Smart Sampling

Section 7

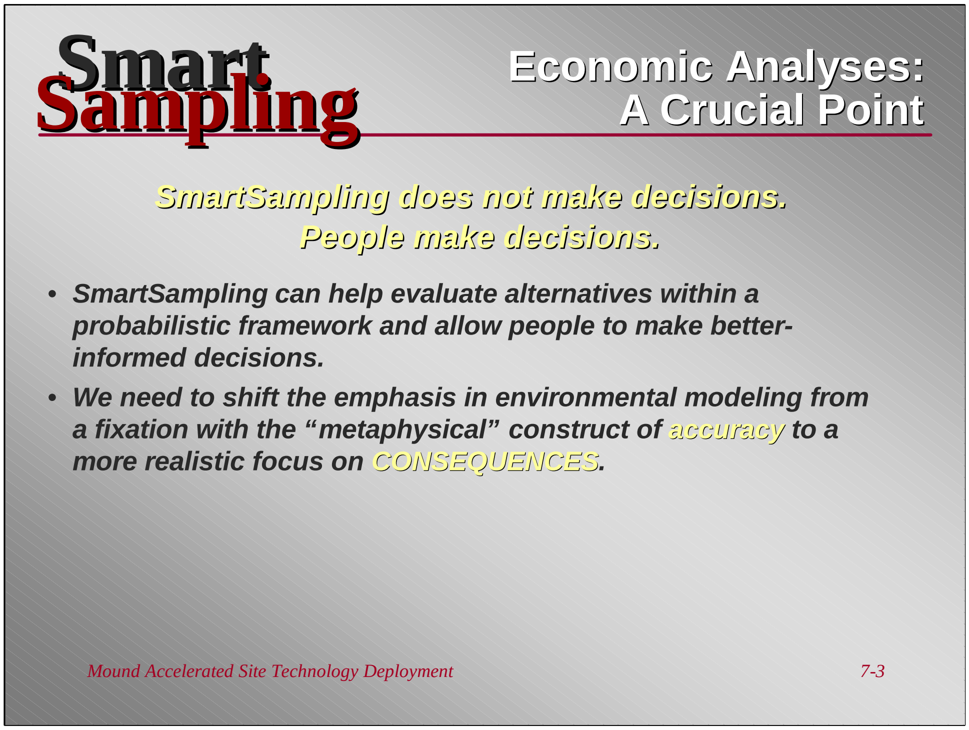
Economics

Mound Accelerated Site Technology Deployment 7-1

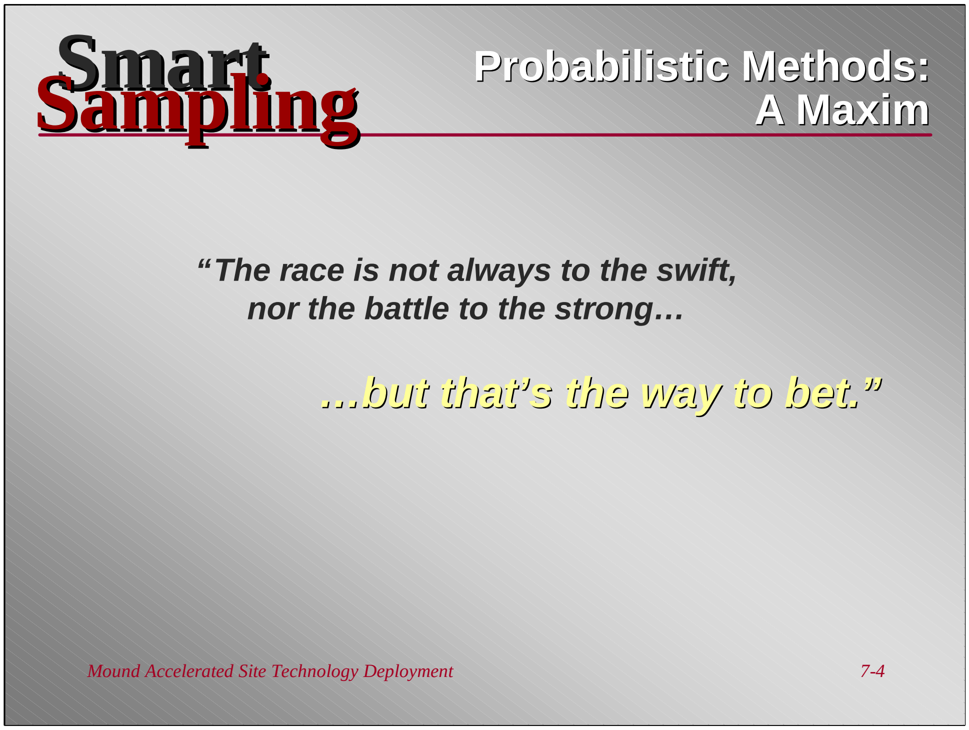
Smart Sampling

Economic Analyses in Environmental Studies

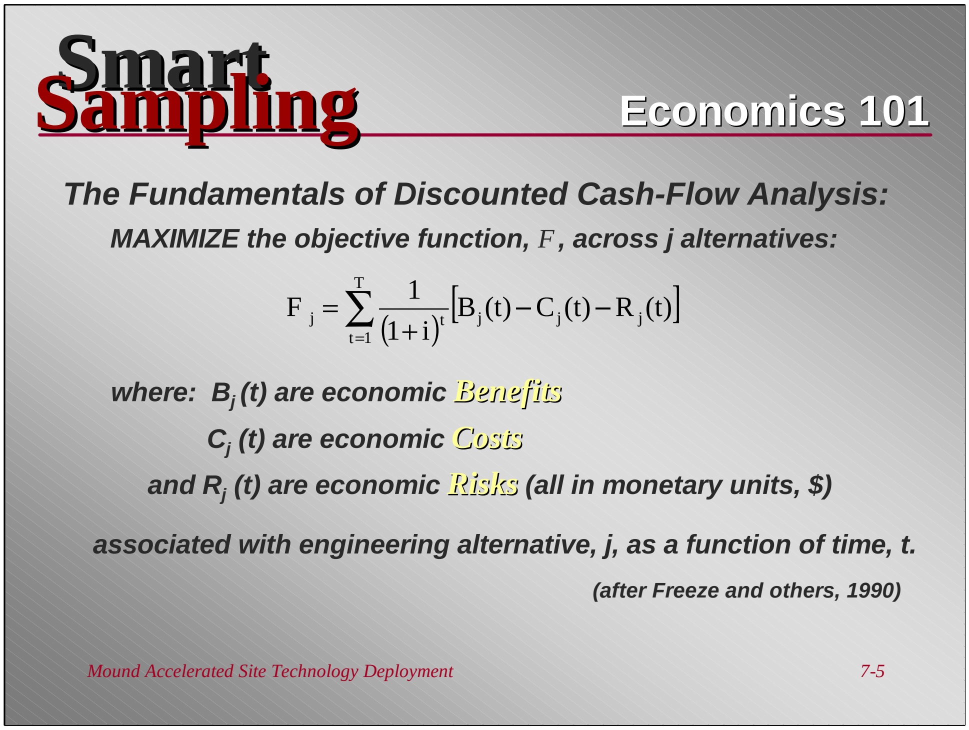
- *Environmental studies typically are decision-driven.*
- *Need to make decisions about:*
  - -*Is this site contaminated?*
  - -*How many samples should we take?*
  - -*What clean-up process should we use?*
  - -*Where do we send the bulldozer?*
  - -*What happens if we goof?*
- *Decisions for action (or for inaction) have economic consequences.*



We know we can never be completely accurate. The question is, can we get close enough that the consequences of our decisions are livable?



Basically the purpose of the geostatistical process of SmartSampling is to come up with a good way to bet.

