



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

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

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.

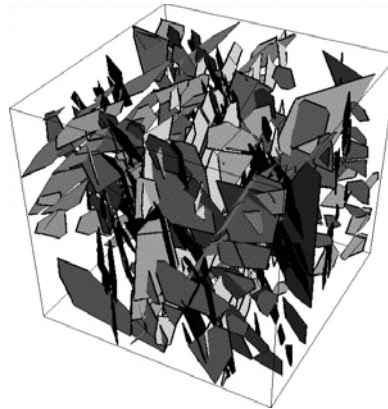
Develop analysis tools based on existing models developed at MIT, integrate the models into a systems model.

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

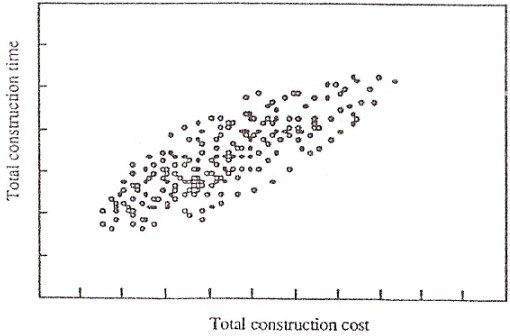
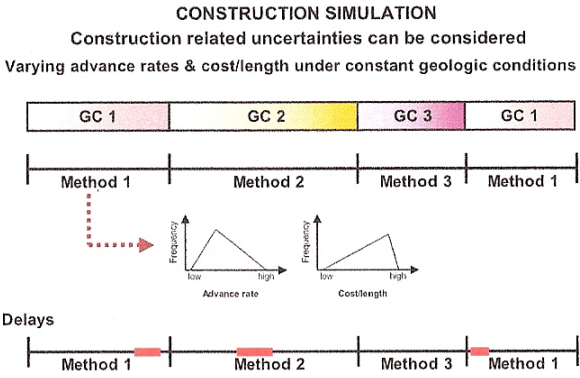
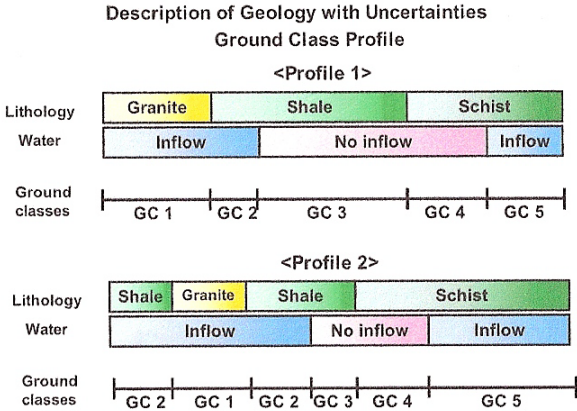
Enhance Surface Part of Model

GEOFRAC – Existing Stochastic Fracture Pattern Model



Development: Fracture Aperture

Effect of Stimulation on Fracture Pattern



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 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 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

