U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Decision Analysis for EGS

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MIT

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DECISION ANALYSIS FOR EGS

- Timeline
  - Project start date, February 1, 2010
  - Project end date, January 31, 2013
- Budget
  - Total project funding: $ 706,438
  - DOE share: $549,148
  - Awardee share: $ 157,290
  - Funding for FY10: $ 226,905/50,350
- Barriers
  - Obtain actual cost/time information
- Partners
  - None

BACKGROUND AND INTENT

EGS are affected by uncertainties. They affect:

- Development
  - Subsurface 1: Exploration, drilling of wells, stimulation.
  - Surface: Construction of heat to power conversion plant, powerlines, etc.
  - Subsurface 2: Redrilling and restimulation (approximately at 6 year intervals)
- Operation
  - Circulation pumping
  - Plant operation
  - Routine maintenance

DECISION ANALYSIS FOR EGS - OBJECTIVES

DEVELOP ANALYSIS TOOLS TO ASSESS:

- Uncertainties associated with exploration for EGS
- Uncertainties associated with development of EGS
- Uncertainties associated with operation of EGS

Emphasis on subsurface parts of EGS

Use process of decision making under uncertainty, which will make it possible to compare alternatives on the basis of risk.

Develop analysis tools based on existing models developed at MIT, integrate the models into a systems model.

TASK OUTLINE

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1. Fracture Pattern Model for EGS
2. Drill Cost and Time Model Considering Uncertainties
3. Circulation Model for EGS
4. Subsurface Time/Cost Model
5. Exploratory Model for EGS
6. Systems Model

   Combine 1-5 and Technology Transfer

   Enhance Surface Part of Model

TASK 1 FRACTURE PATTERN MODEL

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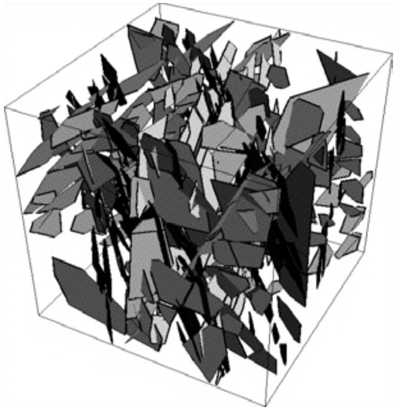
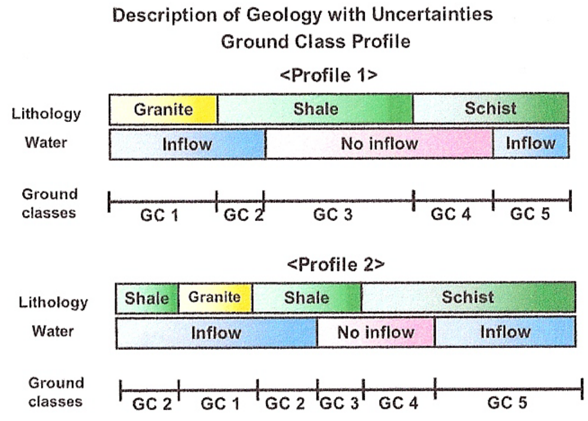
GEOFRAC – Existing Stochastic Fracture Pattern Model

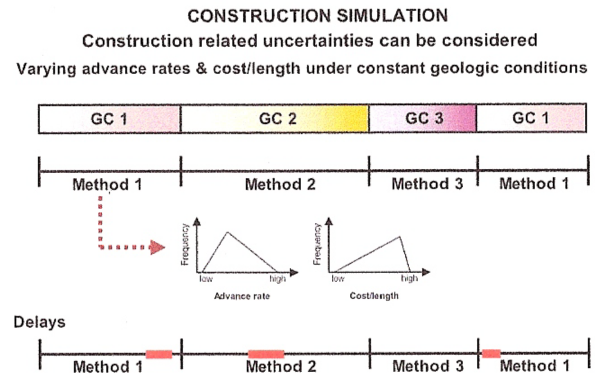


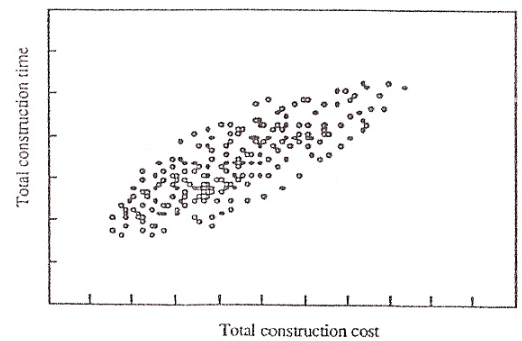
Development: Fracture Aperture

Effect of Stimulation on Fracture Pattern

Decision Aids for Tunnelling (DAT) - Existing Cost/Time Estimation Model







Decision Aids for Tunneling (DAT) Cost-Time Scattergram

Development: Modify Tunnel construction to Drilling
Include Estimation from Well Cost Light
Include Fracture Stimulation

TASK 3 AND TASK 4

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Task 3 Circulation Model for EGS

- Combine Fracture Pattern Model with Simple Flow Model including Uncertainties. (Make flexible enough for further development.)

Task 4 Subsurface Time/Cost Model

- Combine Fracture Pattern and Drilling Model
- Combine with Circulation Model
- Initial consideration of Heat to Power Conversion to get Cost/Revenue Estimates

TASK 5 AND TASK 6

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Task 5 DATE - Decision Aids for Tunnel Exploration – Existing Tunnel Exploration Model

DATE Conducts "Virtual exploration" - expressed in a simplified manner:

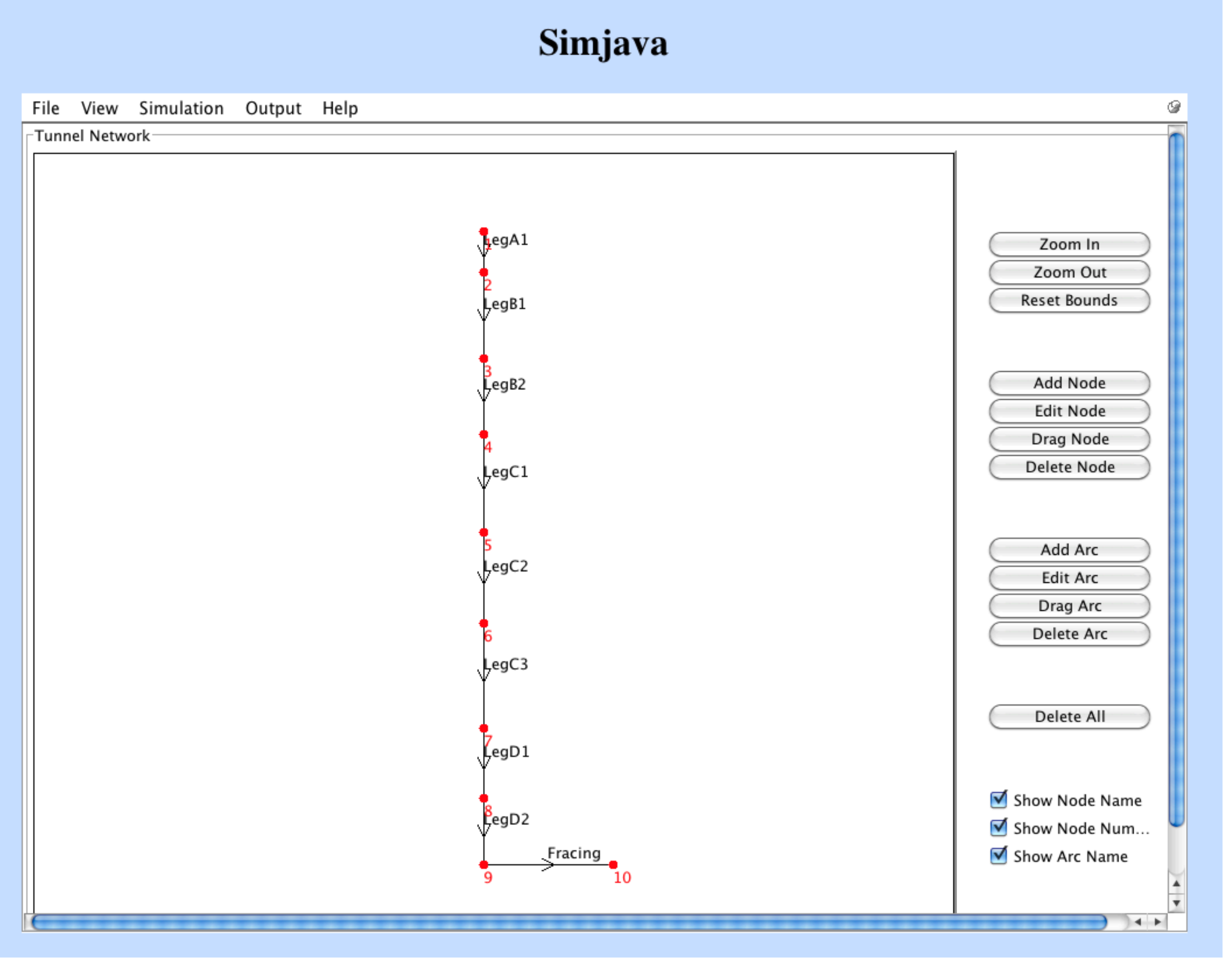
- Given knowledge of existing geology with its uncertainties
- Virtual exploration (e.g. a boring) with uncertainties (exploration reliability)
- Update knowledge of geology (updated uncertainty)
- Estimate EGS cost with updated geology
- Compare original and updated cost to determine if exploration is worthwhile