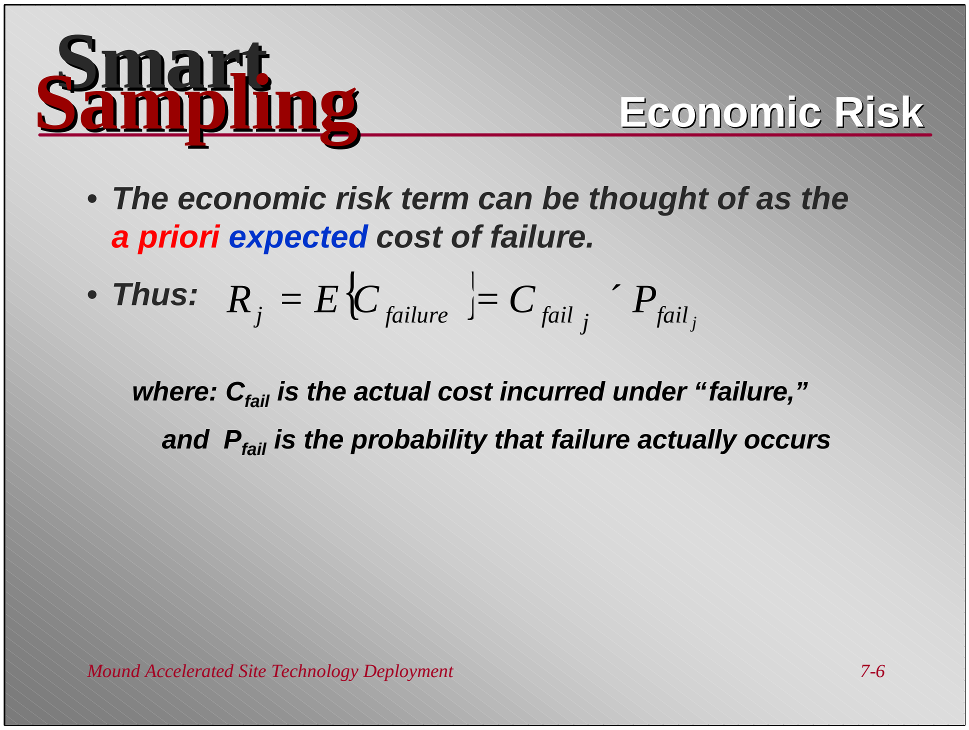


i is the interest rate

t is time throughout the life of the project, company, etc. (usually 5-7 years)

$$\frac{1}{(1+i)^t}$$

is the discount term which adjusts the flow of cash today to how much that flow of cash would be worth at an arbitrary time in the future.



The risk term is your estimate of what it is going to cost if you fail to meet remediation goals. It's computed simply as the cost of the failure (if it occurs) times the probability of the failure. This estimate is made before a failure occurs.

Obviously, if you knew that the plane was going to crash, you would not have gotten on. You have to evaluate the probability of a crash every time you get on an airplane, and "live" with the consequences after the event has passed.