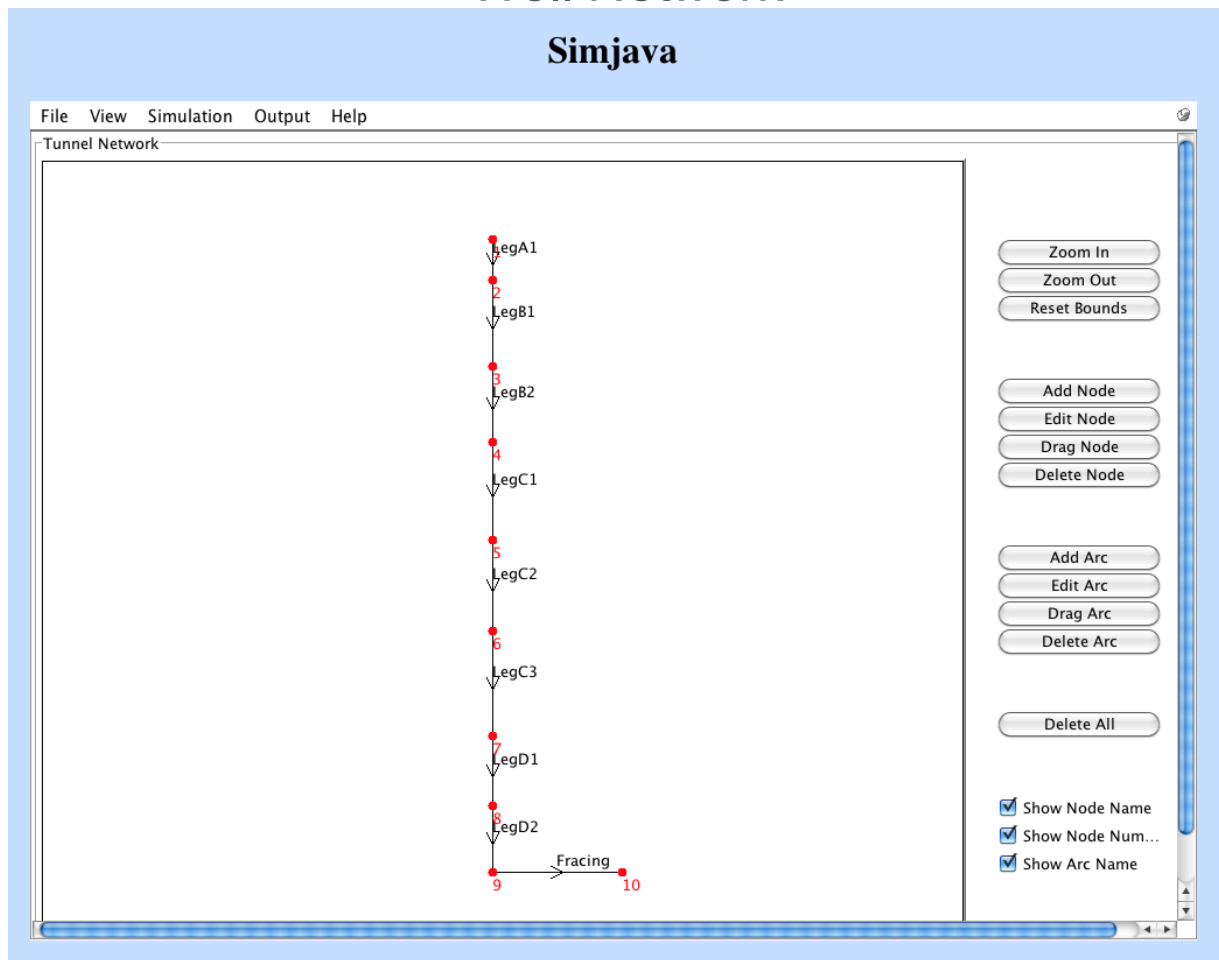
TASK 6 - COMPLETE SYSTEMS MODEL

TASK 1 DRILL COST/TIME MODEL WITH UNCERTAINTY

INITIAL RESULTS

Well Network

Simjava



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

TASK 2 DRILL COST/TIME MODEL WITH UNCERTAINTY

INITIAL RESULTS

Ground Parameter Generation

The screenshot shows the Simjava application window. The title bar is 'Simjava'. The menu bar includes 'File', 'View', 'Simulation', 'Output', and 'Help'. The main window is divided into several sections:

- Ground Parameters Sets:** Contains buttons for '<', '>', 'Read From File', 'Add', 'Insert', 'Copy', 'Delete', and 'Delete All'. Below these is a table with columns 'Nb' and 'Ground Parameter Set Nb'. It shows one entry: '1' for 'Ground Parameter Set Nb 1'.
- Ground Parameter Set Nb 1/1:** Contains a table with columns 'Nb', 'GP', and 'Generation Mode'. It lists four parameters: '1' (Lithology, Semi Deterministic), '2' (Stress Pattern, Semi Deterministic), '3' (Temperature, Semi Deterministic), and '4' (Overpressure, Semi Deterministic). Below the table are 'Add', 'Insert', and 'Delete' buttons.
- Semi Deterministic Values:** Contains a radio button group for 'Reference Point at the Beginning of :', with 'Area' selected and 'Z...' unselected. Below this is a table with columns 'Nb', 'te Name', 'Generation Mode', 'Min. Value', 'Mode Value', and 'Max. Value'. It lists five states: '1' (State 2.1, Length, 500.00, 1,000.00, 1,500.00), '2' (State 2.2, Length, 500.00, 1,000.00, 1,500.00), '3' (State 2.3, Length, 500.00, 1,000.00, 1,500.00), '4' (State 2.4, Length, 500.00, 1,000.00, 1,500.00), and '5' (State 2.5, Length, 4,000.00, 4,000.00, 4,000.00). To the right of the table are 'Add Value', 'Insert Value', and 'Delete Value' buttons.
- Bottom Bar:** Contains three buttons: 'Edit Ground Classes', 'Edit Correlation', and 'Edit Boreholes'.

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 along the 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.

TASK 2 DRILL COST/TIME MODEL WITH UNCERTAINTY

INITIAL RESULTS

Ground Class Definitions

Simjava

Ground Parameters Sets

File View Simulation Output Help

Ground Parameter Set Nb

Ground Parameter Set Nb 1

Ground Class Definition

GP Set 1 - Ground Class Definition

Nb	Ground Class Name	Lithology	Stress Pattern	Temperature	Overpressure
1	Very Good	New State 2.1	New State 3.1	New State 4.1	New State 5.1
2	Very Good	New State 2.1	New State 3.1	New State 4.1	New State 5.2
3	Very Good	New State 2.1	New State 3.1	New State 4.1	New State 5.3
4	Very Good	New State 2.1	New State 3.1	New State 4.1	New State 5.4
5	Good	New State 2.1	New State 3.1	New State 4.1	New State 5.5
6	Very Good	New State 2.1	New State 3.1	New State 4.2	New State 5.1
7	Very Good	New State 2.1	New State 3.1	New State 4.2	New State 5.2
8	Very Good	New State 2.1	New State 3.1	New State 4.2	New State 5.3
9	Good	New State 2.1	New State 3.1	New State 4.2	New State 5.4
10	Good	New State 2.1	New State 3.1	New State 4.2	New State 5.5
11	Very Good	New State 2.1	New State 3.1	New State 4.3	New State 5.1
12	Very Good	New State 2.1	New State 3.1	New State 4.3	New State 5.2
13	Good	New State 2.1	New State 3.1	New State 4.3	New State 5.3
14	Good	New State 2.1	New State 3.1	New State 4.3	New State 5.4
15	Good	New State 2.1	New State 3.1	New State 4.3	New State 5.5
16	Very Good	New State 2.1	New State 3.1	New State 4.4	New State 5.1
17	Good	New State 2.1	New State 3.1	New State 4.4	New State 5.2

