APPENDIX K

Modeling Cost Uncertainty

Solid Waste Facilities Master Plan Technical Memorandum No. 6 - Modeling Cost Uncertainty

PREPARED FOR: Seattle Public Utilities

PREPARED BY: CH2M Hill

DATE: July 31, 2003

Introduction

This memorandum is one of a series of memoranda that document technical analysis conducted by the CH2M HILL consultant team in support of the Seattle Public Utility Solid Waste Facilities Master Plan. The consultant team includes Herrera Environmental Consultants, Ecodata, MainLine Management, Triangle Associates, and Environmental Planning Consultants. The memoranda that document the analysis are as follows:

1. Decision Process
2. Design Criteria and Conceptual Layouts
3. Peak Flows and Waste Stream Analysis
4. Rail Cost Modeling
5. Cost Modeling in Support of SPU's System Cost Model
6. Modeling Cost Uncertainty

This memorandum includes a discussion of how risks and uncertainties were considered when understanding the cost of each option.

Influence Diagram

At Workshop 4, the CH2M Hill team presented a decision analysis approach to capture risk and uncertainty in the evaluation of system costs for each option. This discussion followed the approach shown in the attached document titled Approach to Capture Cost Risks (file: Approach to Cost Risks.ppt). The method uses decision trees to identify key uncertainties and the way that those uncertainties may influence costs.

CH2M Hill staff led the group through an exercise to develop an initial influence diagram. The influence diagram, shown in the second slide of the attached document Decision Tree Assumptions (file: Decision Trees.ppt), graphically indicates how uncertainties affect each other and affect cost. For example, the uncertainty (shown as a green bubble in slide 2) in the rail contract price is influenced by whether or not an intermodal option is selected and also by whether King County participates in the rail contract.

An influence diagram is actually the top layer of a mathematical model used to calculate a probabilistic distribution of total costs. Underlying the influence diagram is a series of interconnected decision trees shown in subsequent slides. These trees depict the potential outcomes associated with each event or cost uncertainty. Slide 10 shows the sub-tree that depicts the influences, possible outcomes and corresponding probabilities for the rail contract price. The structure, values and probabilities of each series of decision trees was developed and refined by SPU and CH2M Hill project team members in a half-day workshop on May 6, 2003. Additional edits were made and subsequently reviewed by the full team.

Decision Trees and Risk Profiles

The influence diagram and underlying decision tree model was built using the Decision Programming Language (DPL) software product. In a "run" of the model, DPL identifies each possible combination of event / cost outcomes and sends the necessary cost assumption to the SPUs cost model (a series of linked Excel worksheets). The cost model then calculates the total cost based on the inputs received from DPL. Each permutation of events and the associated costs are captured by DPL and plotted on a risk profile as shown in the attached document Decision Analysis Results (file: Risk Profiles.ppt). Because there are over a dozen uncertainties for each option, the total number of discrete possible cost outcomes is in the thousands (exponential expansion of the decision trees). The DPL software constructs risk profiles by plotting all total cost outcomes, along with their corresponding probabilities, beginning with the lowest cost outcome. (X-axis = cost, Y-axis = cumulative probability). Subsequent points are plotted by moving along the X-axis to the cost of the next lowest cost outcome. Then moving up the cumulative probability axis by adding the next event's probability. Hence, the resulting curve is a "smooth" risk profile.

For each option, the risk profile illustrates several financial parameters of interest to SPU:

- The range of possible cost outcomes for each proposed option.
- The chance that a given level of cost will be exceeded, and by how much.
- The expected value, a measure of cost weighted by the range of possible outcomes and their respective probabilities, often used to represent cost adjusted for risk.

For each option, the 10^{th}, 90^{th}, expected value, and base estimate (result from the SPU cost model with baseline assumptions) is shown on the risk profile and summarized in the third slide. The 10^{th} percentile is the cost level where you'd have a 10 percent chance of being at or below (similar for the 90^{th} percentile). Therefore the difference between the 10^{th} and 90^{th} percentile is an indicator of realistic project cost risk. There is an 80% chance total option costs will fall between those two points.

For example, slide 6 shows the risk profile for Option 0. The vertical line at $640 million denotes the expected value. For reference, the Base estimate is shown ($626 million). Since costs are usually more likely to escalate than decline, the base estimate is often slightly lower than the expected value. The 90th percentile can be found by locating the point where the risk profile crosses the 90th percent line on the Y-axis (cumulative probability) - then reading cost from the X-axis. So for option 0, there is a 90% chance total costs will be at or below $742 million. Similarly, there is only a 10% chance costs will be at or below $553 million. The difference between the 10th and 90th is therefore $189 million ($742m - $553m).

Sensitivity Analysis

A sensitivity analysis was performed to identify which uncertainties drive costs, and to understand the impact of the team's estimations of probabilities and outcomes. The relative effects of uncertainties were compared by adjusting each uncertainty across its possible range of outcomes while keeping all others constant at their most likely values. The resulting variance in the total costs is shown by the horizontally bar on the tornado diagrams in slides 7, 9, 11 and 13 of the Decision Analysis Results document. Uncertainties are listed from top to bottom in decreasing effect on total costs. The horizontal bars therefor become narrower towards the bottom of the diagram and resemble the shape of a tornado.

Slide 7 shows the tornado diagram for Option 0. The second horizontal bar from the top shows that when the residential recycling rate is varied from a low possible outcome (the city only gets one quarter to goal) to a high possible outcome (city meets goal), total cost varies from $563 million to $669 million. Thus the relative impact of this uncertainty is $106 million ($669m - $563m). A summary of the impact of the three most influential uncertainties is shown on the fourth slide.

Findings

The Decision Analysis Results document provides a summary of conclusions drawn from the decision analysis. Slide 3 summarizes the primary findings based on model runs for Options 0, 5, 8, and 11.

- Non-intermodal options (0 and 8) have the greatest cost uncertainty (high spread between their 10th and 90th percentiles). [See slide 4].
- Growth in the city's waste stream and recycling rate has the greatest impact on total costs. [See slide 5].
- Intermodal options are much less sensitive to variations in city waste and recycling growth rates. [See slide 5].
- Construction cost uncertainty is lowest with Options 0 and 8 [See slide 5].
- In all options, the expected value of costs is 5-7 percent greater than our baseline cost estimates. This means that there is more upside risk than downside opportunity in the estimates.