Development:

- Extend to multiple exploration
- Extend to EGS Exploration

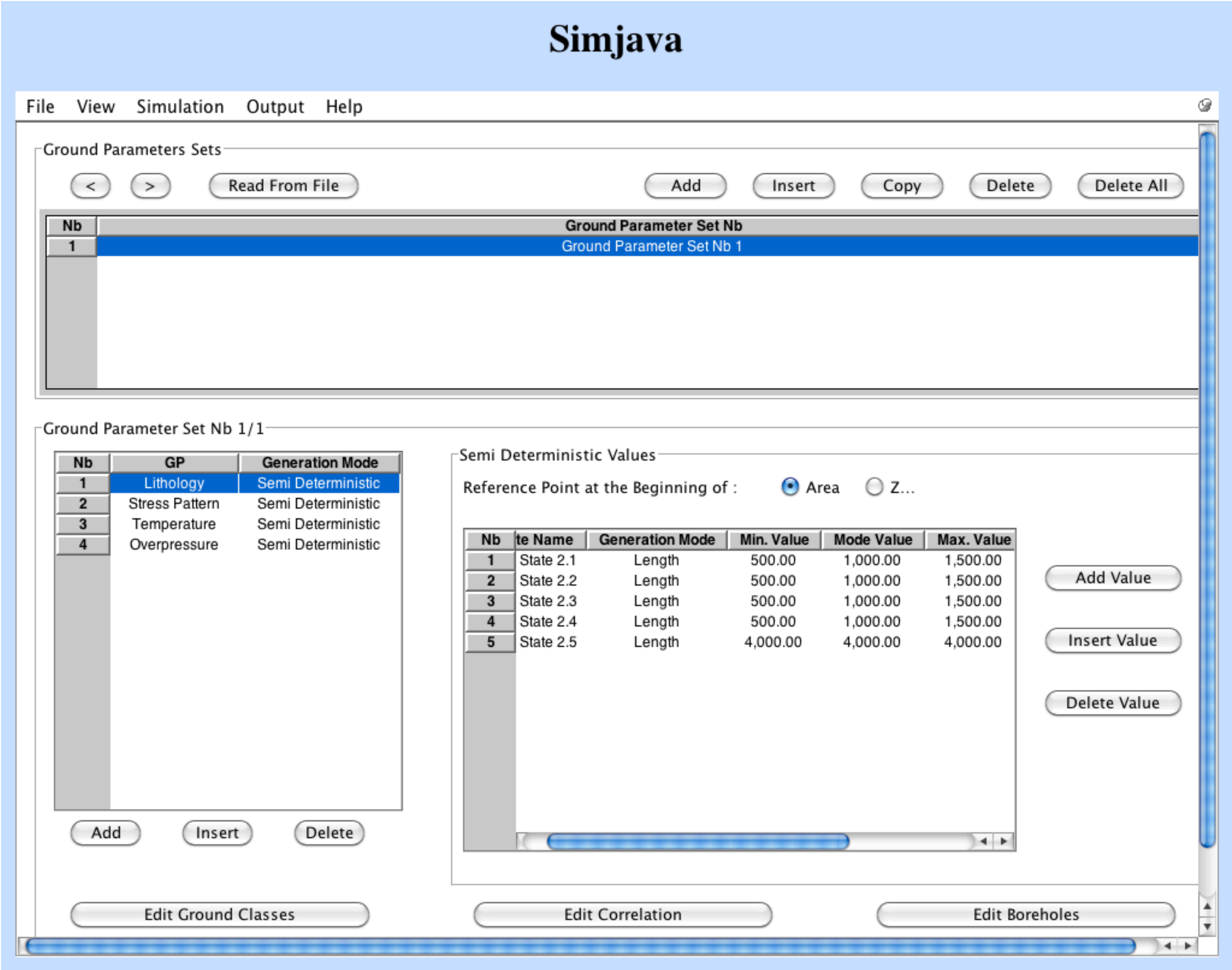
TASK 6 - COMPLETE SYSTEMS MODEL

Well Network



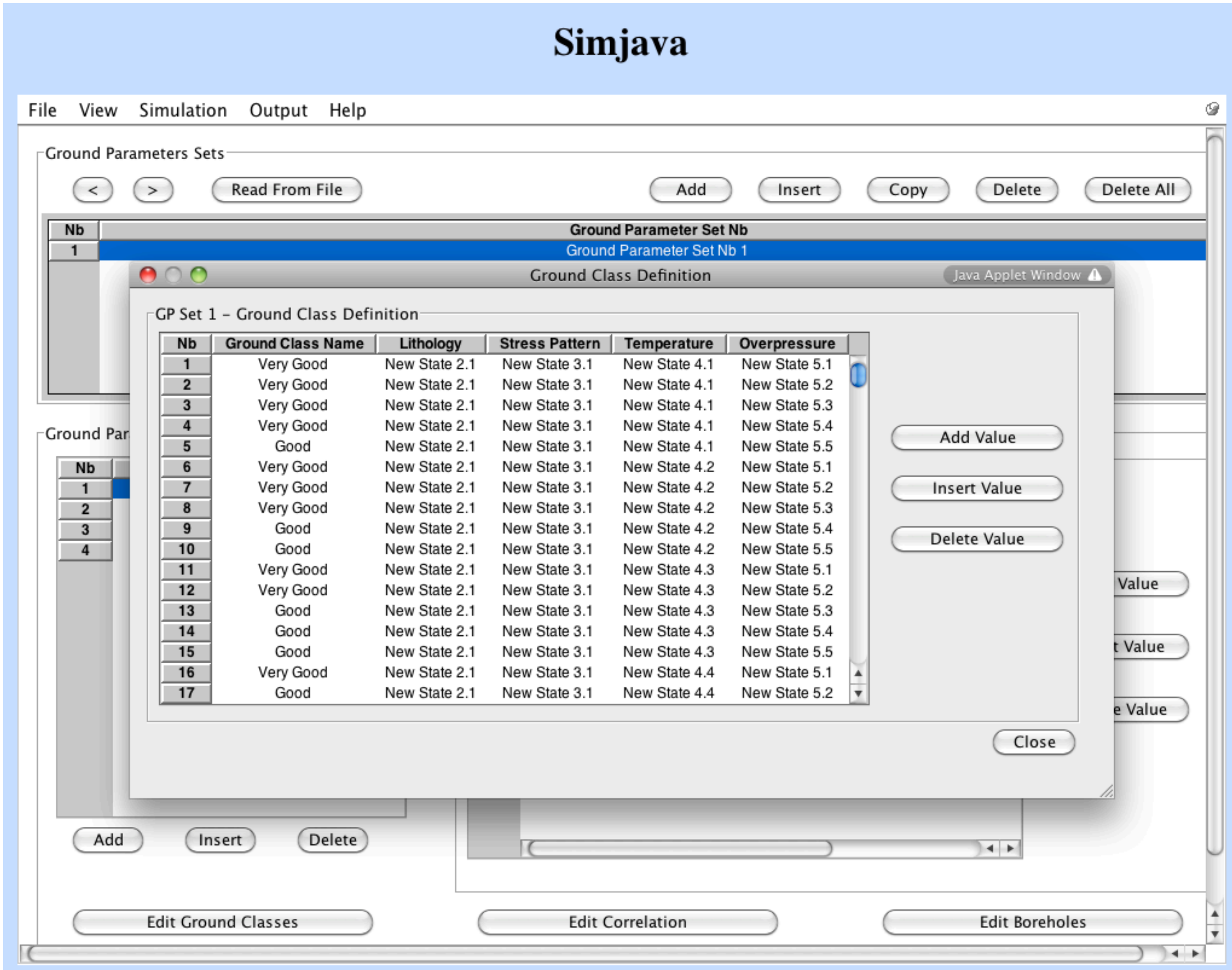
The well (tunnel) network used in this example has nine legs, eight corresponding to drilling activities, and a final ninth corresponding to hydraulic fracturing.

Ground Parameter Generation



The distribution of parameter states along the well is generated independently for each parameter (there is currently no cross-correlation assumed between lithology and stress pattern states, for example). In this example, it is assumed that alongthe length the parameter state transitions from state 1 to state 2, and so on sequentially to state 5, with the length of each parameter state defined by a triangular distribution of extremes at 500m and 1500m and mode of 1000m.

Ground Class Definitions



Each possible set of ground parameter states corresponds to one of five ground classes.

Structure Variables

Simjava