Add Value

Insert Value

Delete Value

Close

Add

Insert

Delete

Edit Ground Classes

Edit Correlation

Edit Boreholes

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

TASK 2 DRILL COST/TIME MODEL WITH UNCERTAINTY

INITIAL RESULTS

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

TASK 2 DRILL COST/TIME MODEL WITH UNCERTAINTY

INITIAL RESULTS

Method Cost and Time Equations

Simjava

File View Simulation Output Help

Activities

< > Add Insert Delete Delete All

Nb	Name	Method	Time Equation	Cost Equation
1	Very Easy Well Drilling	Very Easy Dig	$0.5 \cdot \text{round_length}() / \text{AdvanceRate}$	$0.5 \cdot \text{round_length}() \cdot (\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost})$
2	Easy Well Drilling	Easy Dig	$0.75 \cdot \text{round_length}() / \text{AdvanceRate}$	$0.75 \cdot \text{round_length}() \cdot (\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost})$
3	Average Well Drilling	Average Dig	$1 \cdot \text{round_length}() / \text{AdvanceRate}$	$1 \cdot \text{round_length}() \cdot (\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost})$
4	Hard Well Drilling	Hard Dig	$1.25 \cdot \text{round_length}() / \text{AdvanceRate}$	$1.25 \cdot \text{round_length}() \cdot (\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost})$
5	Very Hard Well Drilling	Very Hard Dig	$1.5 \cdot \text{round_length}() / \text{AdvanceRate}$	$1.5 \cdot \text{round_length}() \cdot (\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost})$
6	Stimulation	Hydrofracture	FracingTime	FracingCost

Activity 1/6

Activity Name : Very Easy Well Drilling

Method Variables:

Nb	Name	Min.	Mode	Max.	Prob. Min.	Prob. Max.
1	DrillingVarCost	580.00	580.00	580.00	0.00	0.00
2	DrillingFixCost	140.00	140.00	140.00	0.00	0.00
3	CasingCost	340.00	340.00	340.00	0.00	0.00
4	TroubleCost	100.00	100.00	100.00	0.00	0.00

Heads:

Nb	Head	Cycle Length
1	Head 1	1.00

General Variables:

Nb	Name	Description	Min.	Mode	Max.	Prob. Min.	Prob. Max.
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Resources:

Nb	Resource	Variable	Type	Det. Value	Min	Mode	Max	Prob.
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< > Add Insert Delete

Resource Equations :

Amount Used = --

Amount Produced = --

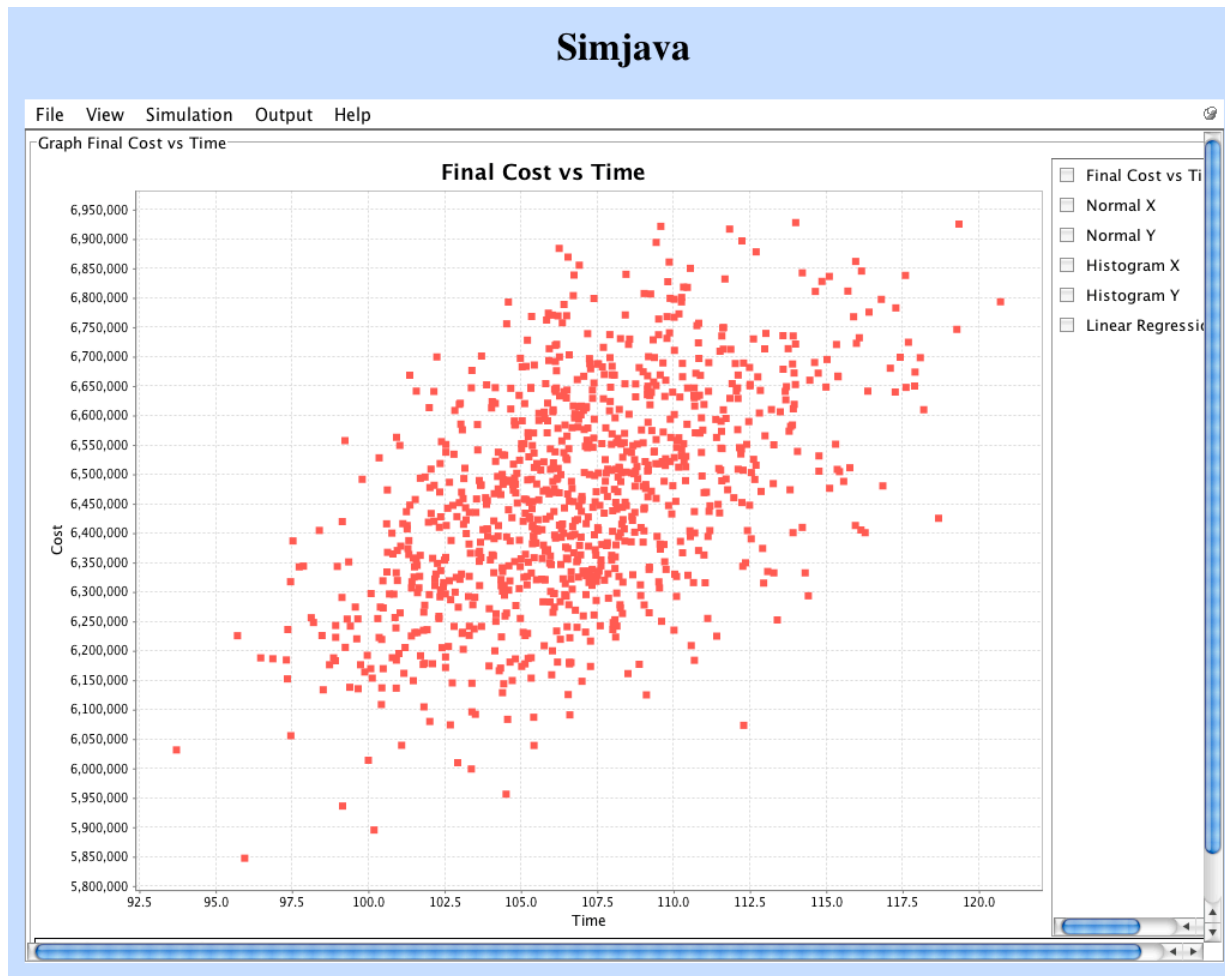
Time Equation = $0.5 \cdot \text{round_length}() / \text{AdvanceRate}$

Cost Equation = $\text{DrillingVarCost} + \text{DrillingFixCost} + \text{CasingCost} + \text{TroubleCost} + \text{PreSpudCost}$