SPU SW Facilities Masterplan

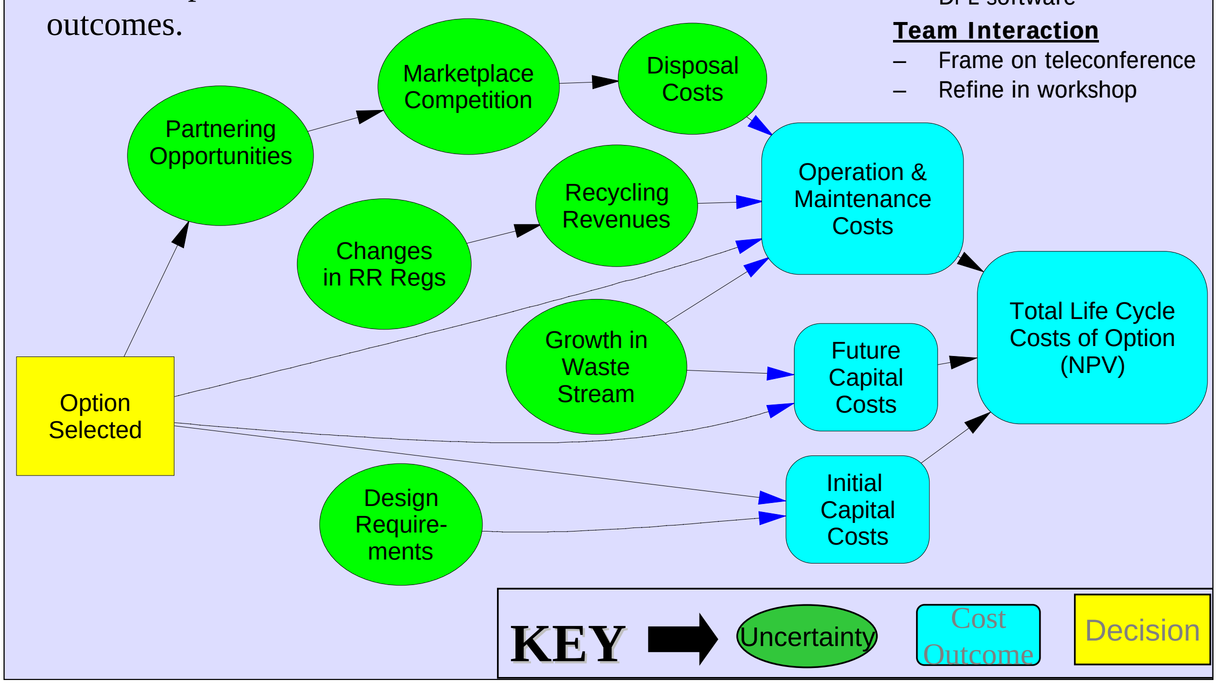
Approach to Capture Cost Risk

Step 1: Identify Cost Drivers and Risks
Influence Diagram

Influence Diagrams illustrate conditional relationships between decisions, uncertainties, & outcomes.

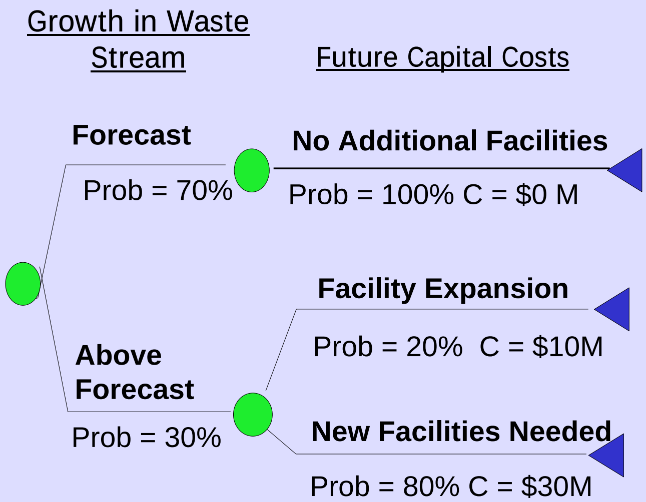
Tools Used
- Whiteboard
- DPL software

Team Interaction
- Frame on teleconference
- Refine in workshop



Step 2: Potential Cost Outcomes and Probabilities   Tool: Decision Tree

Example



For each possible outcome of a decision,
Decision Trees show:

- **The Pathway -** How did this happen?
- **The Probability -** How likely is this?
- **The Cost -** How much will this outcome cost?

The influence diagram is actually the top layer of a mathematical model. The underlying model is a series of interconnected decision trees. In our simplified example *only possible one tree is shown* (above).

Tools Used
- DPL software

Interaction
- Workshop and/or questionnaires to define branch outcomes and estimate probabilities and costs

Calculating the Decision Tree [Example Tree]

The influence diagram is actually the top layer of a mathematical model. The underlying model is a series of interconnected decision trees. In our simplified example *only possible one tree is shown* (see below).

Costs (NVP):
No Additional Facilities = $0M
Facility Expansion = $10M
New Facilities Needed = $30M

Prob of Outcome = 0.7 * 1.0 = 0.7
Cost of Outcome = $0

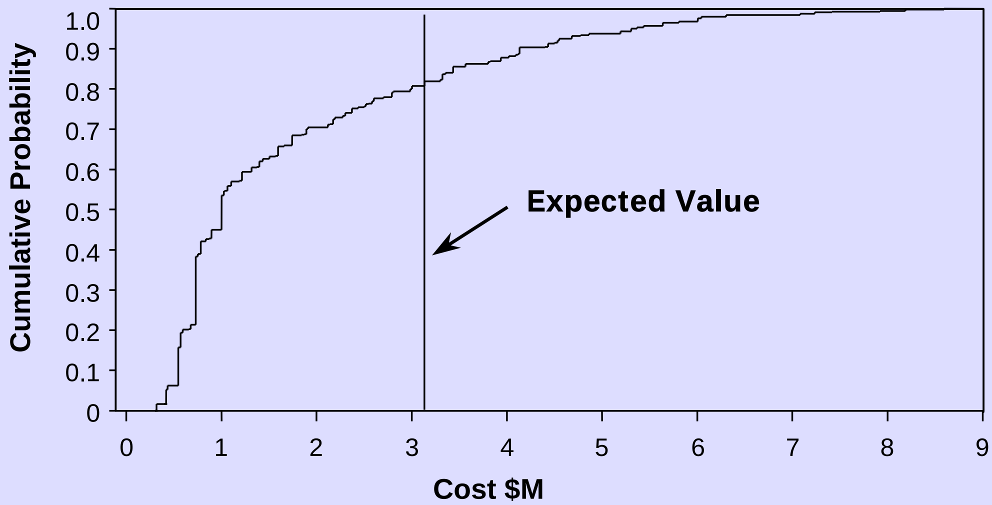
Prob of Outcome = 0.3 * 0.2 = 0.06
Cost of Outcome = $10M

Prob of Outcome = 0.3 * 0.8 = 0.24
Cost of Outcome = $30M

Cost Outcomes and Probabilities Tool: DPL Software

Using DPL Software, complex trees with thousands of costs outcomes can be modeled. The result is a "smoother" profile shown below.

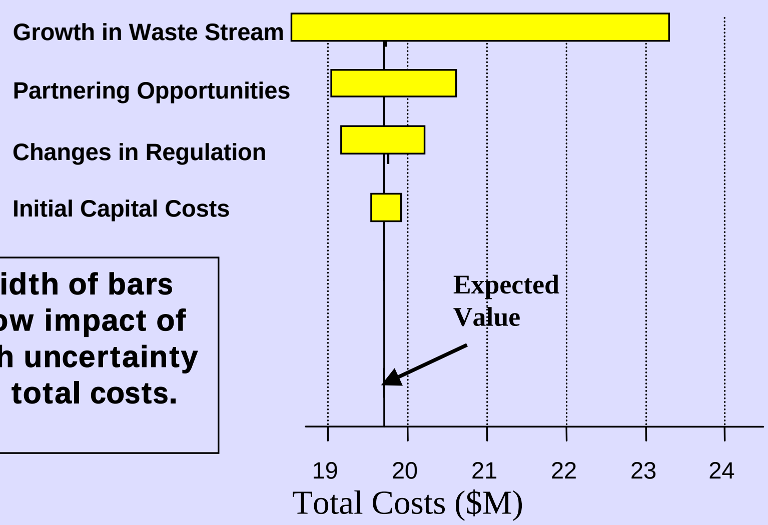
Generic Example



Step 3 Rank Uncertainties Driving Costs; Tool - Tornado Diagram

Tornado Diagrams help focus analysis and data needs

Example



Width of bars show impact of each uncertainty on total costs.