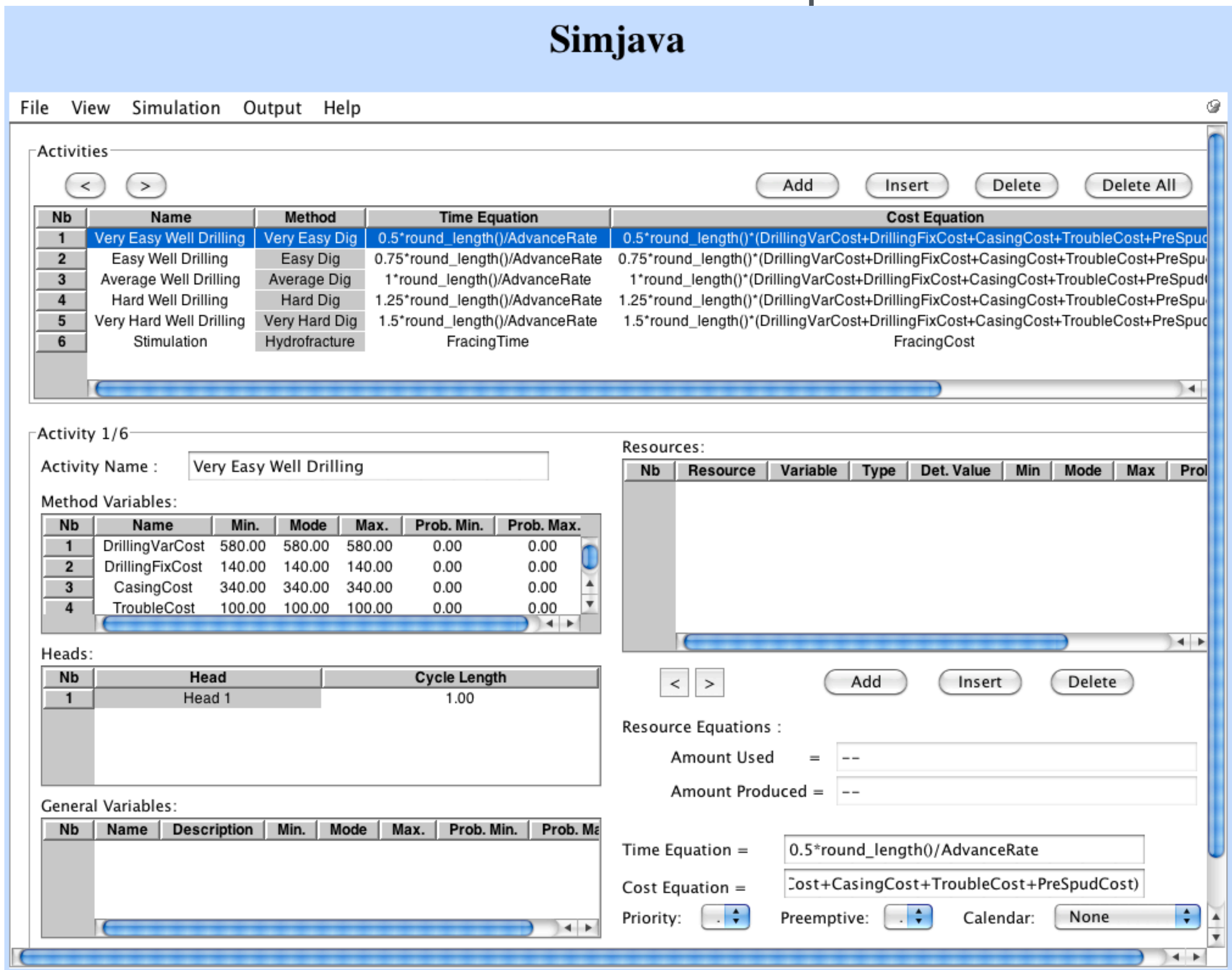
File View Simulation Output Help

Structure Variables

Nb	Name	Tunnel	Min.	Mode	Max.	Prob. Min.	Prob. Max.
1	Diameter	LegA1	28.00	28.00	28.00	0.00	0.00
2	Depth	LegA1	190.00	190.00	190.00	0.00	0.00
3	Diameter	LegB1	20.00	20.00	20.00	0.00	0.00
4	Depth	LegB1	690.00	690.00	690.00	0.00	0.00
5	Diameter	LegB2	20.00	20.00	20.00	0.00	0.00
6	Depth	LegB2	1,262.00	1,262.00	1,262.00	0.00	0.00
7	Diameter	LegC1	14.75	14.75	14.75	0.00	0.00
8	Depth	LegC1	1,977.00	1,977.00	1,977.00	0.00	0.00
9	Diameter	LegC2	14.75	14.75	14.75	0.00	0.00
10	Depth	LegC2	2,800.00	2,800.00	2,800.00	0.00	0.00
11	Diameter	LegC3	14.75	14.75	14.75	0.00	0.00
12	Depth	LegC3	3,600.00	3,600.00	3,600.00	0.00	0.00
13	Diameter	LegD1	10.38	10.38	10.38	0.00	0.00
14	Depth	LegD1	4,250.00	4,250.00	4,250.00	0.00	0.00
15	Diameter	LegD2	10.38	10.38	10.38	0.00	0.00
16	Depth	LegD2	4,750.00	4,750.00	4,750.00	0.00	0.00
17	Permeability	Fracing	1.00	2.00	3.00	0.00	0.00
18	Porosity	Fracing	1.00	2.00	3.00	0.00	0.00
19	Thermal Output	Fracing	1.00	2.00	3.00	0.00	0.00