Priority: -- Preemptive: -- Calendar: None

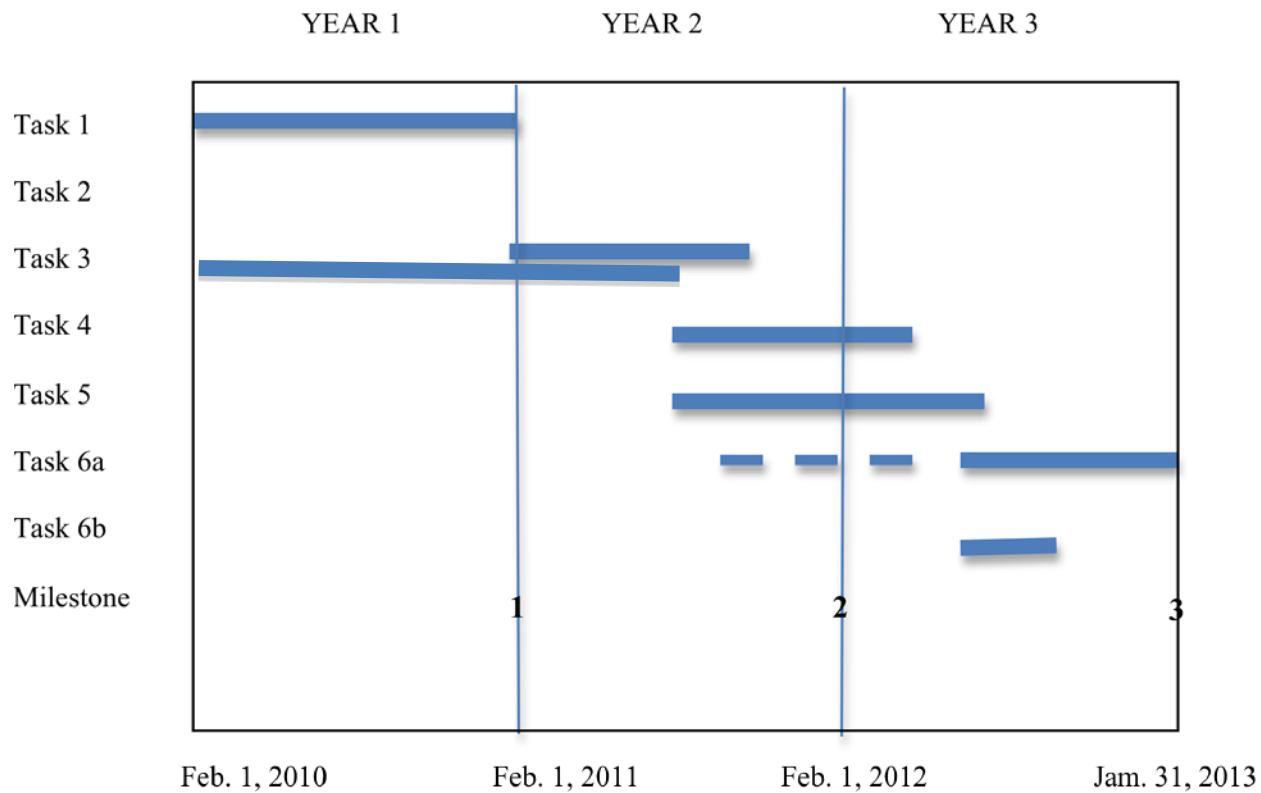
Method variables are used in a cost equation and schedule equation to evaluate the cost and time required to perform a “method” across the length of a segment.

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:

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

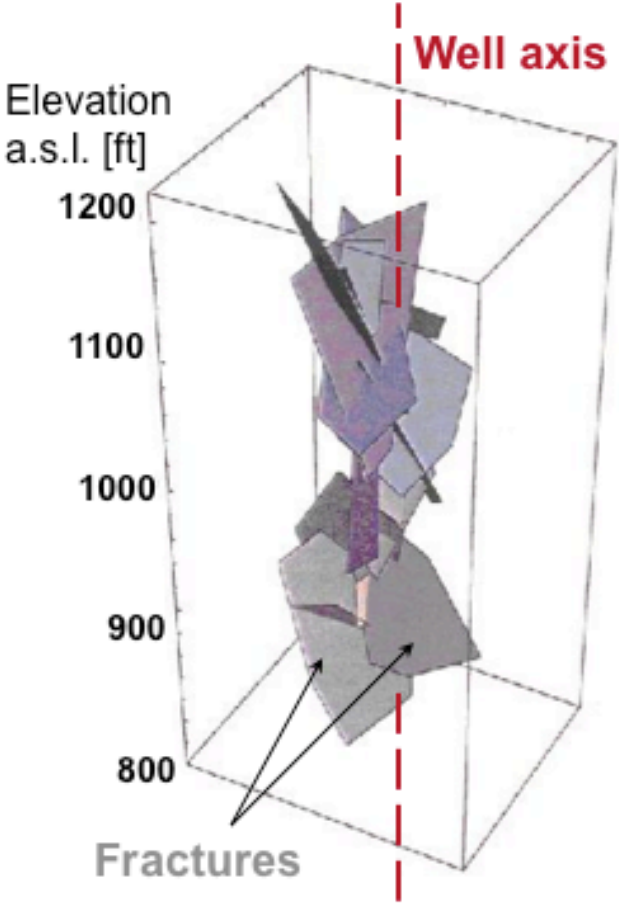
- Effect of changes in circulating water (see above)
- Random variability of operation
- Occurrence of major interruptions
- Labor and replacement material cost

Maintenance

- Labor and material cost
- Regulatory requirements

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 _a]=30 ft						
YU1711	250	52995	0.787	7.95	7.59	32
		53865	0.837	8.06	12.29	30
		52456	0.780	7.51	8.51	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 _a]=30 ft						
YU4007	150	48273	0.600	9.68	10.04	12
		43844	0.584	7.41	6.45	13
		45684	0.594	7.42	7.45	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