*** Tornado Diagrams can dramatically change initial assessment of critical issues, and save information collection costs.**

Decision Tree Assumptions

SPU Solid Waste
Facilities Masterplan

June 24, 2003
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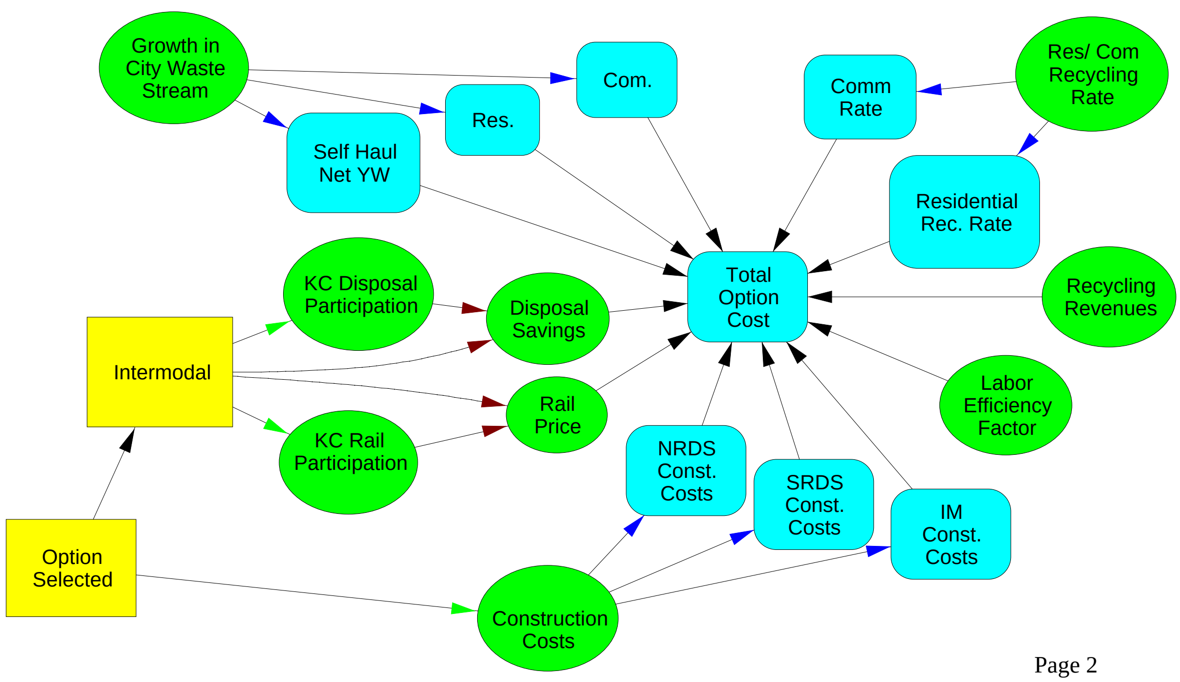
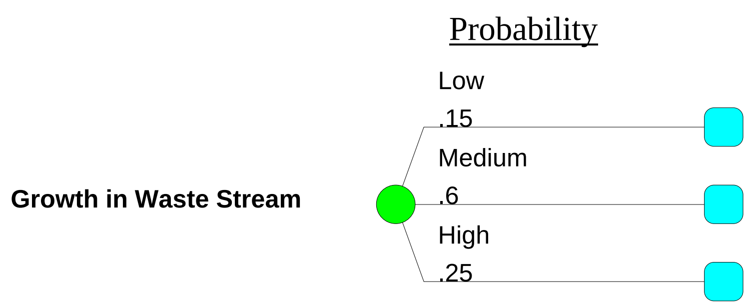
Cost Drivers and Uncertainties Affecting NPV of Options

The Influence Diagram below illustrates conditional relationships between decisions, uncertainties, & outcomes.

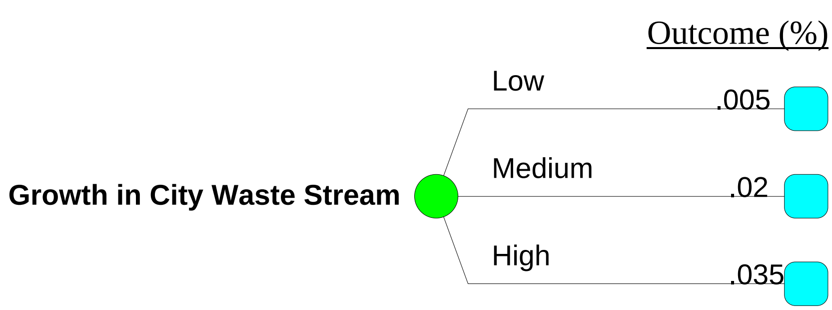


Uncertainty Branch - Waste Stream Growth Rate



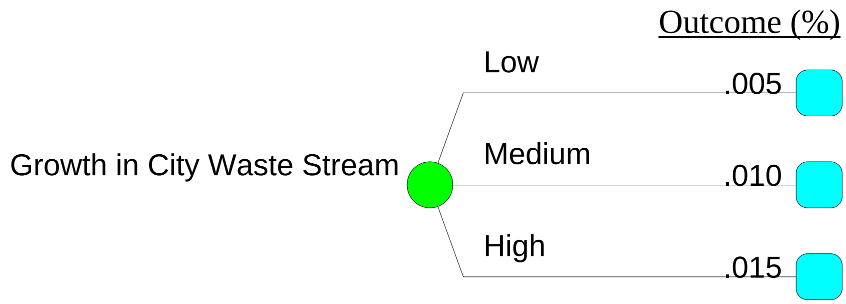
Note: Values broken out by waste stream types on subsequent slides

Uncertainty Branch - Commercial Waste Growth Rate



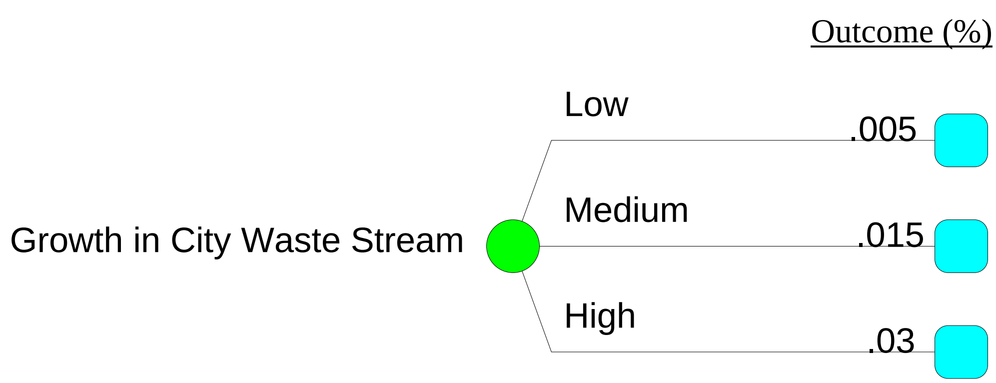
Note: Branch Probabilities on previous slides