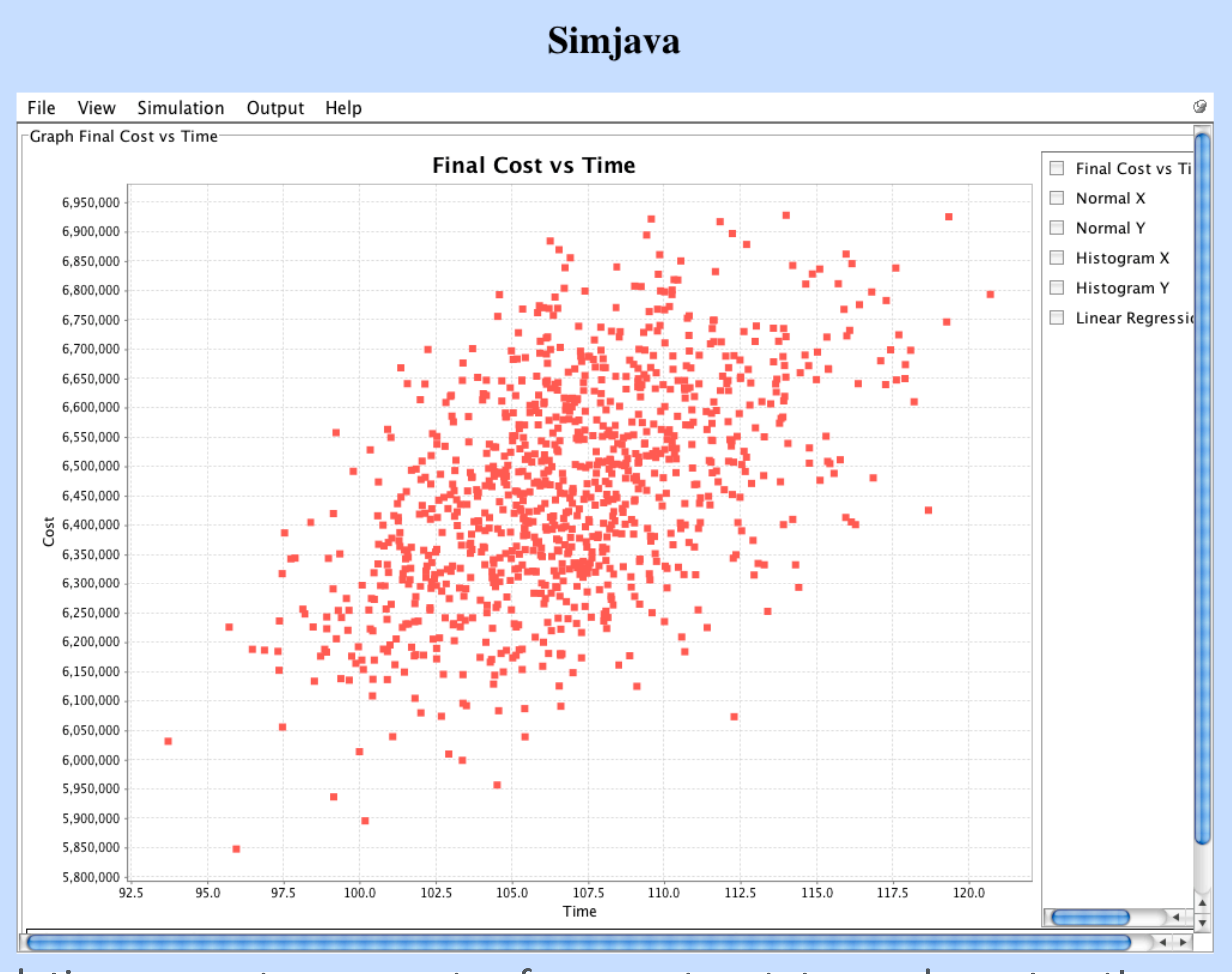
These are the average depths (midpoints) of each drilling segment, and the drilling diameter along the segment. These segments have a total length of 5km, and represent four distinct casing strings

Method Cost and Time Equations



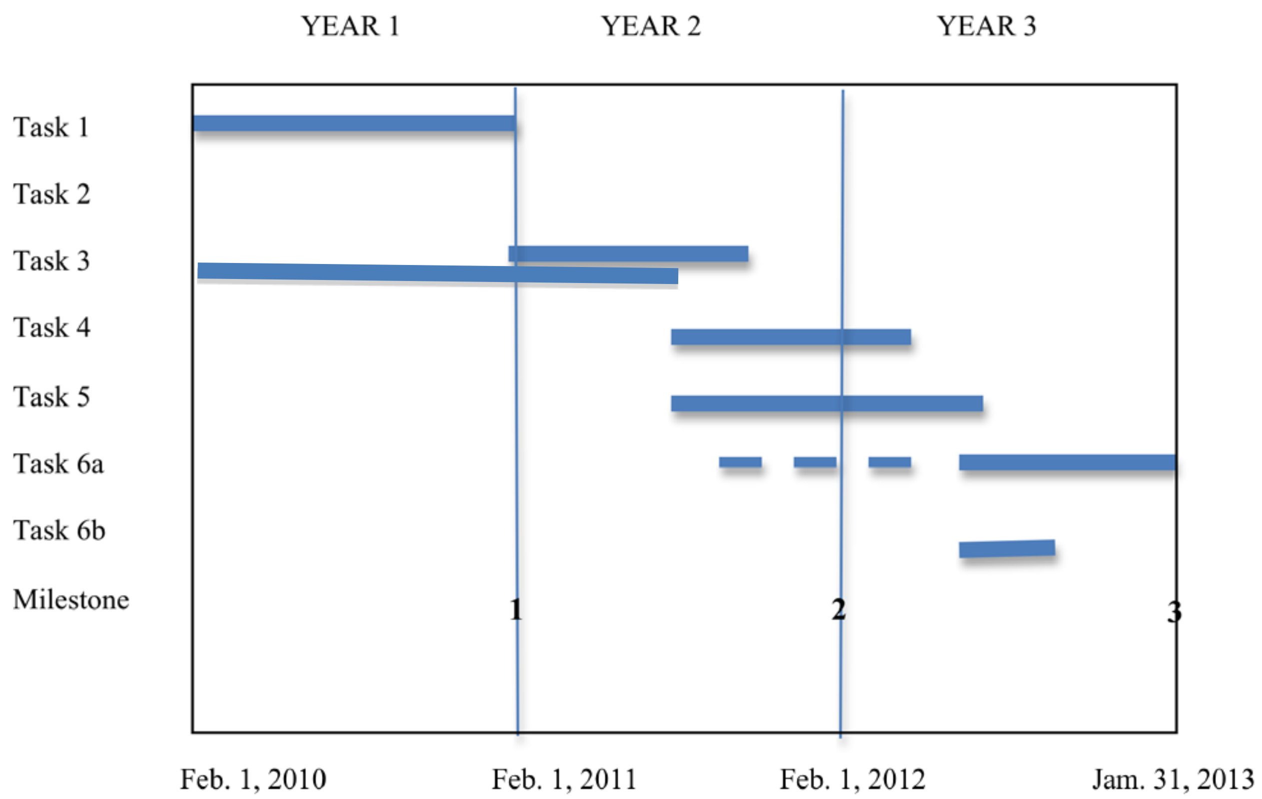
Method variables are used in a cost equation and schedule equation to evaluate the cost and time required to perform a "method" across the length of a segment.