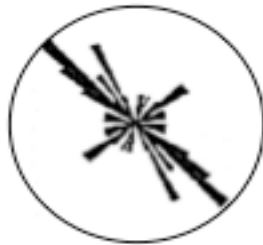
WELL YU1711



Log analysis 1
124 fractures



Log analysis 2
20 fractures



Simulation 1
32 fractures

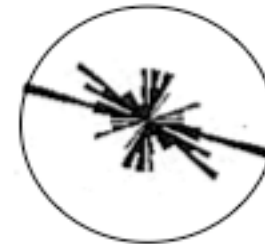


Simulation 2
30 fractures

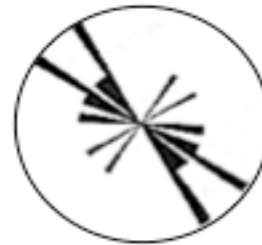
WELL YU4007



Log analysis 1
105 fractures



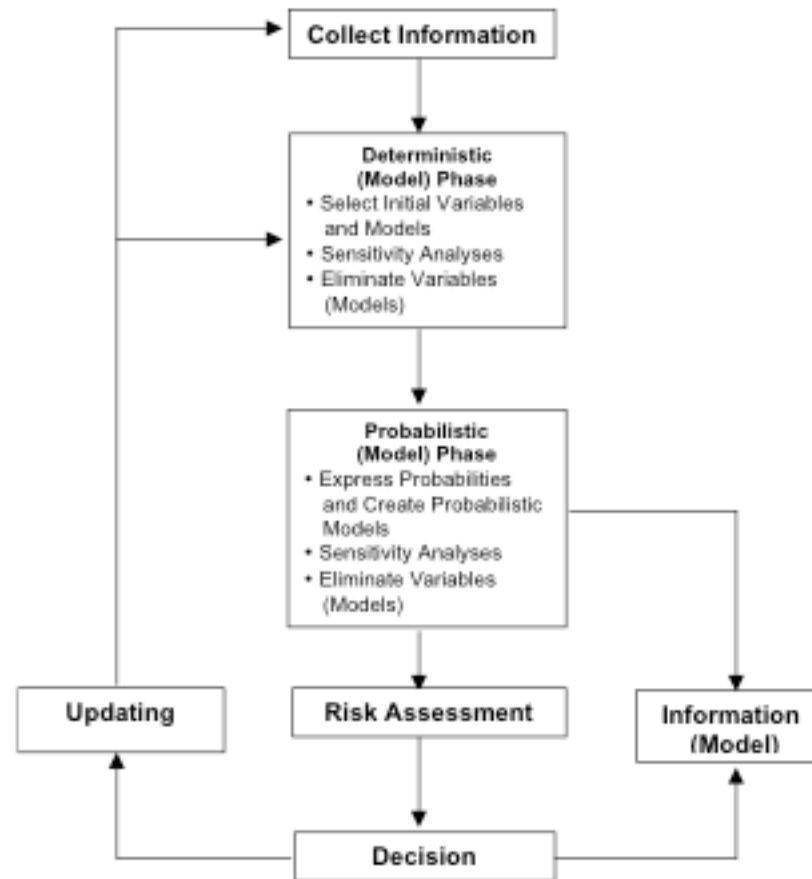
Log analysis 2
71 fractures



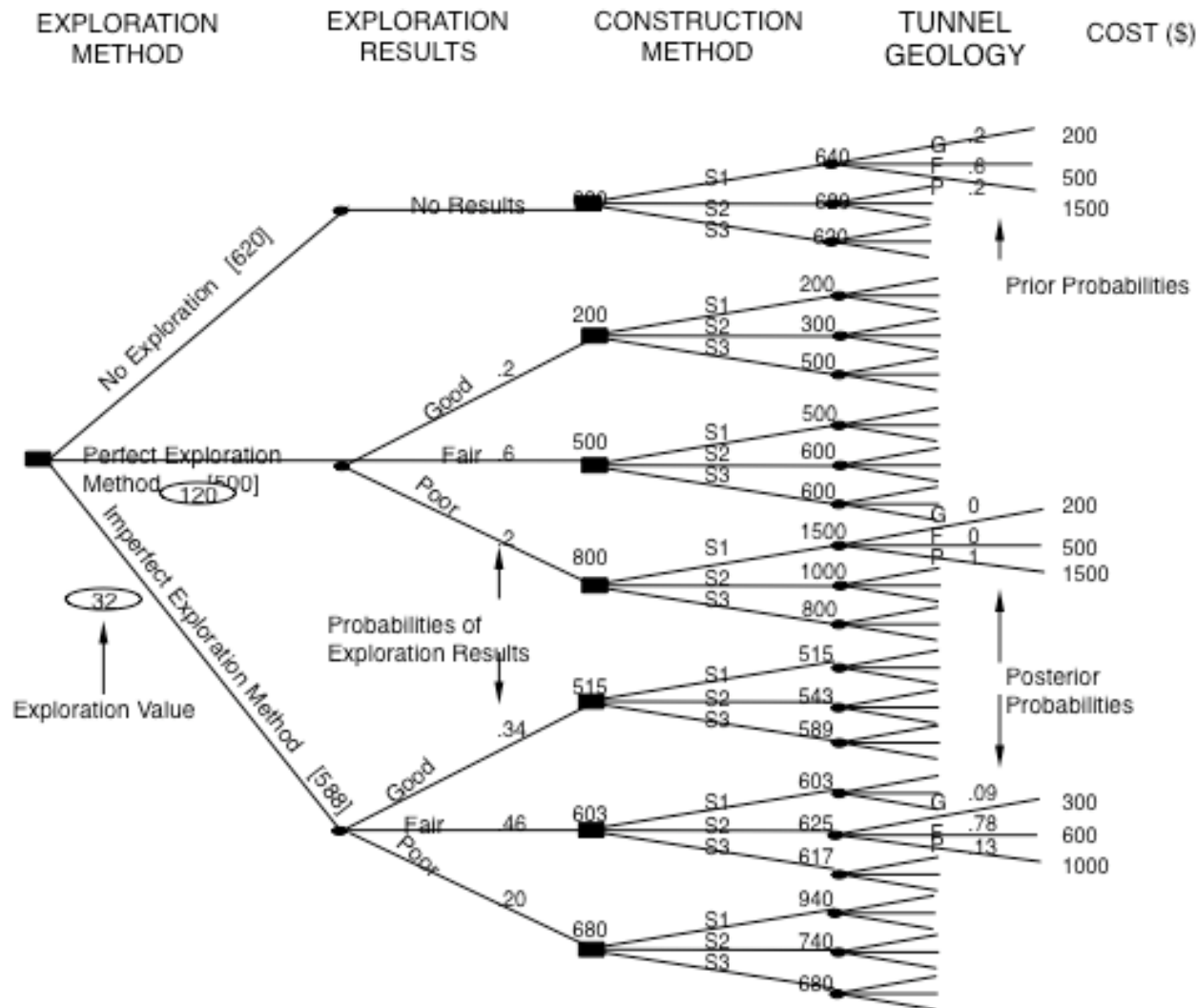
Simulation 1
12 fractures



Simulation 2
13 fractures