Uncertainty Branch - Residential Waste Growth Rate



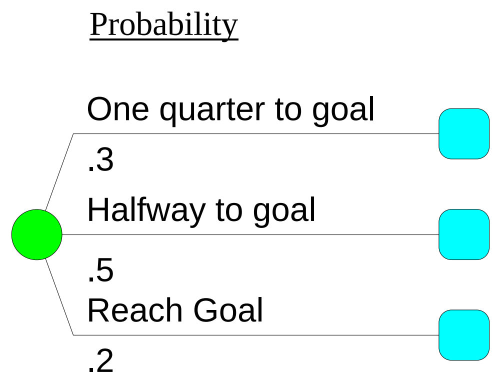
Note: Branch Probabilities on previous slides

Uncertainty Branch - Self Haul Net YW Growth Rate



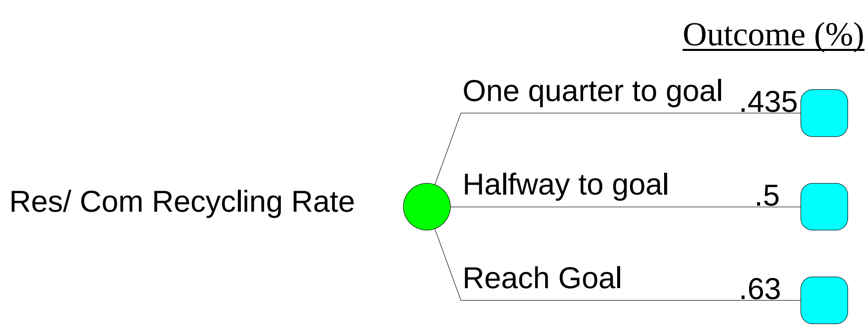
Note: Branch Probabilities on previous slides

Uncertainty Branch - Res/ Com Rec. Rate



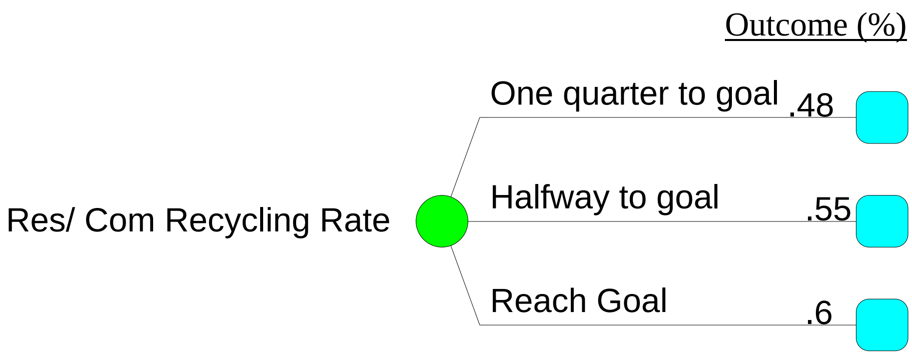
Note: Values broken out on subsequent slides

Uncertainty Branch - Commercial Recycling Rate



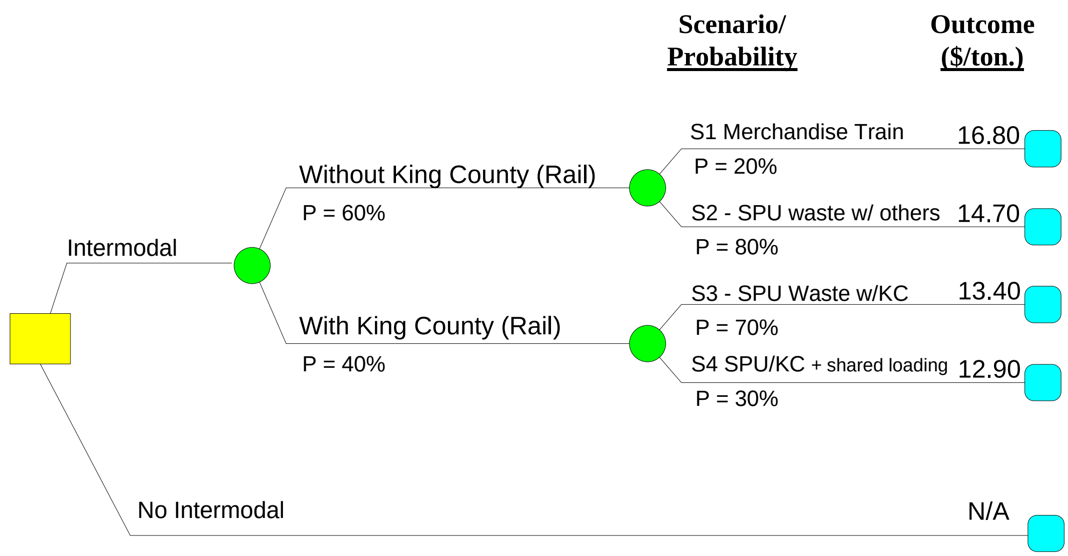
Note: Branch Probabilities on previous slides