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Optimization Through Trade-Offs

Consider planning for a new landfill:

- ***Do we construct using a clay liner (alternative j = 1) or clay plus synthetic fabric (alternative j=2)?***
  - ***Benefits, B(t), (the income stream from operations) most likely will be the same with or without the synthetic liner.***
  - ***Costs, $C_2(t)$, will be greater than $C_1(t)$, because of the added capital cost of the synthetic liner.***
  - ***Risk term, $R_1(t)$, will be greater than $R_2(t)$, because of the greater likelihood of "failure," defined as leachate escaping from the landfill and creating a contamination problem.***
- ***Which alternative has the greater Net Present Value (F)?***

Smart Sampling — Economics 102

Reality check for environmental sciences:

- *There are rarely "economic benefits" in the conventional sense of an on-going revenue-stream involved in most environmental remediation projects.*
- *Hence, it may be considerably more simple to think of the objective function in terms of a cost-minimization exercise.*

MINIMIZE (across j alternatives)

$$\Phi_j = \sum_{t=1}^{T} \frac{1}{(1+i)^t}\left[C_j(t) + R_j(t)\right]$$

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The function above shows the economic objective function restated without the benefits term.

Most environmental remediation benefits are non-economic (allowed to continue business, no jail time…). The most "beneficial" reclamation activity is to choose an engineering alternative that minimizes the risk of incurring a cost.

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Economics 501: the graduate level course

- ***The point is not the academic sophistication of one's analysis.***
- ***Rather, the point of an objective function is to make one think rigorously and objectively about the consequences of various decision alternatives.***
- ***It is also helpful to use an analytical framework that promotes communication and which is acceptable to all stakeholders in an environmental decision.***

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Time Value of Money

- *The discount-rate term,* $\frac{1}{(1+i)^t}$ *, is intended to allow for the fact that near-term cash* values *are more "certain," and thus more valuable than cash* values *far in the future.*
    - *A corollary, however, is that cash flows discounted more than perhaps 5–7 years contribute vanishingly small amounts to the net present value.*
- *This requires either great care in projecting the amount of those future cash flows (adjustments for inflation, etc.) or neglecting the discount-rate term (in effect stating that today's costs in today's dollars are directly relevant).*

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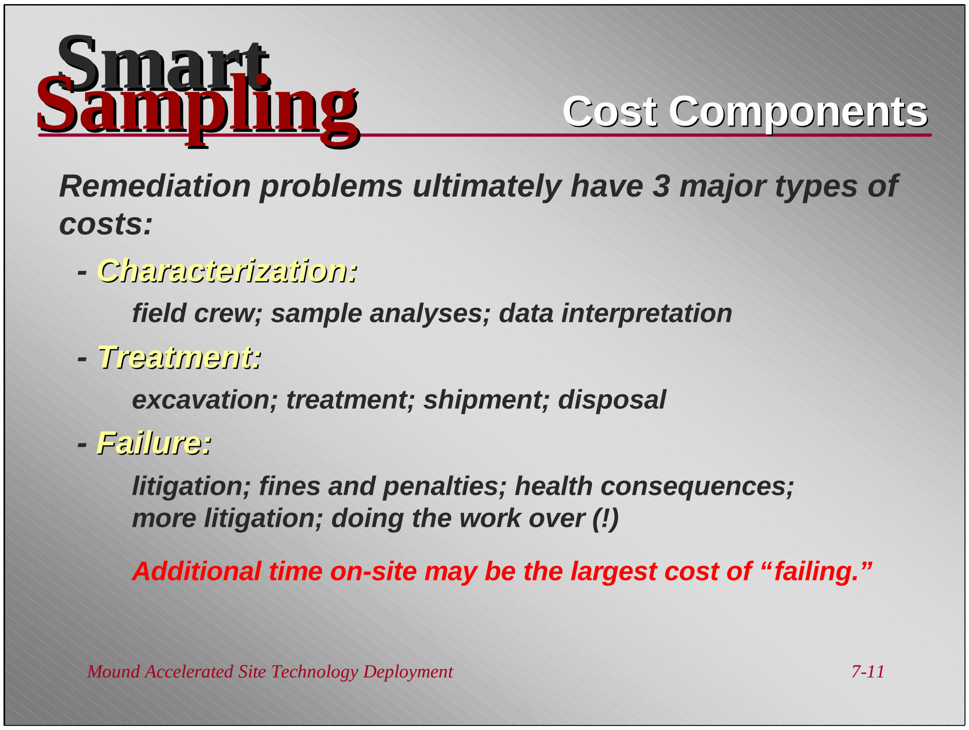
For government remediation projects that are funded on a year-to-year basis, the only functional approach is to drop the discount-rate term and use today's costs/dollars to solve the function.

Chris - work up the sweepstakes analogy - initial cost of a million dollars over 50 years - to explain discounted cash flow / time stuff?



To achieve the information that application of SmartSampling provides, you have to reduce things to the common denominator of money. If you can't quantify costs, you cannot do an engineering evaluation.