Cost and Time Simulations



Each simulation generates new sets of parameter states and construction cost/schedule variations, and a group of simulations can be graphed as a scattergram.

Planned Schedule



Summary and Assessment

Summary:

Work was started Feb. 1, 2010 with one RA.

Progress on Task 2 as expected (actually somewhat faster than anticipated).

Work on Task 1 will start in May with Postdoctoral Associate

Assessment:

Given the effect of uncertainties on EGS, the research is very relevant.

- A systematic approach including available tools is being used.
- Progress as planned.

UNCERTAINTIES IN DEVELOPMENT

Subsurface 1

Prior to exploration
- estimates on geologic and temperature profile
- financing and taxation
- permitting for exploration
- placement of exploration wells

Exploration
- drill time/cost (random and major event uncertainties)
- interpretation and extrapolation of geology, particularly of fractures and of temperature profile

Stimulation
- well drill time/cost
- major incidents
- created fracture pattern
- (fracture) flow
- additional well placement

UNCERTAINTIES IN DEVELOPMENT (continued)

Surface

Plant design
- depends on temperature level of circulation medium, which is affected by many of the uncertainties mentioned above
- permitting
- financing
- environmental issues

Plant construction
- uncertain site conditions
- material and labor cost

Subsurface 2
- analogous to Subsurface 1 but exploration mostly replaced by interpretation of circulation; this interpretation is the basis for restimulation
- operation with associated uncertainties

UNCERTAINTIES IN OPERATION

Circulation
- Water loss
- Temperature decrease (rate)
- Scaling of fractures and well
- Mineralization/demineralization of water

Plant Operation
- Effect of changes in circulating water (see above)
- Random variability of operation
- Occurrence of major interruptions
- Labor and replacement material cost

Maintenance
- Labor and material cost
- Regulatory requirements

Supplemental Slides

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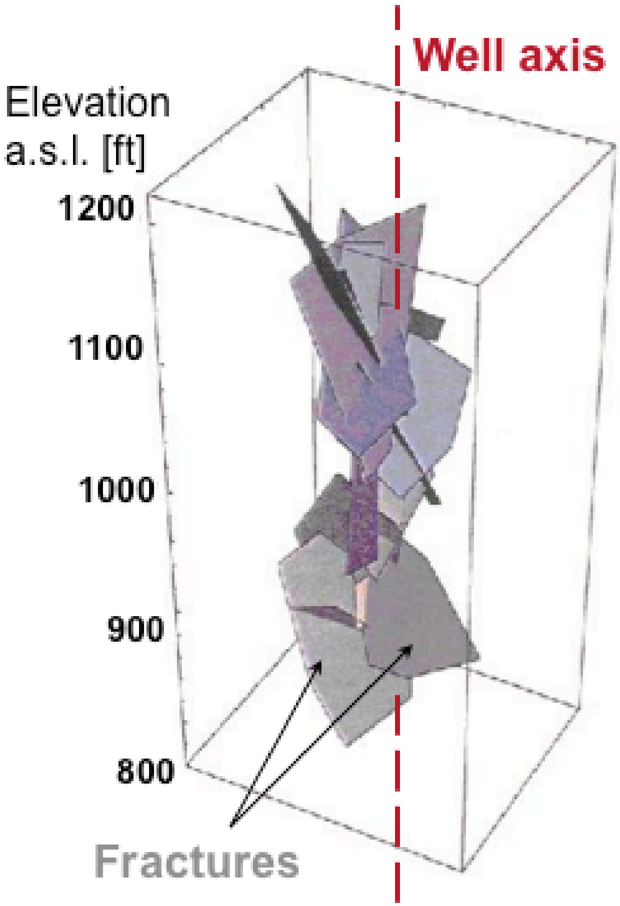
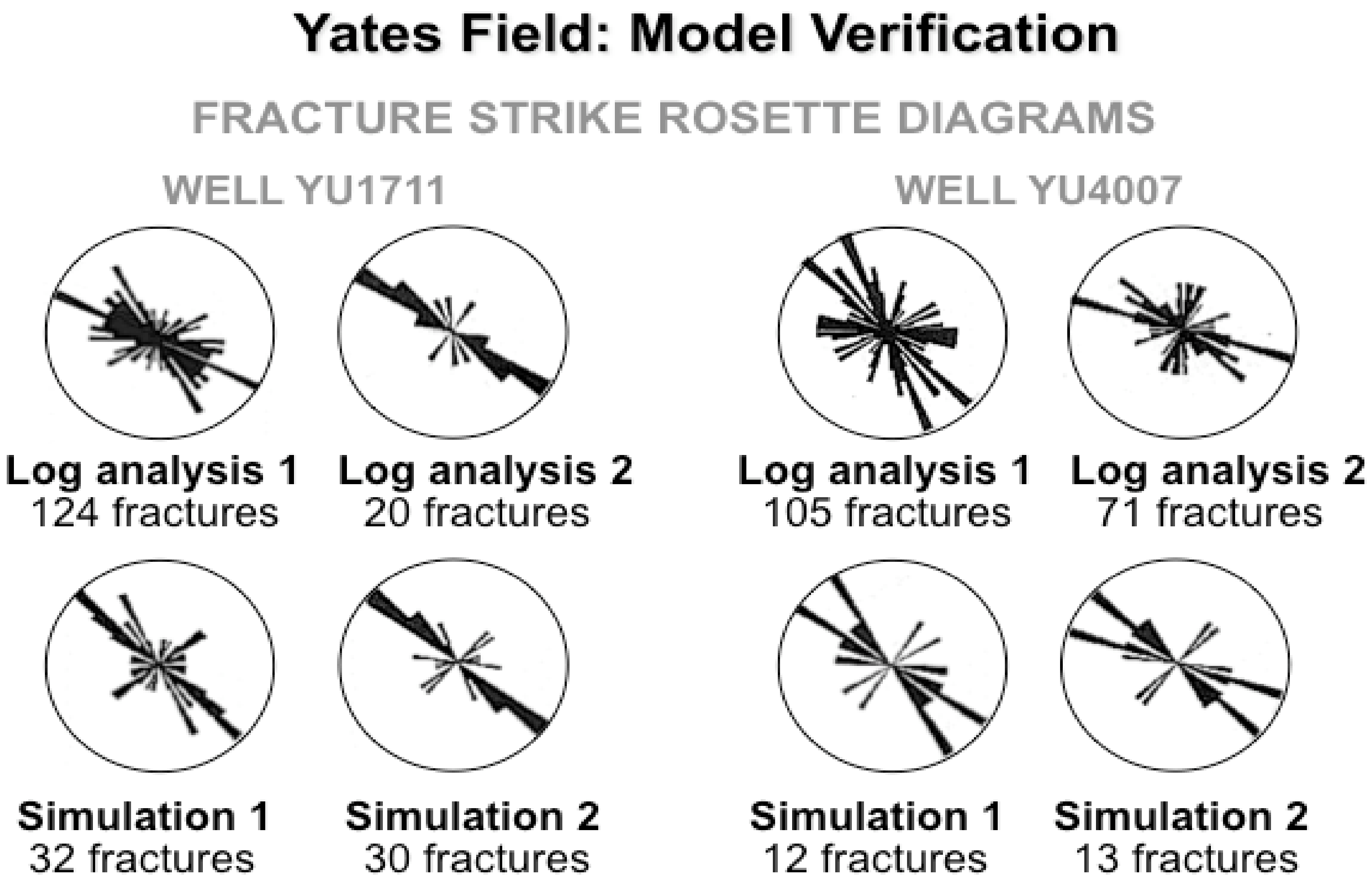
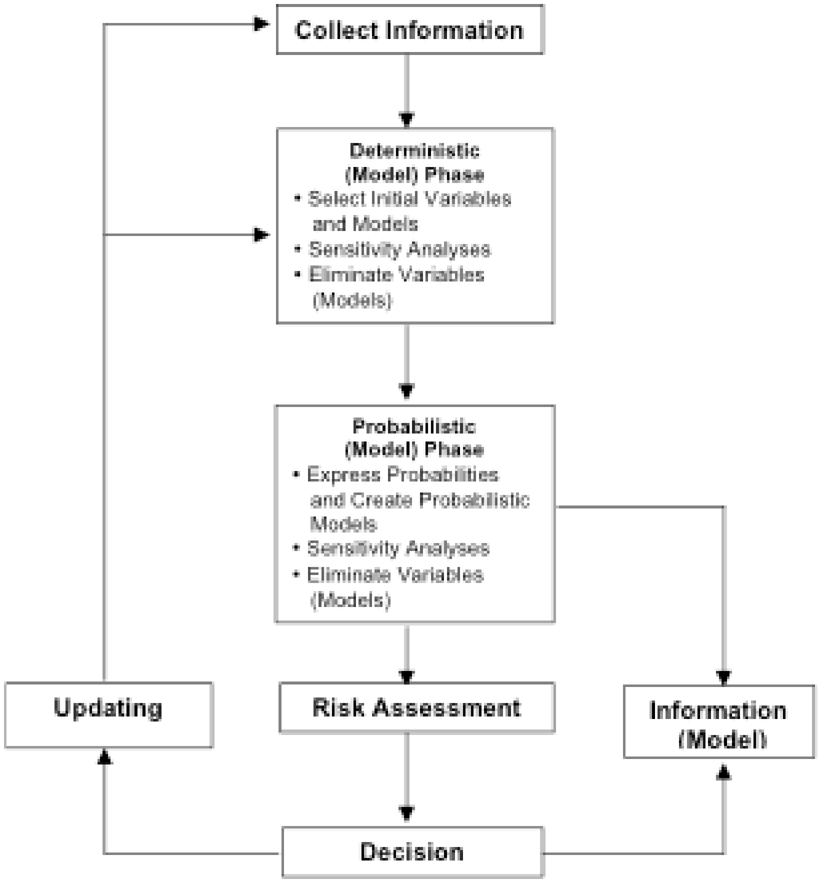
Yates Field: Fracture Simulations