Uncertainty Branch - Residential Recycling Rate

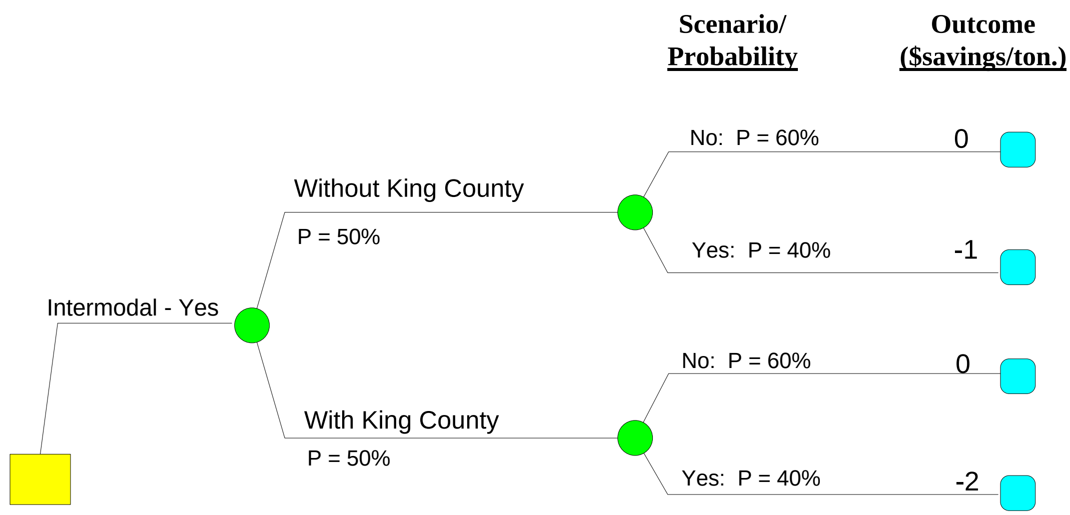


Note: Branch Probabilities on previous slides

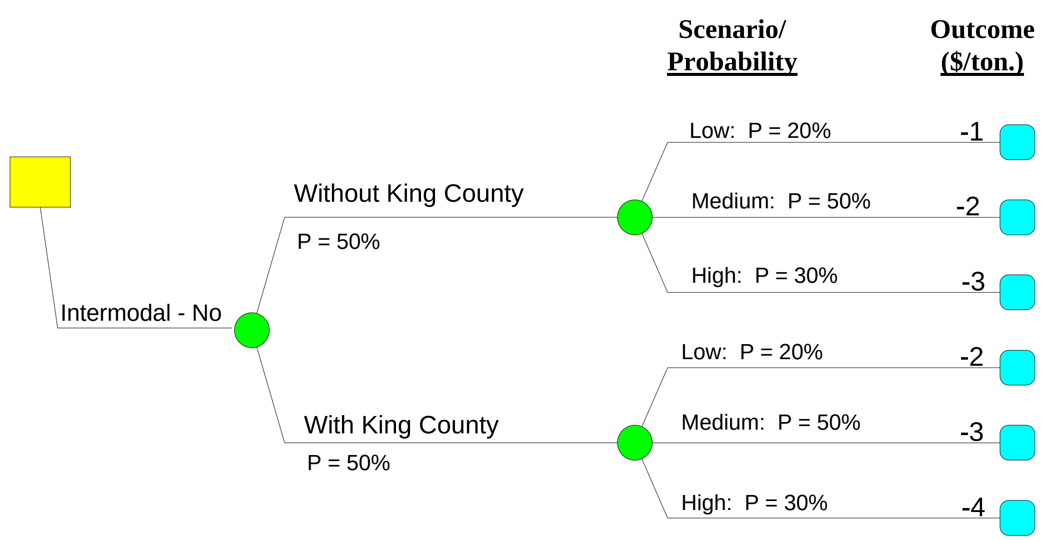
Uncertainty Branch - Rail Price



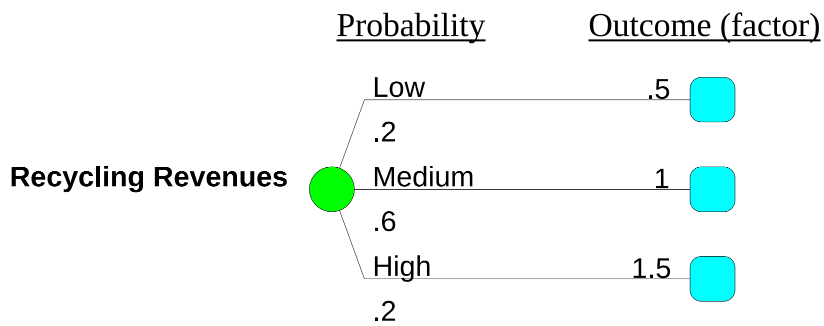
Uncertainty Branch - Disposal Savings with Intermodal



Uncertainty Branch - Disposal Savings w/o Intermodal

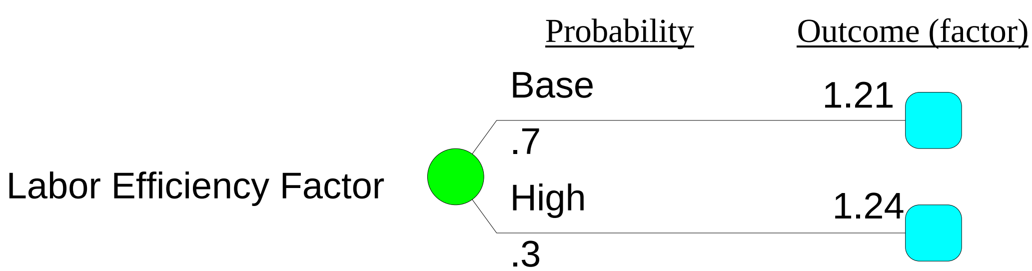


Uncertainty Branch - Recycling Revenues



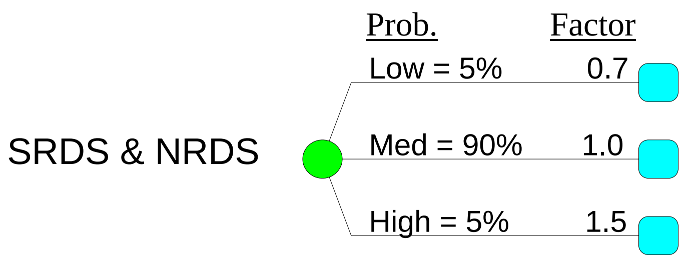
Note: Numbers on left represent branch probability.
Numbers on right represent value (factor: 1 = 100% of base estimate)

Uncertainty Branch - Labor Efficiency Factor



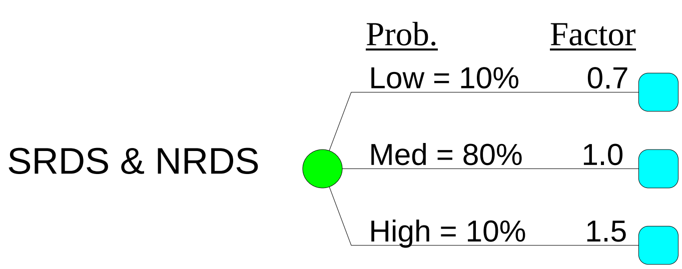
Note: Numbers on left represent branch probability.
Numbers on right represent value (efficiency factor)

Uncertainty Branch: Option 0
Construction Costs



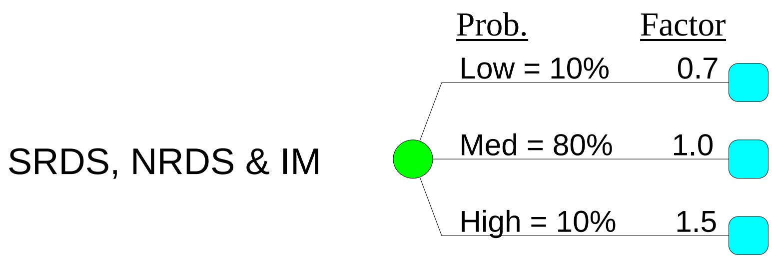
Note: Assign probabilities and factors (factor = 1 = 100% of base estimate) for each facility for each option.

Uncertainty Branch: Option 8
Construction Costs



Note: Assign probabilities and factors (factor = 1 = 100% of base estimate) for each facility for each option.

Uncertainty Branch: Options 9-11
Construction Costs



Note: Assign probabilities and factors (factor = 1 = 100% of base estimate) for each facility for each option.