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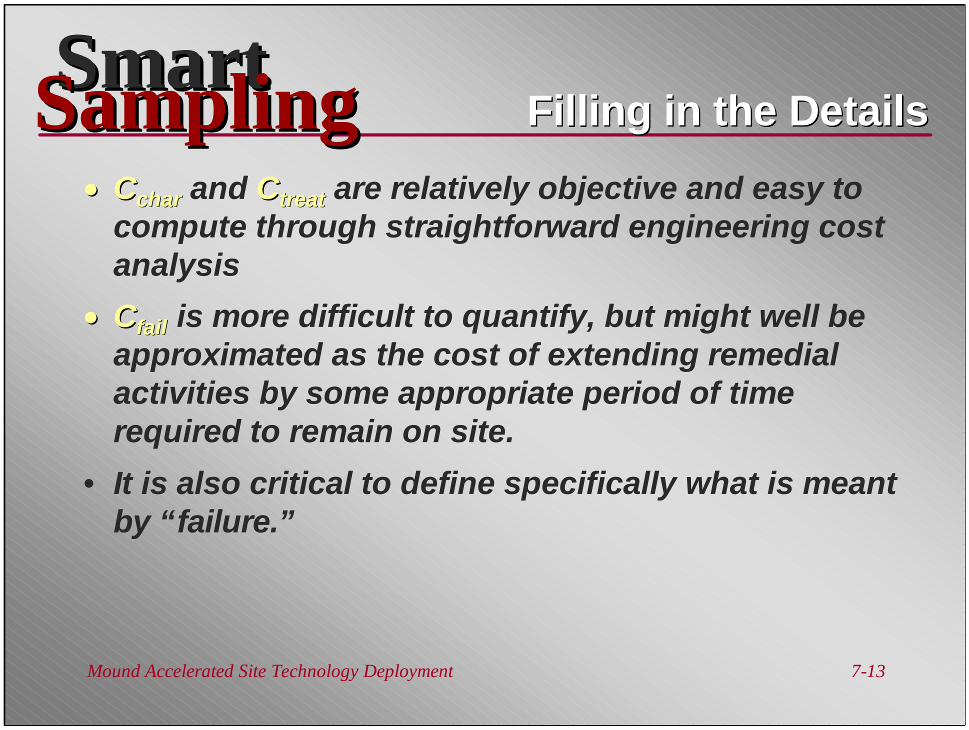
Cost Minimization

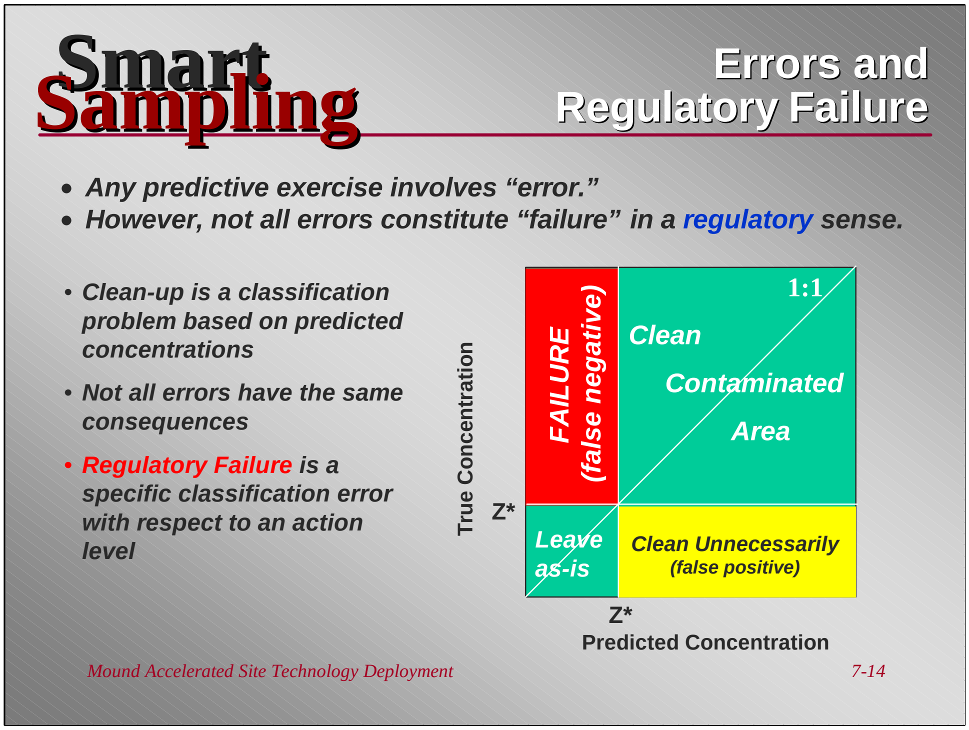
- *Usually, there are a number of alternative remedial efforts that can be proposed for an environmental problem.*
- *For a set of alternatives i =1, 2,…, N, we want to select the alternative solution that **MINIMIZES** total cost:*

$$C_{total\,i} = C_{char\,i} + C_{treat\,i} + C_{fail\,i} \cdot P_{fail\,i}$$

where: C_{total} *is total cost*
C_{char} *is cost of characterization*
C_{treat} *is cost of treatment*
C_{fail} *is the cost of failure*
and P_{fail} *is the probability that such failure occurs*