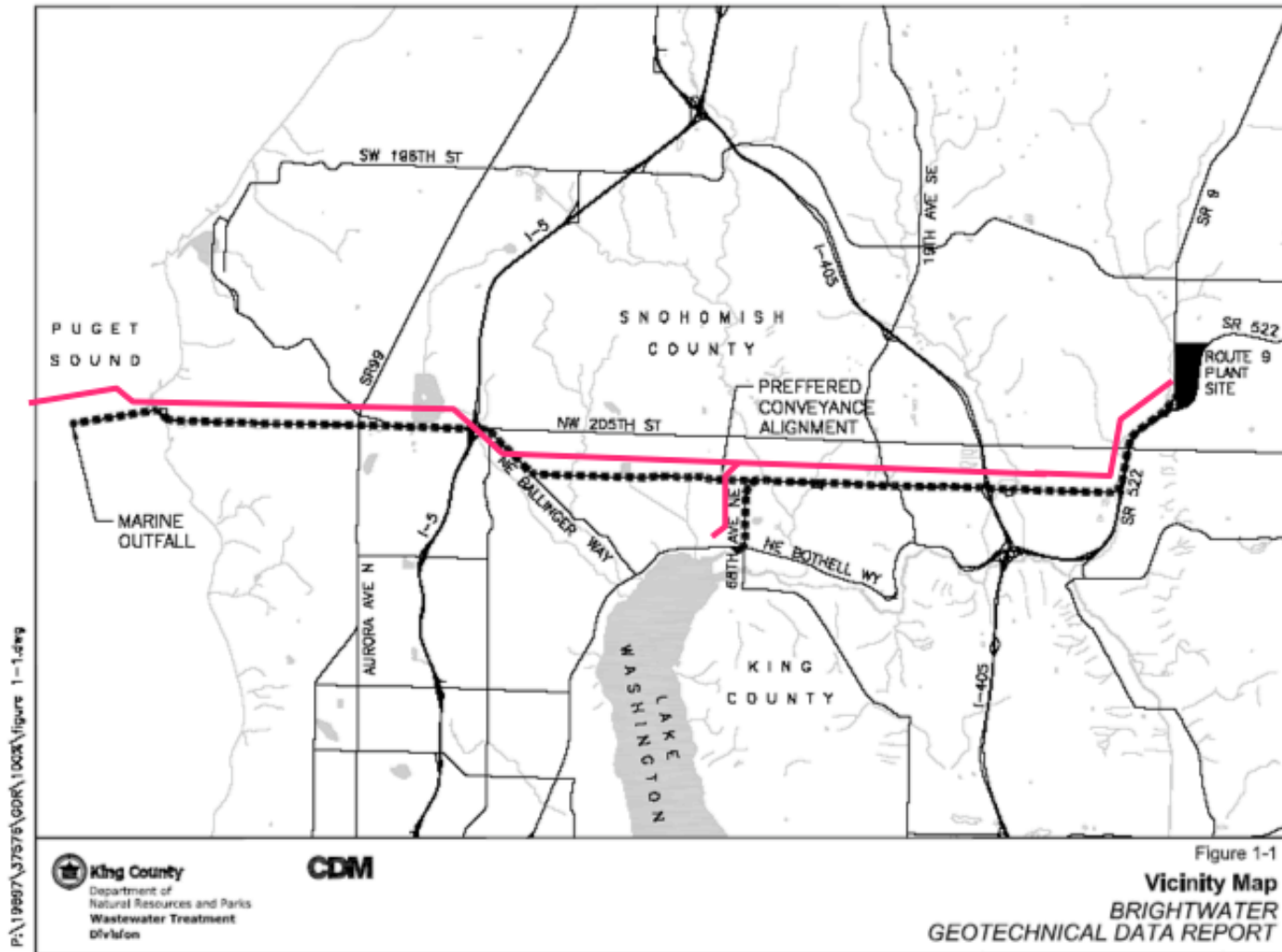


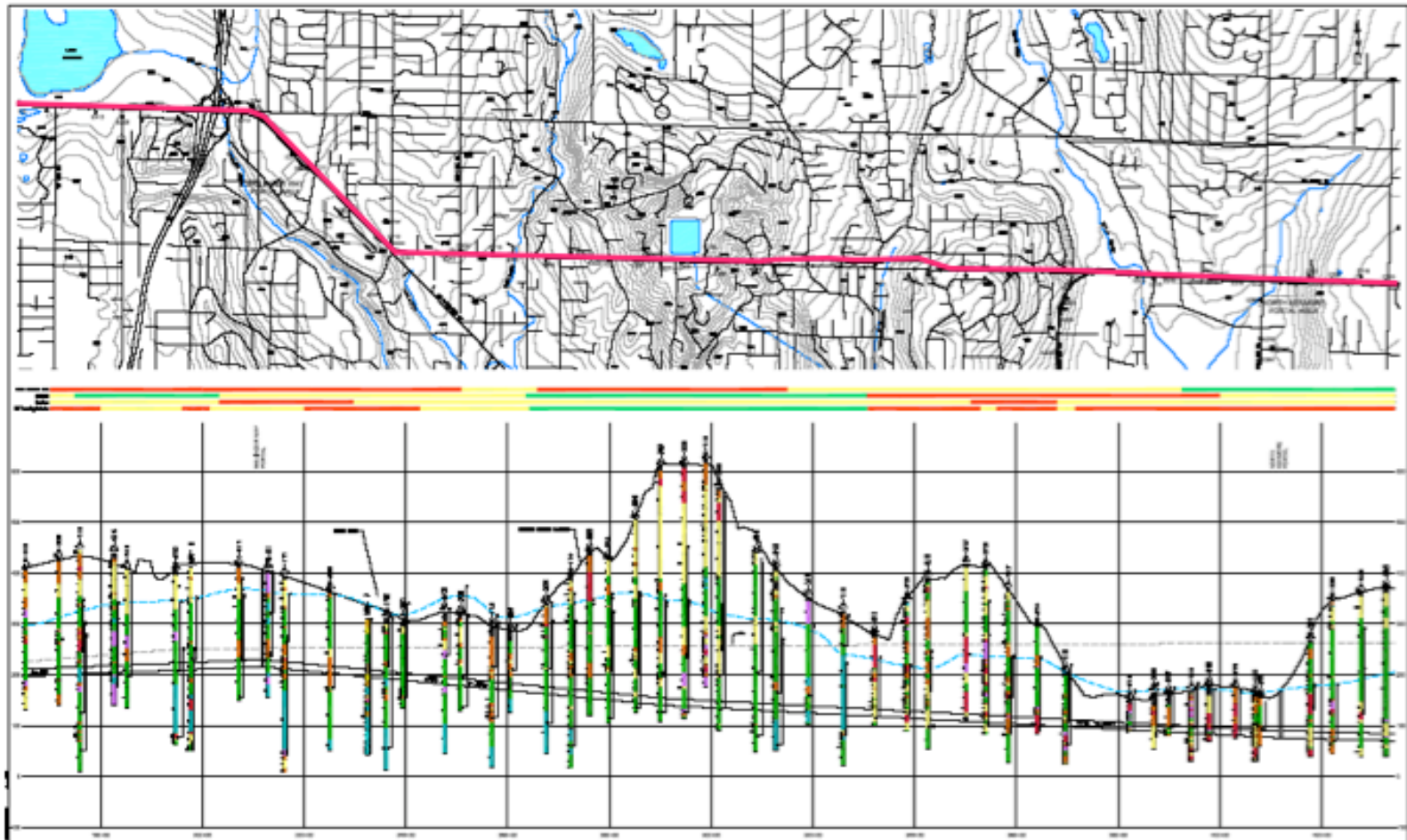
Decision Analysis Cycle



“Virtual Exploration” - Exploration Decision Tree

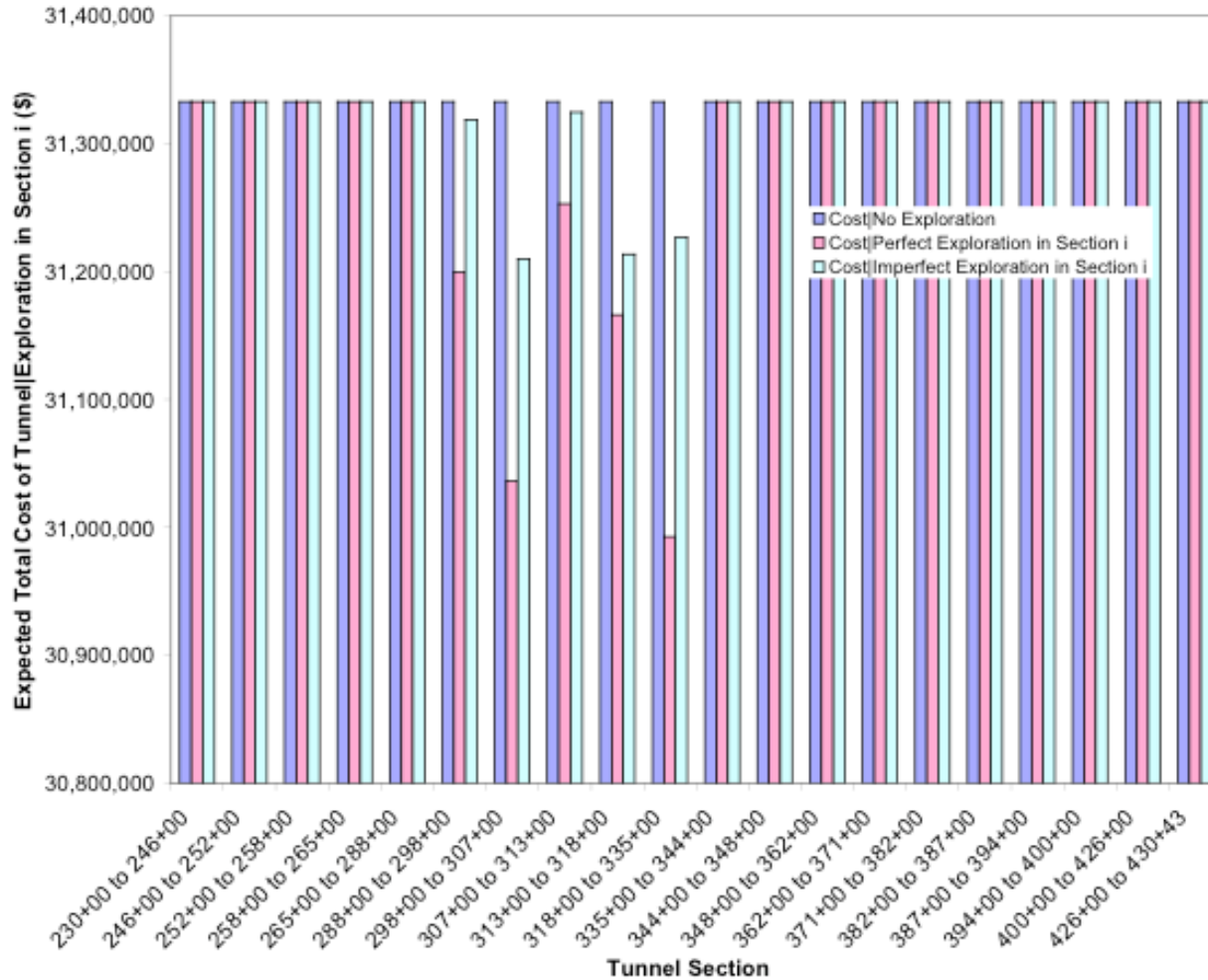
BRIGHTWATER CONVEYANCE SYSTEM