WELL	L[ft]	SIMULATION		SIMULATED WELL		
		N	P_{32}[ft^{-1}]	S_{ave}[ft]	σ_s[ft]	N
TRACT 17: E[P_{32}]=0.8 ft^2/ft^3, E[R_e]=30 ft						
YU1711	250	52995 53865 52456	0.787 0.837 0.780	7.95 8.06 7.51	7.59 12.29 8.51	32 30 33
YU1755	300	49776	0.821	7.24	10.65	41
YU17D5	1500	77743	0.806	2.23	2.49	672
TRACT 49: E[P_{32}]=0.6 ft^2/ft^3, E[R_e]=30 ft						
YU4007	150	48273 43844 45684	0.600 0.584 0.594	9.68 7.41 7.42	10.04 6.45 7.45	12 13 17
YU4903	200	50321	0.592	8.34	8.55	24
YU5127	200	49106	0.589	10.64	10.64	19




Yates Field: Model Verification
FRACTURE STRIKE ROSETTE DIAGRAMS
WELL YU1711
WELL YU4007
Log analysis 1
124 fractures
Log analysis 2
20 fractures
Log analysis 1
105 fractures
Log analysis 2
71 fractures
Simulation 1
32 fractures
Simulation 2
30 fractures
Simulation 1
12 fractures
Simulation 2
13 fractures