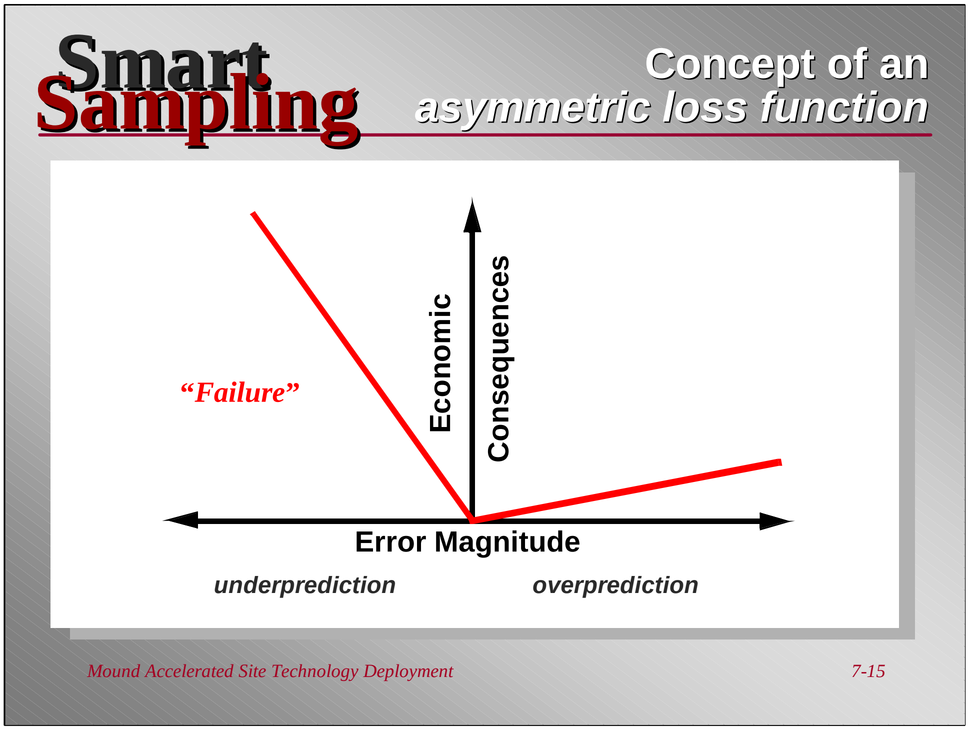


If you're spending 200 million dollars a year on a remediation program and you expect that if you fail to meet your goals it would cost you at least another five years on site, you have a billion dollar cost of failure (an order of magnitude).

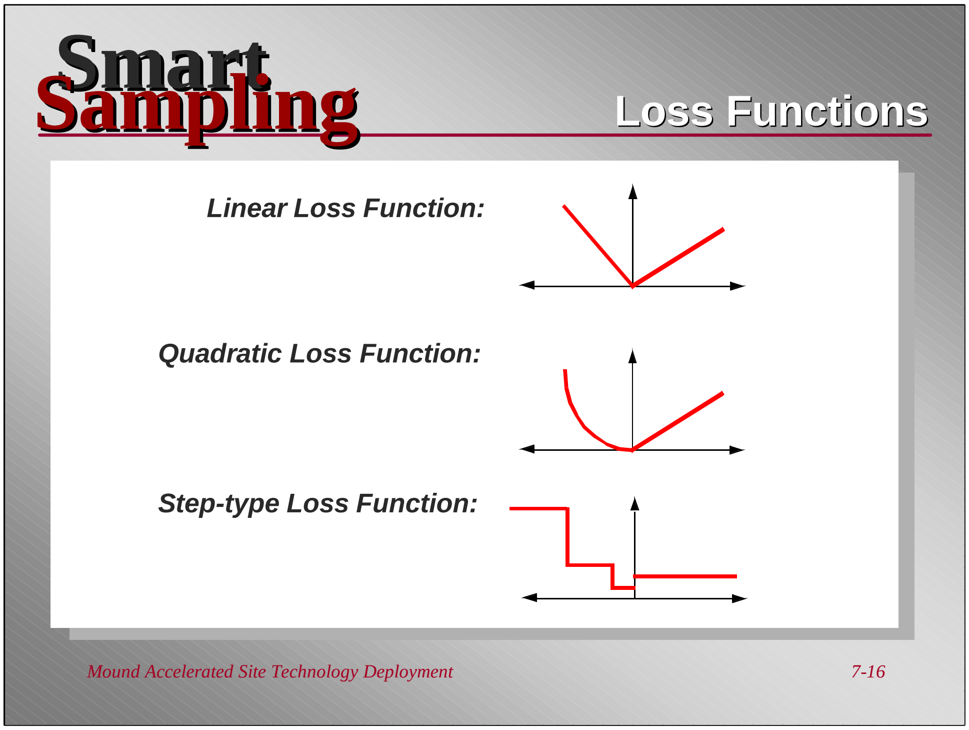


Z* is the critical threshold of interest.

If you predict that an area is contaminated and it is not, you incur some unnecessary costs remediating soil that does not require it. Regulatory bodies probably don't care about this kind of error. However, if you predict contamination below threshold in an area and the actual concentration is above it, the error is a regulatory failure and penalties will be assessed.



The consequence of underprediction (false negatives) is Regulatory Failure. The consequence of overprediction (false positives) is unnecessary cleanup.



Different loss functions apply to different sorts of failures.

Categories of failures include:

- Small number of small value errors
- Large number of small value failures
- Small number of large value errors
- Large number of large value errors

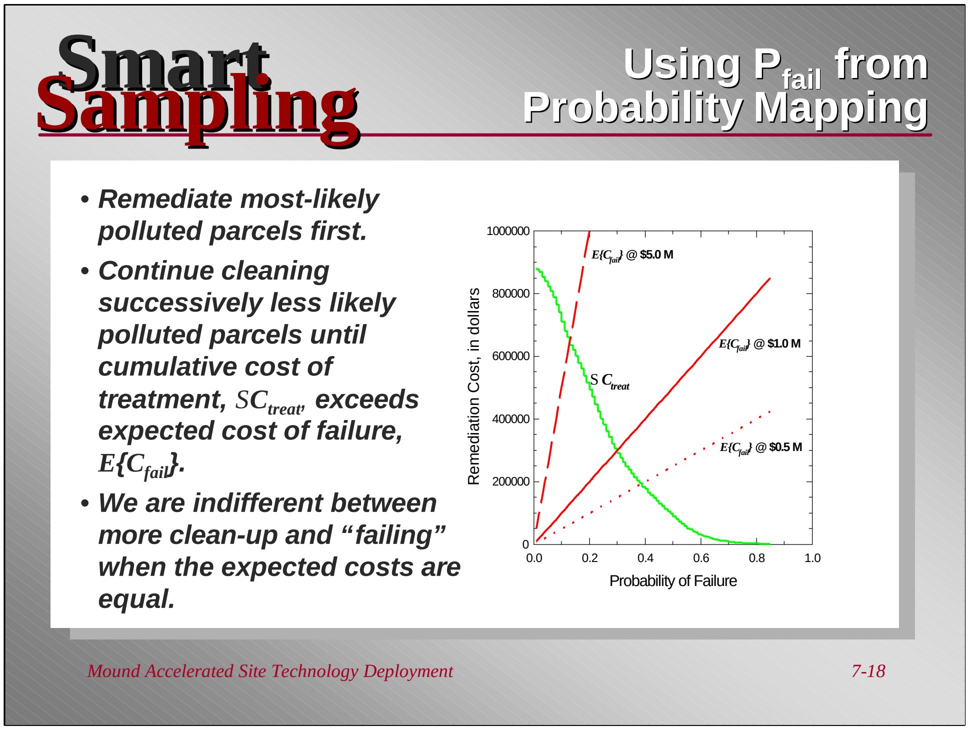
If lots of differing value failures, would need another axis showing # of failures vs. magnitude of failures.