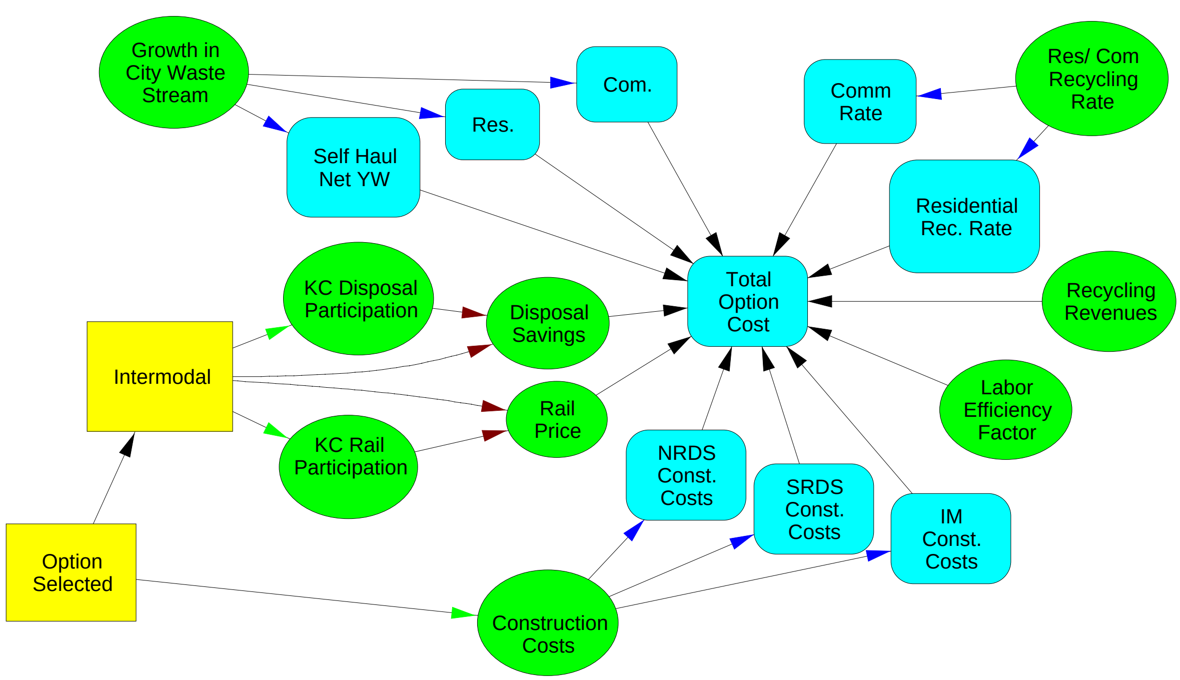
Decision Analysis Results

SPU Solid Waste
Facilities Masterplan

July 27, 2003
Dan Pitzler and Jeff Haight - CH2M HILL

Cost Drivers and Uncertainties Affecting NPV of Options

The Influence Diagram below illustrates conditional relationships between decisions, uncertainties, & outcomes.



Conclusions

- Non-intermodal options (0 and 8) have the greatest cost uncertainty (high spread between their 10th and 90th percentiles).
- Growth in the city's waste stream and recycling rate changes have the greatest impact on total costs.
- Intermodal options are much less sensitive to variations in city waste and recycling growth rates.
- Construction cost uncertainty is lowest with Options 0 and 8.
- In all options, the expected value of costs is 5-7 percent greater than our baseline cost estimates. This means that there is more upside risk than downside opportunity in the estimates.

Cost Uncertainty Summary ($M)

	Base	Expected Value	10th %	90th %	10-90% Spread
Option 0	626	640	553	742	189
Option 5	796	810	744	893	149
Option 8	649	665	574	769	195
Option 11	657	670	604	744	140

Impact of Key Uncertainties ($M)

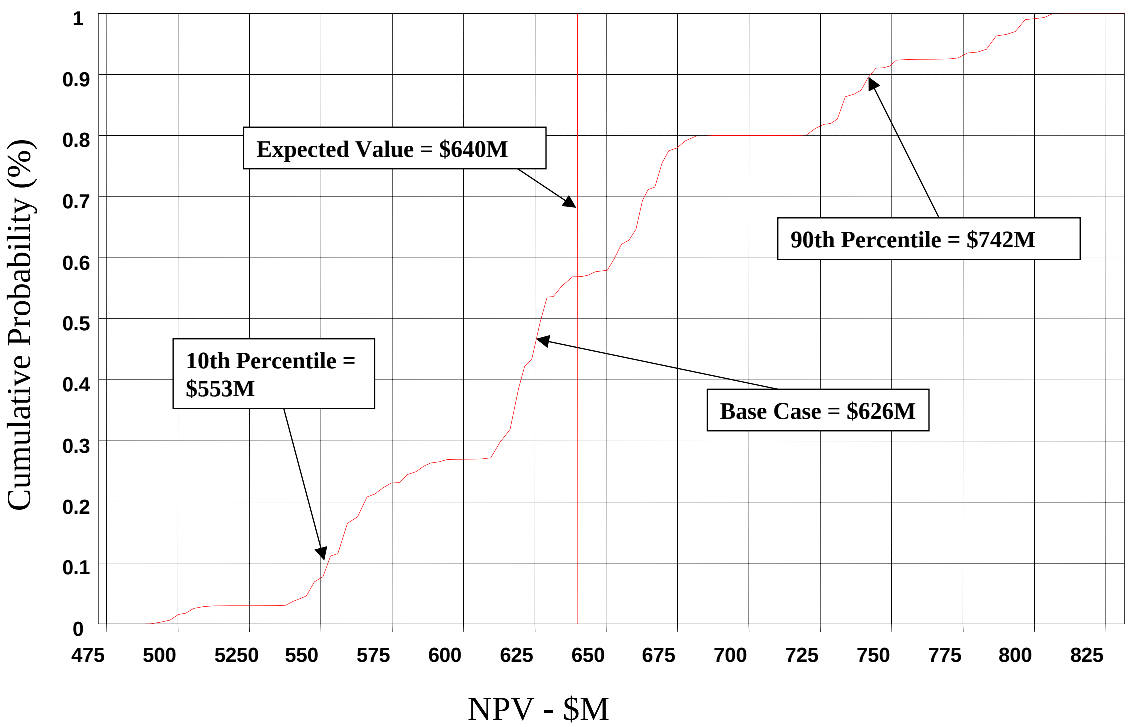
Values shown reflect the impact on total cost when an uncertainty is varied across its range of outcomes. All other uncertainties are held constant at their base states.

	Waste Stream Growth	Recycling Rate	Construction Costs
Option 0	189	106	12
Option 5	129	73	114
Option 8	192	106	39
Option 11	135	73	84

