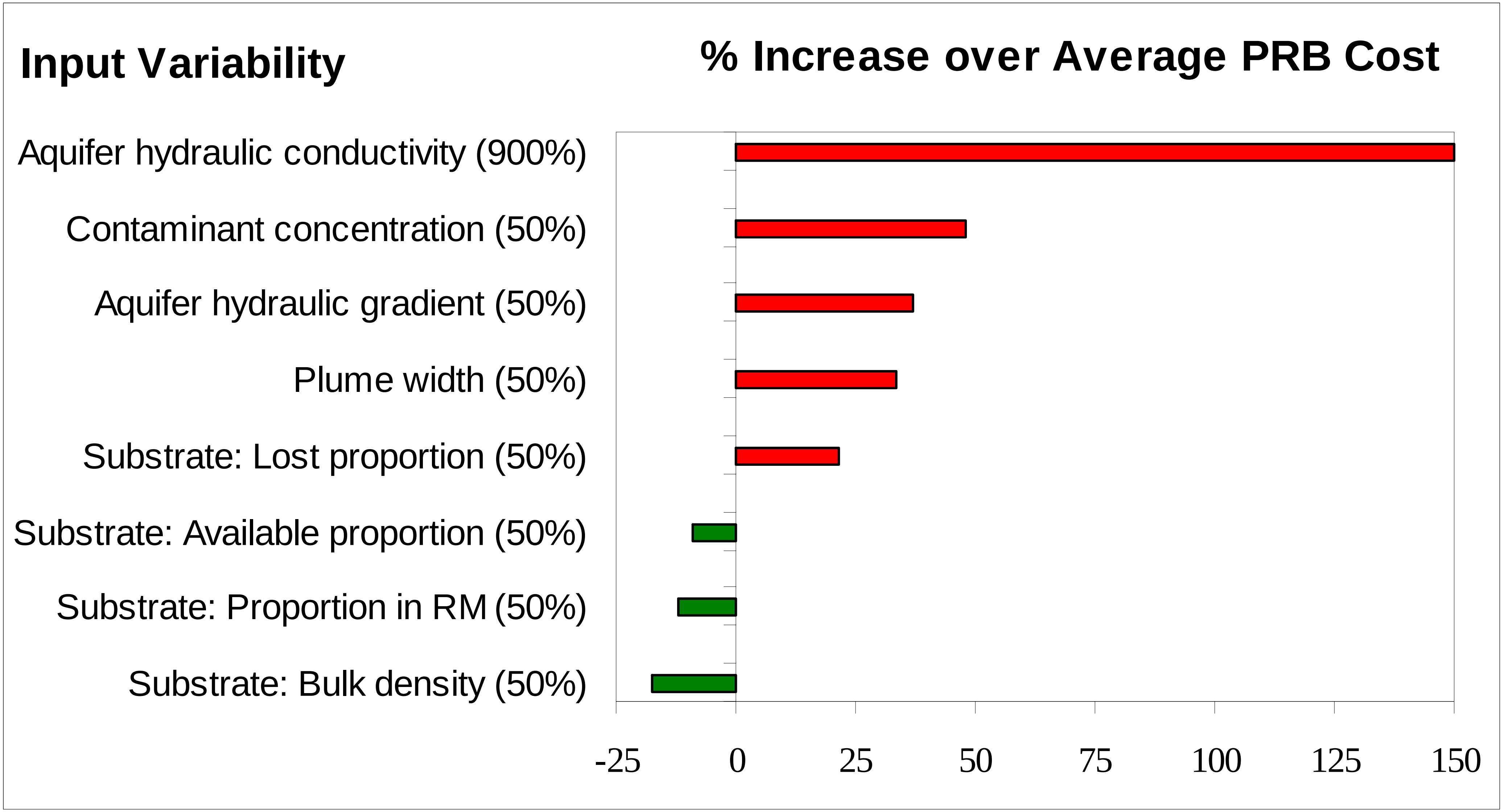
- Screens a set of factors (user inputs) to learn which produce an effect.
- Estimates the magnitude of the main effect of each factor and of the interactions between factors.

Fractional Factorial Analysis

- Selects a particular fraction of experiments to enable the analysis of many factors in an efficient manner.

- Higher order interactions between factors are initially combined, but significant interactions can be separated out with further experiments.

Fractional Factorial Analysis Example



Factorial Analysis Conclusions

- Offers the advantages of scenario analysis plus the effect on PRB cost of variability in any user input or input combination.

- Fractional factorial analysis allows customized analysis of many user inputs in an efficient manner.

Future Research Opportunities

- Further hydraulic modeling and analysis is required to optimize partially penetrating PRB systems.
- Field testing of the accuracy of characterization and construction techniques is required to test the practicality of the proposed methodology.