Sites need to know the costs of these categories of failures (from regulators) to integrate them in their risk term.

Smart Sampling

Estimating the Probability of Failure

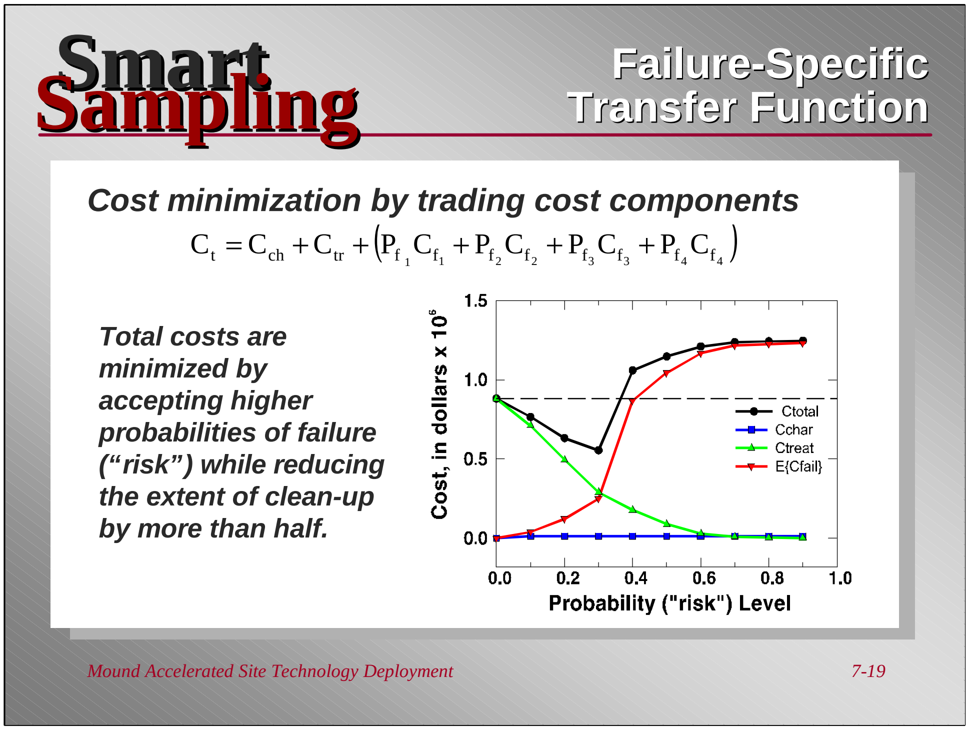
- *To apply the cost-minimization approach, we require a quantitative and relatively objective method of estimating the likelihood of "failure" P_{fail} .*
- *P_{fail} can be estimated **empirically** in one of two ways:*
  1. ***Direct probability mapping using geostatistical simulation or indicator kriging.***
  2. ***Post-processing a suite of simulated models through a failure-specific transfer function.***



Green line: cost involved in remediating total number of panels

Red lines: expected costs of failure at various actual costs

Minimum total cost function is at point where the two costs are equal (where the red and green line intersect).



This example is from project work at Fernald.

Cost of characterization: this is shown as a constant. It was a relatively small cost, task already completed with no plans for further performance.

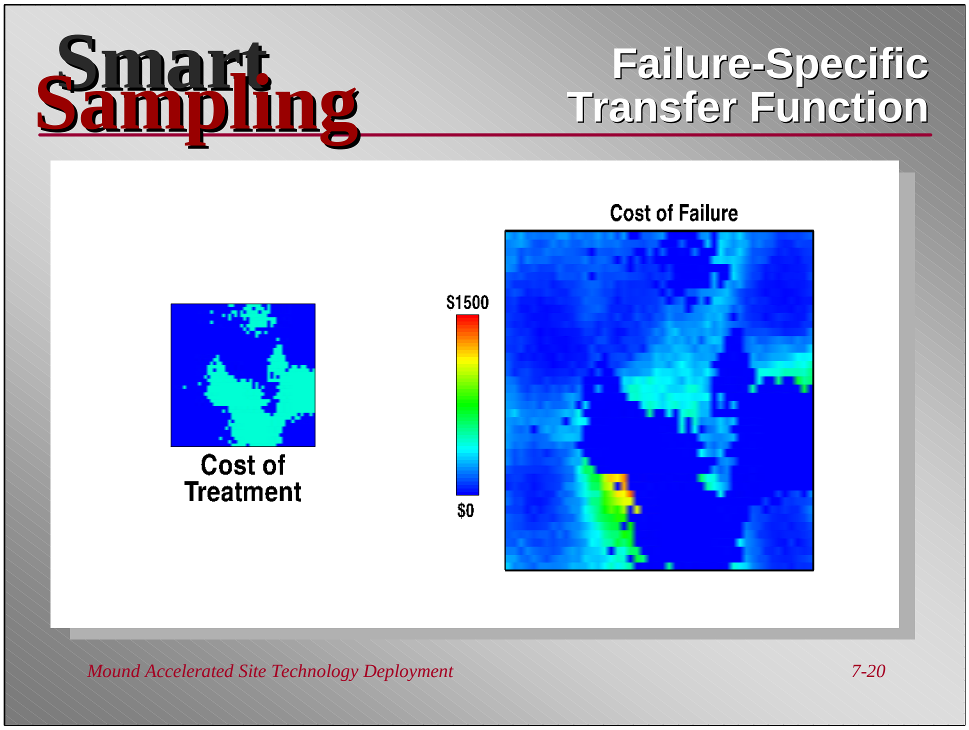
Cost of treatment drops successively as the least contaminated panels are removed from equation