7/27/03

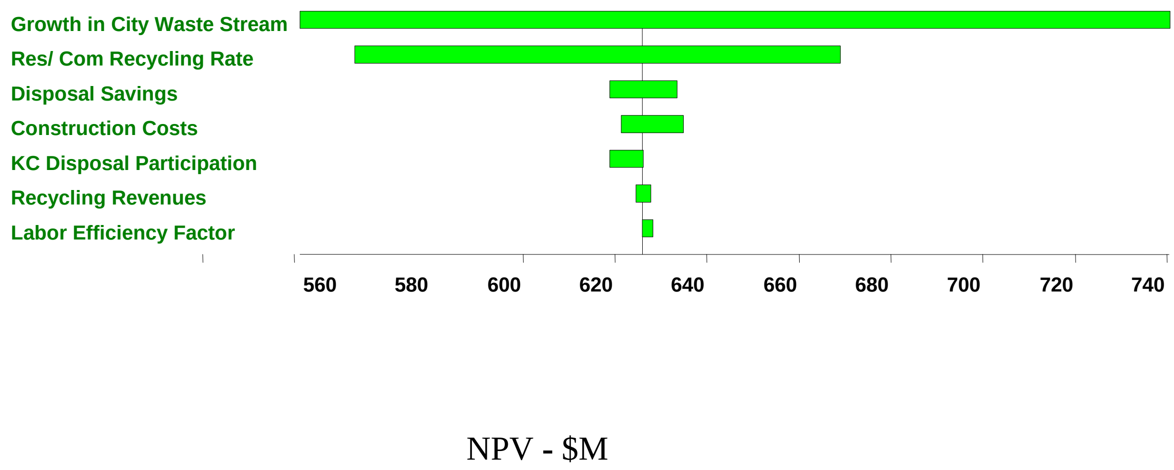
COST RISK PROFILE

Probabilistic Range of Option 0 Cost



BASE CASE TORNADO DIAGRAM

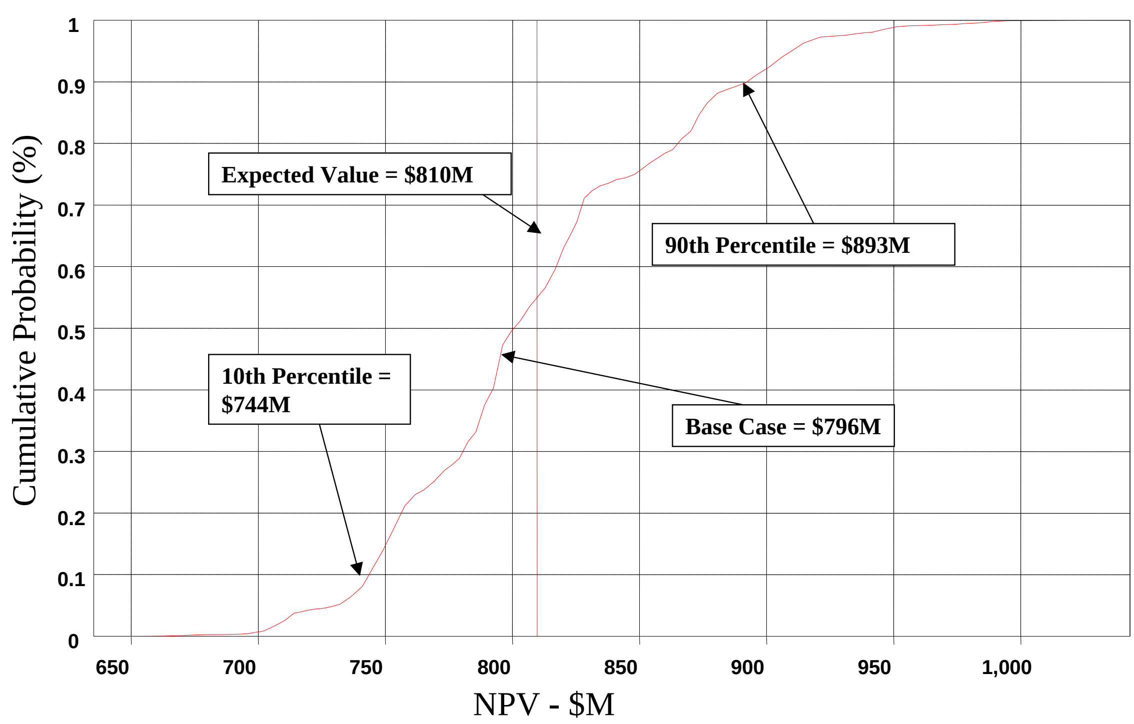
Relative Impact of Uncertainties Option 0



A "Base Case" Tornado Diagram evaluates the impact of each uncertainty by varying it from its best to worst state, while fixing all other uncertainties to their base (most likely) state. The width of the bar shows the impact on total option cost.

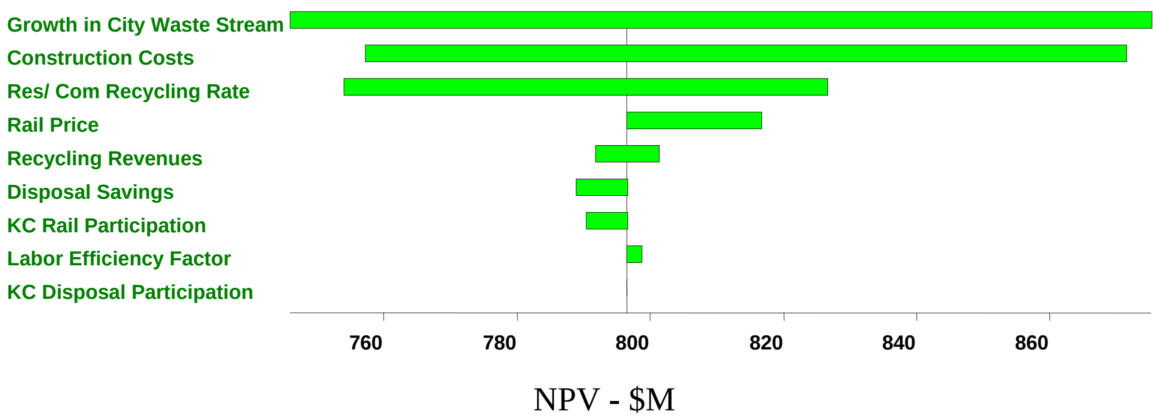
COST RISK PROFILE

Probabilistic Range of Option 5 Cost



BASE CASE TORNADO DIAGRAM

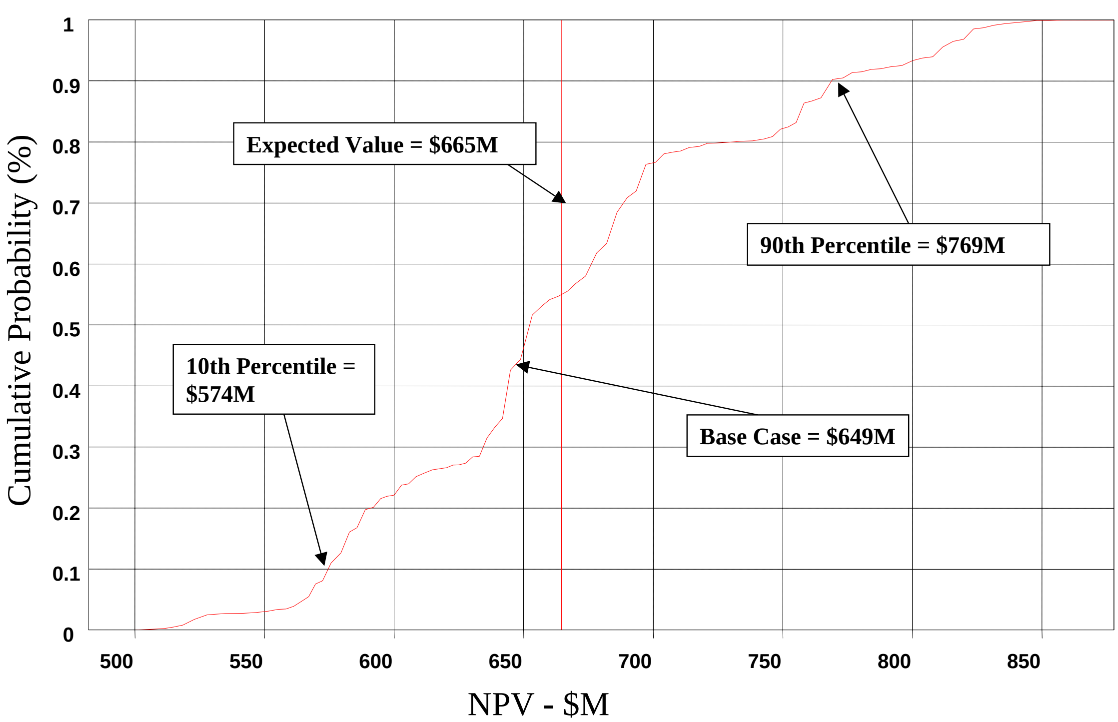
Relative Impact of Uncertainties Option 5



A "Base Case" Tornado Diagram evaluates the impact of each uncertainty by varying it from its best to worst state, while fixing all other uncertainties to their base (most likely) state. The width of the bar shows the impact on total option cost.