Supplemental Slides



Decision Analysis Cycle

Supplemental Slides

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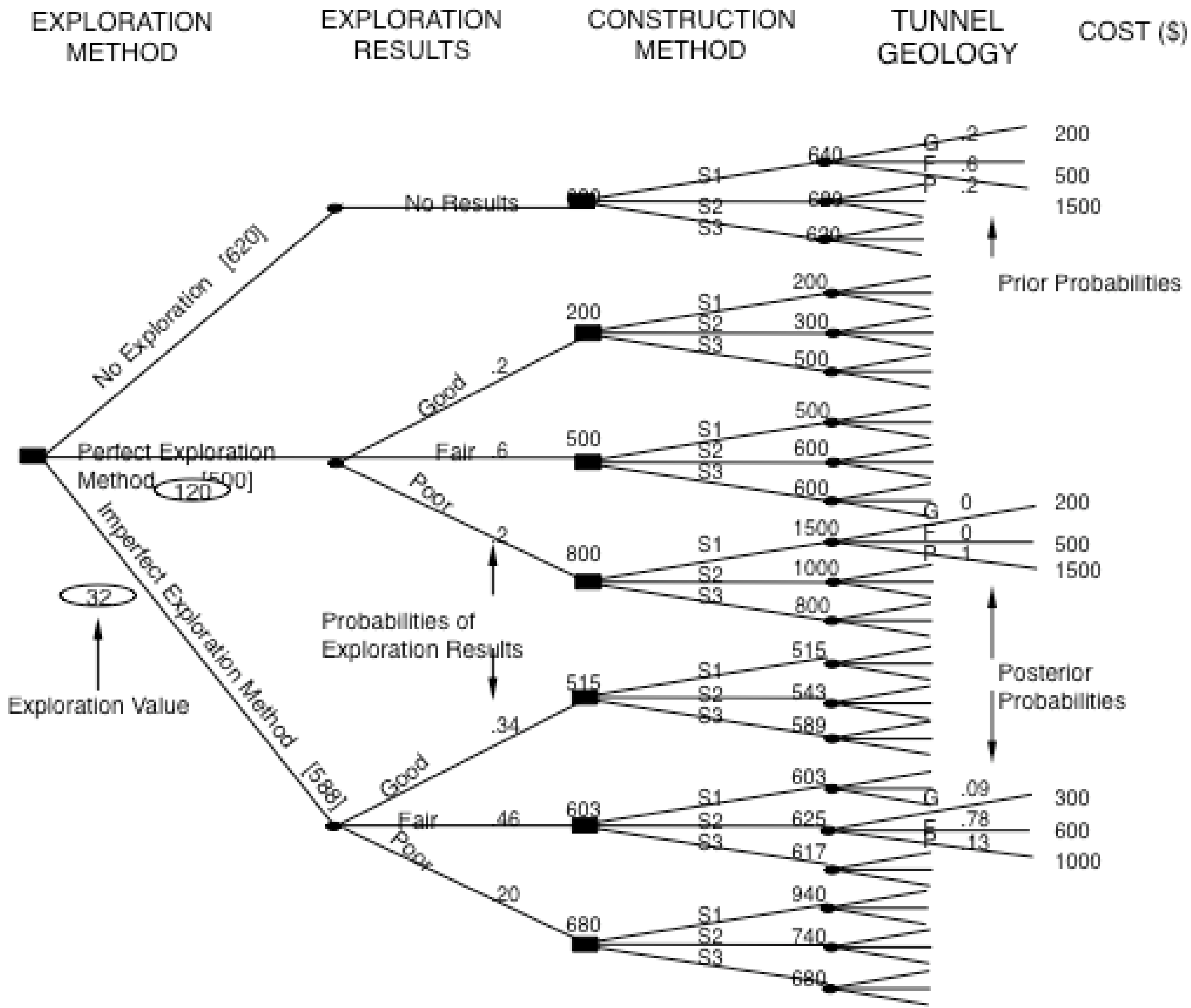
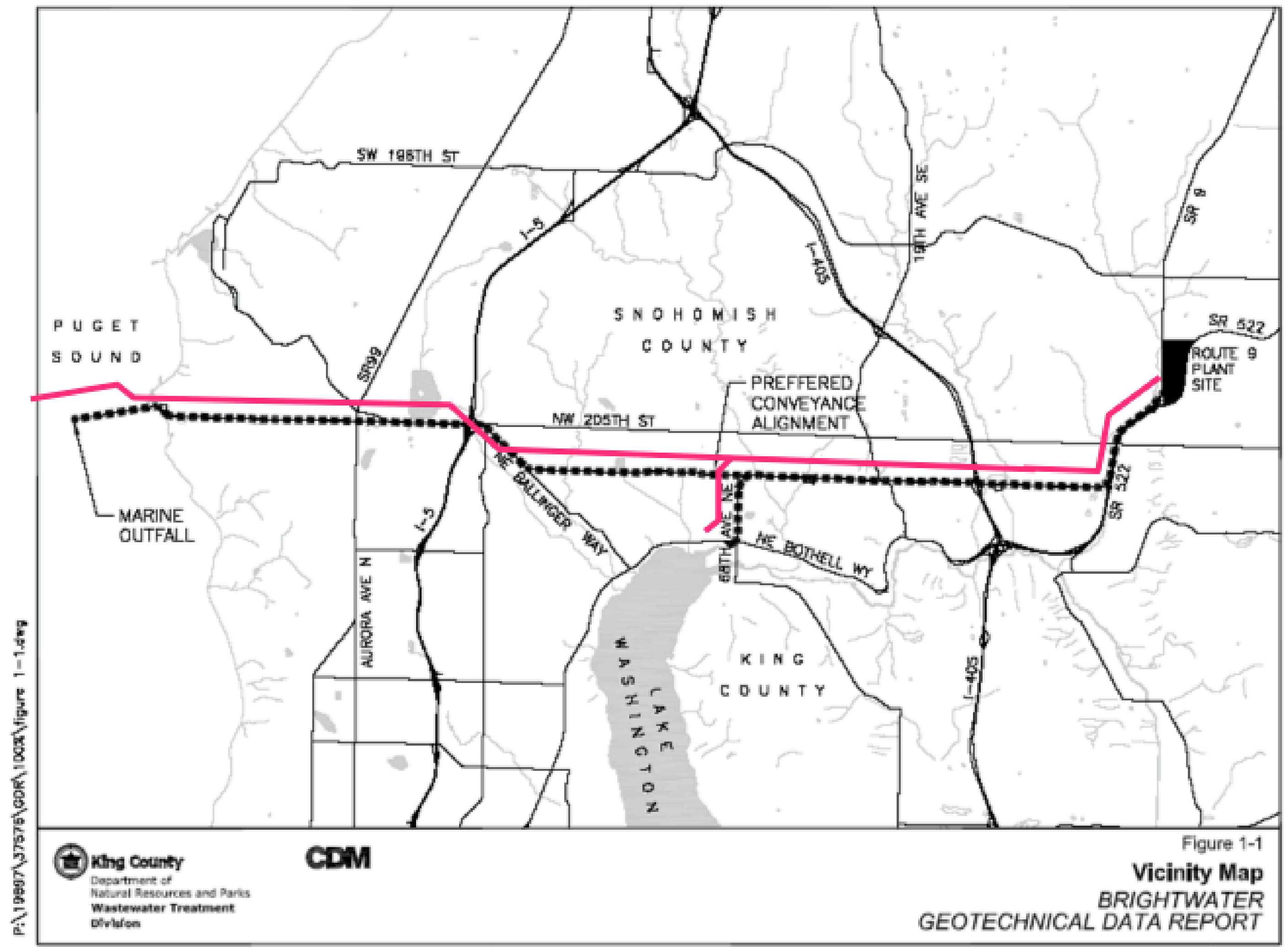
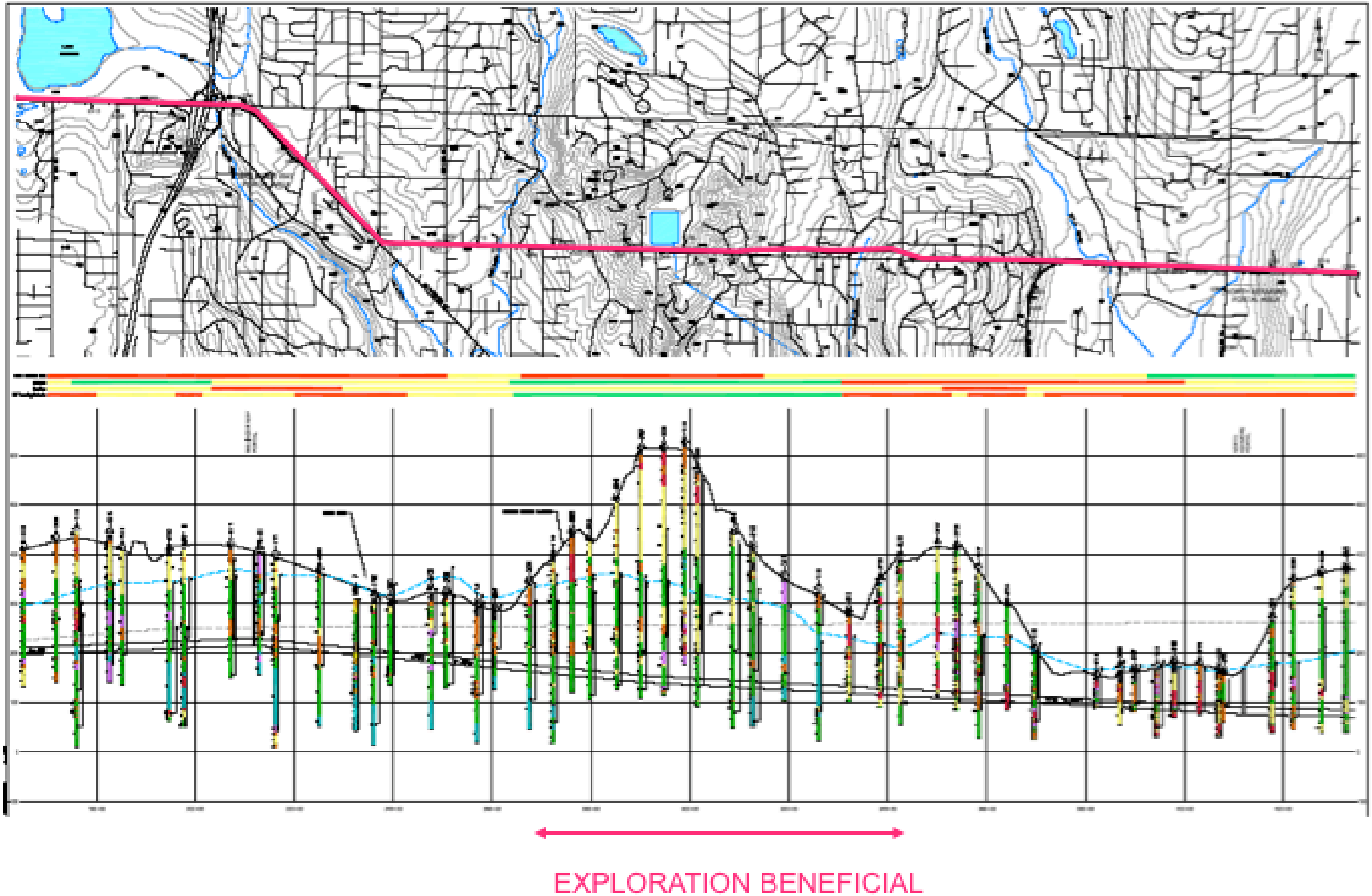