Cost of failure: 4 different failure costs and associated probabilities of failure

- C_{f_1} If you made a few small-value errors; consequence: no penalty cost, had to "pick up the garbage"
- C_{f_2} If you made a lot of small-value errors; consequence: assumption that you were not doing it right, penalty plus "pick up the garbage"
- C_{f_3} If there were one or two major errors; consequence: a particular cost associated and "pick up the garbage"
- C_{f_4} If there were many major errors; consequence: assumption of flagrant and fraudulent representations and "Throw the book at them"

The **minimum total cost** is where costs of treatment and failure are equal.

Chris - on our recording, you mention clarifying the set up for this. Also, it could use an explanation of the Total Cost graph.



These maps show the cost of failure in an aerial sense. Maps are spatial expression of P_{fail} times C_{fail}.

Smart Sampling — Concept of Data "Worth"

- *Additional sampling has no "worth" or "information content" if it does not change the decision or reduce uncertainty.*
- *Examples:*
  - *continued sampling in the immediate vicinity of several samples all of which are markedly over the relevant action level.*
  - *continued sampling in regions of extensive background levels.*
- *Additional sampling should emphasize regions of maximum uncertainty*

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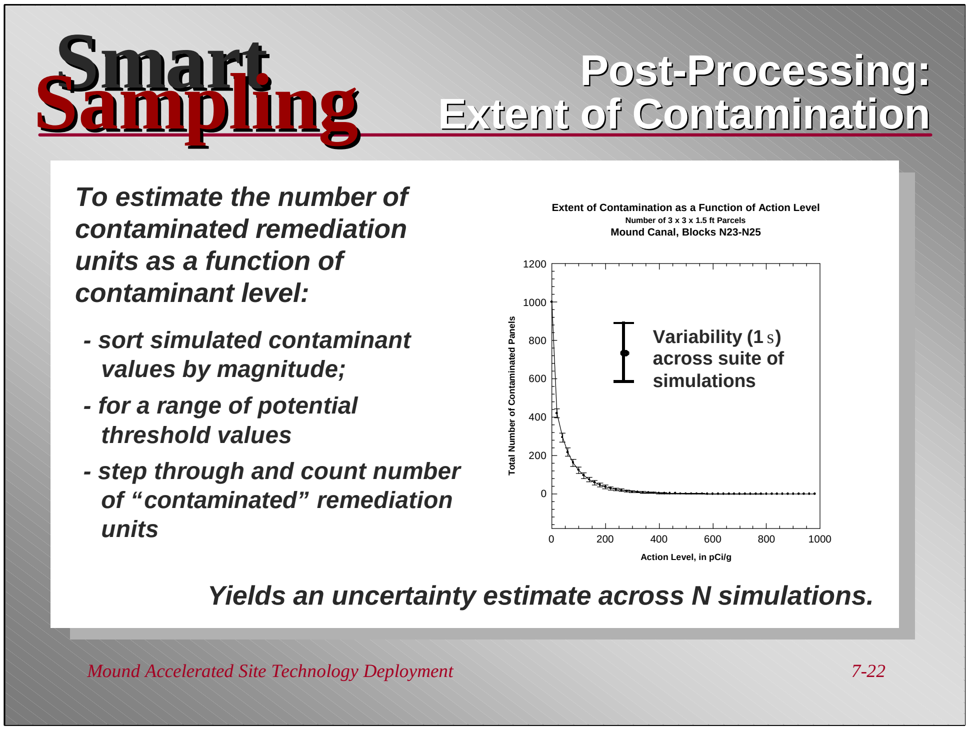
Point of geostatistics is to use spatial continuity information to help make predictions into unsampled areas.

If the probability of failure is .5 at a location, you have an equal chance of making the right or wrong decision. That's the point at which additional sampling gives you "the biggest bang for the buck."