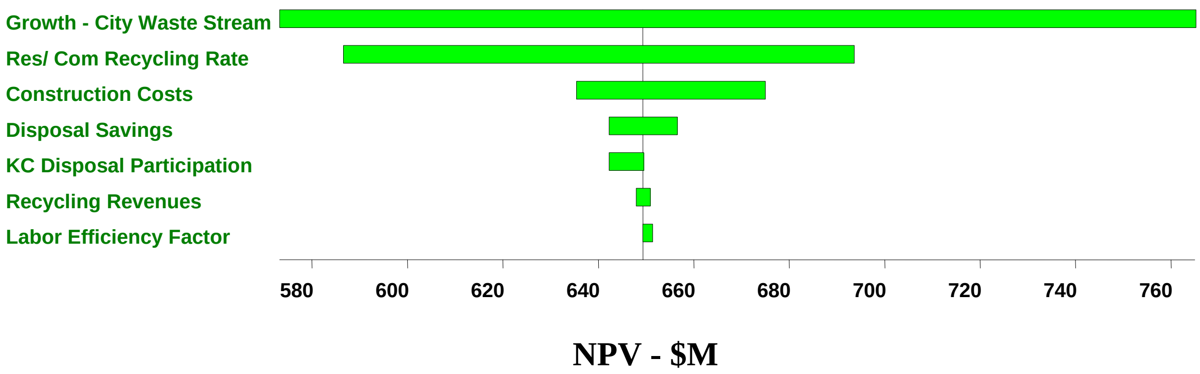
COST RISK PROFILE

Probabilistic Range of Option 8 Cost



BASE CASE TORNADO DIAGRAM

Relative Impact of Uncertainties Option 8



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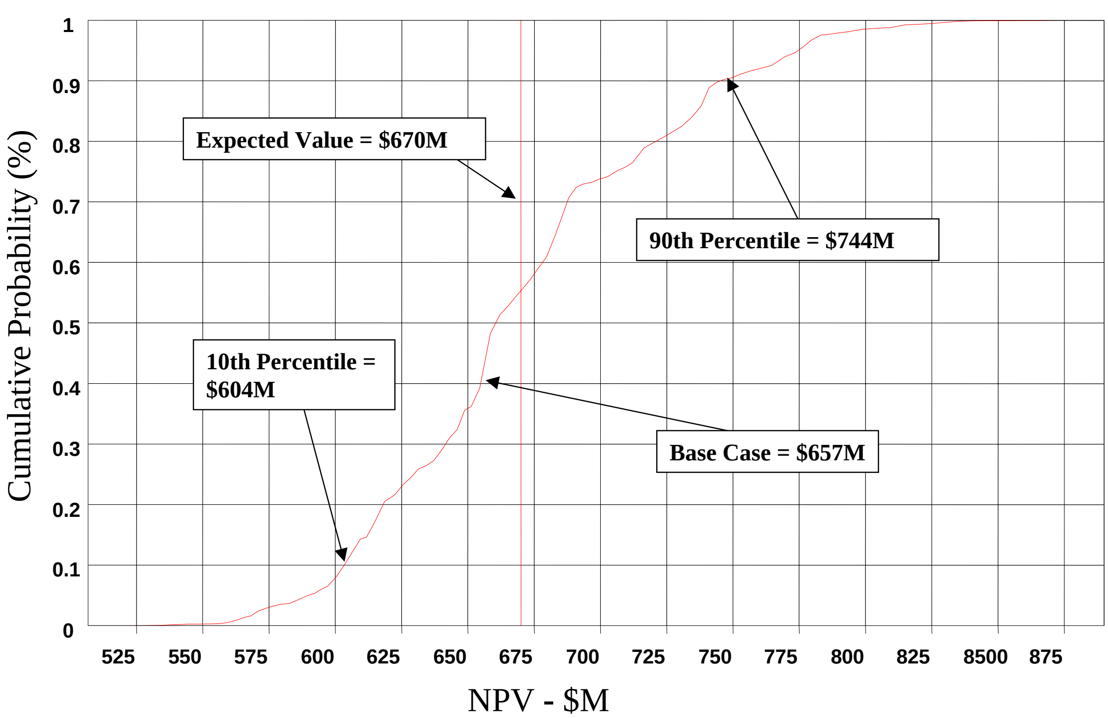
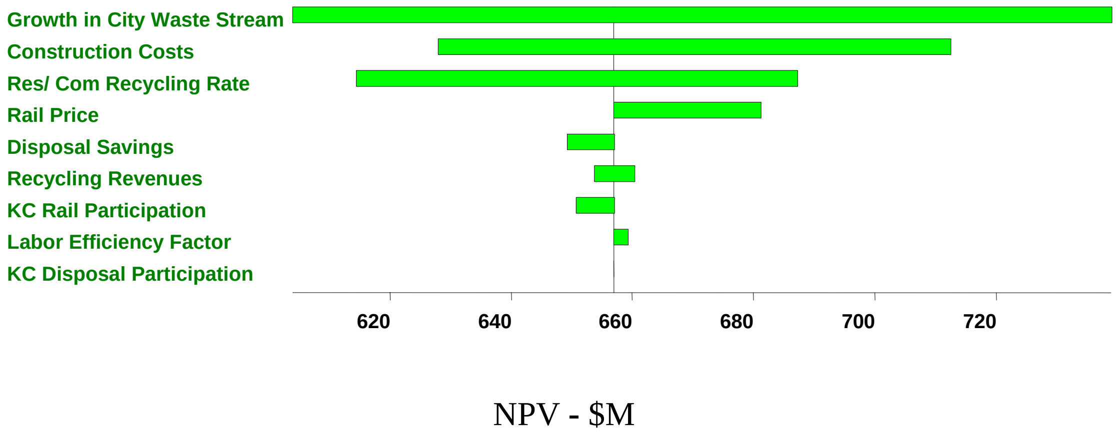
COST RISK PROFILE

Probabilistic Range of Option 11 Cost



BASE CASE TORNADO DIAGRAM

Relative Impact of Uncertainties Option 11



A "Base Case" Tornado Diagram evaluates the impact of each uncertainty by varying it from its best to worst state, while fixing all other uncertainties to their base (most likely) state. The width of the bar shows the impact on total option cost.