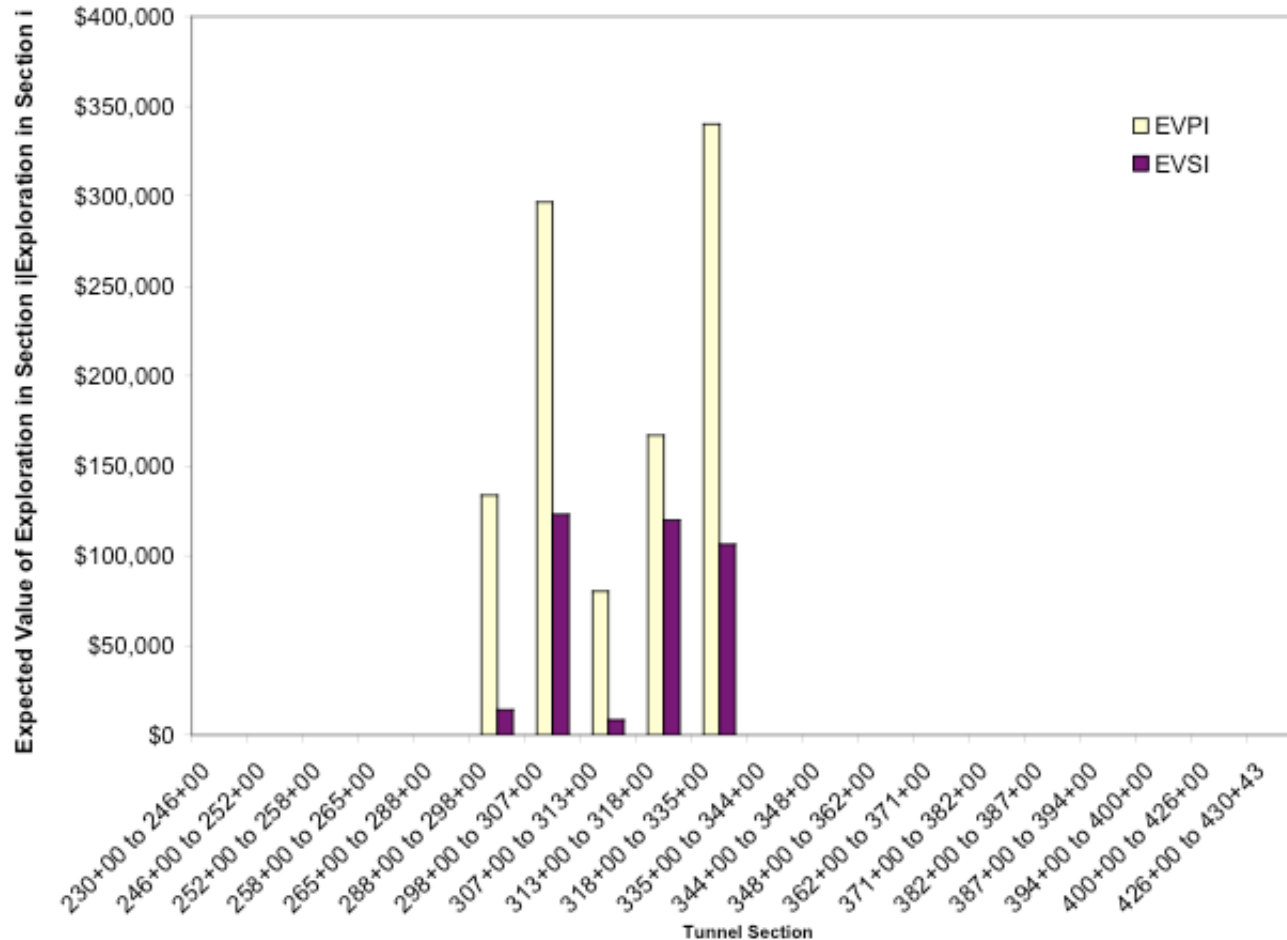
EXPLORATION BENEFICIAL

BRIGHTWATER CONVEYANCE



BRIGHTWATER CONVEYANCE

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



BRIGHTWATER CONVEYANCE

Expected Value of Perfect/ Sample Information