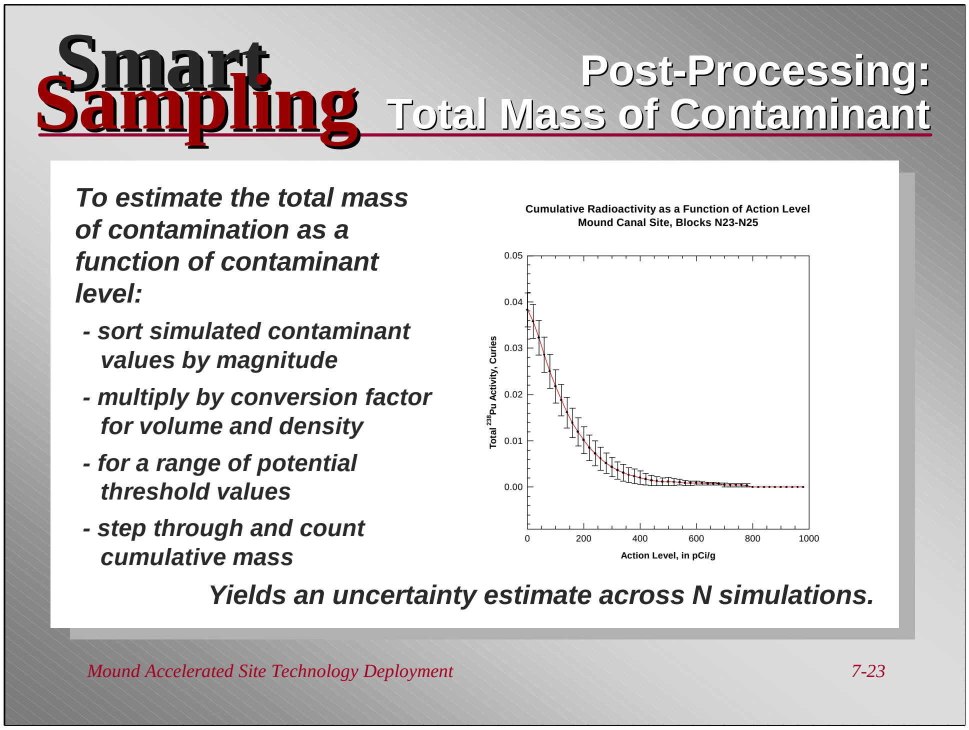


To do this post-processing, set the remediation unit size by the size of the remedial “spoon” (eg. a teaspoon, a bulldozer with 10’ blade, etc.). You can then estimate the concentrations for each panel, sort them from highest to lowest and and count the number of contaminated panels for a range of threshold values.

The solid line in the graph is the empirical estimate, the most likely number of contaminated panels at each action level. Across N simulations you’ve got an uncertainty estimate because in some simulations there will be a few more panels above threshold; in some simulations, a few less. 1 sigma standard deviation around the number of contaminated panels at each action level shows the uncertainty.

This is a mechanical exercise. You iterate the computer from 0 to 1000 by 10 or by 5 or by 2 (whatever you choose), process your suite of simulations and make your estimate of uncertainty.

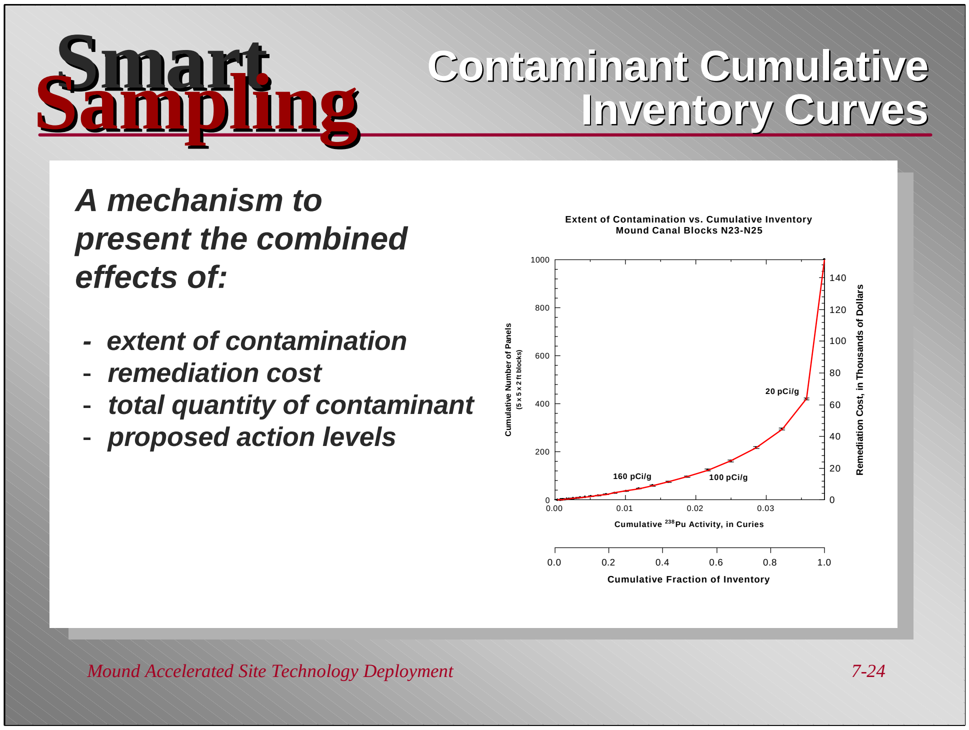
This graph shows that there is very little contamination at the site that is higher than 200 pCi/g and that if an action level of 0 is insisted upon, everything must be cleaned up.



Here is another way of looking at the same information. This graph depicts the estimated total radioactivity, in Curies, as a function of action level.

You can see that one or two panels with really high values contribute the most mass to the overall problem, whereas many panels with relatively low contamination levels don't add up to a whole lot of actual material.

The graph also shows that there is a fair amount of uncertainty, particularly at low action levels, but as you get to higher and higher action levels, the modeling has made fairly tight predictions of the total amount of material loose in the environment. If you remediate the most contaminated panels first, at some point you have gotten most of the contamination and you still have done a fairly simple remediation program.



The same information has been recast again in this graph.

The cumulative total amount of plutonium has been brought down as a fraction (0 to 100%) of the total inventory (scale below graph)

The total number of contaminated panels (scale on left) relates directly (at a fixed cost per panel) to the remediation cost (scale on right).

In this example, moving from an action level of 20pCi/g (95% of inventory of loose plutonium) to 0pCi/g (100%of inventory) doubles the cost of the remediation program.

There are error bars associated with each one of these estimates. It's a standard deviation across a hundred realizations (66% of the realizations were within the error bars).

These last three slides are all different ways of looking at the same information.