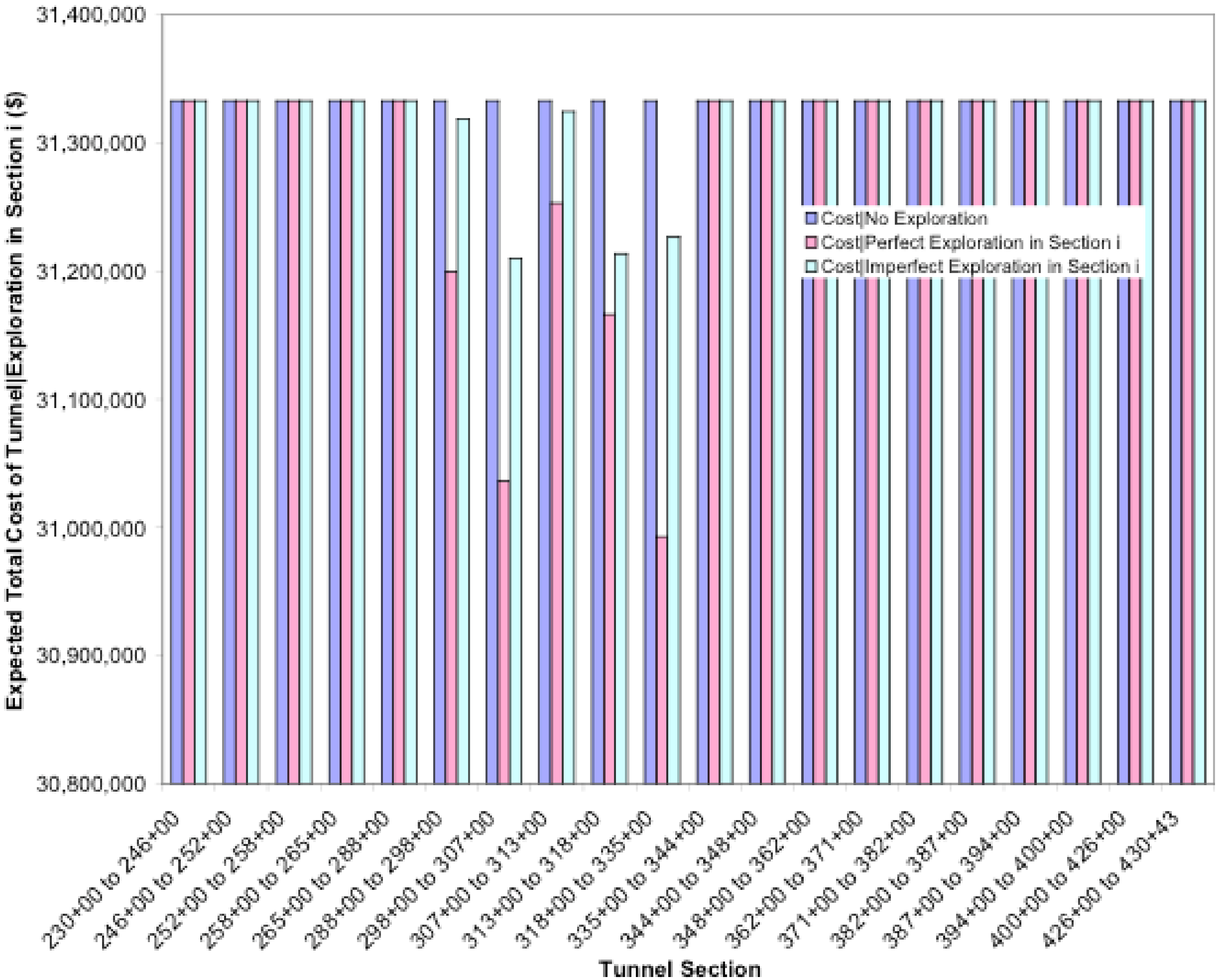
"Virtual Exploration" - Exploration Decision Tree

BRIGHTWATER CONVEYANCE SYSTEM





BRIGHTWATER CONVEYANCE



BRIGHTWATER CONVEYANCE

Tunnel Cost/Section with No Exploration, Imperfect Exploration, Perfect Exploration

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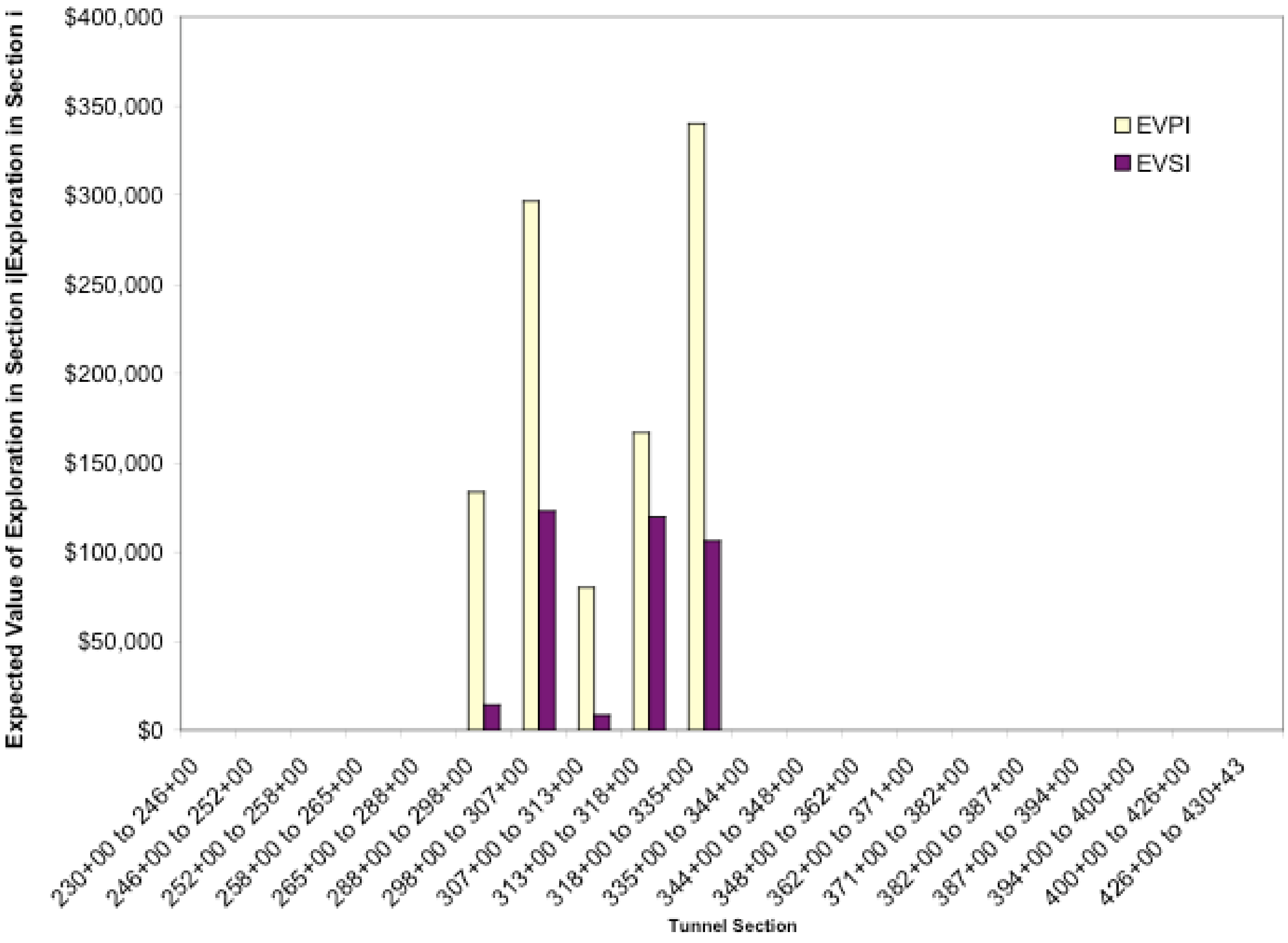

BRIGHTWATER CONVEYANCE

Expected Value of Perfect/ Sample Information