The Valuation of Contaminated Land[†]

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***Abstract*. This study presents a Monte Carlo-based method for explicitly accounting for uncertainty in the valuation of contaminated property. Environmental risk is being quantified by the scientific methods described in this work. Financial risk is also quantifiable by these techniques. A 1993 Supreme Court case known as *Daubert* has changed the admission requirements for scientific evidence by expert witnesses. Hoyt (1997) notes that it is "imperative that real estate appraisers who testify be sure that their scientific evidence will stand up to the scrutiny of Daubert or their testimony may be rejected." A scientific method of quantifying the unique financial risk of this type of asset is used for the valuation of contaminated land. It has been noted that the insurance industry uses a similar technique in order to calculate premiums for providing insurance for contaminated sites, providing market acceptance as a *Daubert* factor for admissibility.**

Introduction

The valuation of undeveloped land can be one of the most challenging appraisal assignments. One of the reasons can be the uncertainty of its highest and best use. Another is the uncertainty of the timing of its highest and best use, due to business cycles and other factors. The assignment becomes even more challenging when it is found that the land is seriously contaminated. The contamination might alter both the highest and best use of the land and the time required to obtain the regulatory approvals that are required to develop the site.

A client will often ask an appraiser to simply value the land under the assumption that it has no contamination. In other cases, the client may provide the appraiser with an estimate of the cost of remediating a contaminated site. The expected assumption is that the property be valued by simply subtracting the estimated remediation cost from the value of the acreage, assuming that it has no contamination. Both of these scenarios have occurred because, as Simons (1998) notes, there are few appraisers with training adequate to place a value on a contaminated property "as is".

The following is an example of an actual appraisal problem that was used to create a presentation for a study dealing with stigma. The property is referred to as Property A

> A developer wanted to build a shopping center on Property A, a site that cost \$48 million. The purchaser paid \$24 million in cash and financed the balance with a \$24 million loan. Some contamination was found while soil borings were being done for the foundation. A remedial investigation was subsequently made. The resulting 'approved' cost of cleanup was estimated at \$8 million.
>
> Let's say that this \$8 million cost is financed by a second trust deed. The appraiser for the transaction valued the property at \$40 million, 'as-is,' or

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> subject to the contamination. Many would say that a loss in value due to stigma would also occur. If you were the owner of the second mortgage and the owner of the first mortgage foreclosed, would you pay the $24 million required to protect your interest? If not, you have lost $8 million. You would be buying the property -- and its contamination -- for $24 million. How many of you would pay off the $24 million dollar mortgage?

A methodology is needed to quantify the downside risk of the $8 million remedial cost seriously understating what will eventually be the total remedial cost in order to answer questions like these. What about the risk of the land losing value while the remedial action is in process? It could well be that the land could lose its highest and best use during this time frame due to the development of other nearby retail sites.

Lenders are not the only ones that need to have these risks quantified. Any purchaser of contaminated land needs to quantify the financial risk. There is also a need for accuracy for corporate balance sheets. If a major environmental liability is not recognized, the value of an asset can be significantly inflated.

Summary of the Literature

As Guntermann notes (1995), there is a significant amount of literature that documents reductions in property value around toxic, chemical and solid waste landfills and an emerging literature on stigma-related damage. The literature referenced in this study was confined to that dealing with the valuation of land that is itself contaminated, not other real estate that is near a contaminated site.

The seminal article by Patchin (1988) provided some examples of how he has valued contaminated property, including one example of how he valued contaminated land - the topic of this study. In the example, he included the cost of cleanup as a line item number and did not discuss the uncertainty of the estimate. The example also assumed that the land lost its highest and best use, since technological constraints precluded remediation to the point where its prior highest and best use would have been allowed. Patchin noted that when some appraisers found that a property was contaminated, they assumed that it was unmarketable and therefore that it was worthless. Patchin disagrees by saying, “the extent and nature of the contamination are the crucial factors in estimating the after value of a contaminated property.”

In his second article, Patchin (1991) dealt specifically with the concept of stigma that he broadly defined as a loss in value beyond the cost to cure the contamination itself. He went on to list stigma as being caused by the following factors:

1. Fear of Hidden Cleanup Costs
2. The Trouble Factor
3. Fear of Public Liability
4. Lack of Mortgageability
5. Residential vs. Commercial
6. How Clean is Clean?

Patchin discussed the uncertainty in cleanup cost under the first item above and quotes Houston (1989) as saying that “If the estimated cleanup cost is ‘X’, . . . the typical buyer will deduct '2X' from his purchase offer. Both Patchin and Wilson describe each contamination problem as being as unique as a fingerprint and Wilson (1992) stated that that a consultant should provide a variety of costs. These are the most probable cost, the expected cost and a probable cost range. He gave an example of the cost range from a current assignment. Wilson quoted costs that ranged from a low of $5.5 million to a high of $63 million.

The second issue refers to the return that should be allocated to an entrepreneurial effort that is required to deal with the contamination. An allocation for entrepreneurial profit can be readily made by the use of a developmental approach to value.

The third item refers to the possibility that soil contamination will seep onto another owner's property. The likelihood of this seepage happening can be assessed by the use of soil borings from a remedial investigation and can also be quantified.

In the discussion of the fourth factor, Patchin provides an example of a situation in which a property owner cannot get financing for new construction until the remediation has been completed. The prospective future value at the time of completion of the remediation is discounted for the five years of delay required to clean the site.

Healy and Healy (1992) and Kinnard (1996) surveyed lenders to find out how decisions on lending are affected by contamination issues. Both surveys found that one of the greatest concerns on the part of lenders was groundwater contamination. Kinnard devised a survey that shows 35.6% of lenders and 25% of investors avoid property with known soil contamination. The survey results also show that 45.8% of lenders and 41.1% of investors avoid property with known groundwater contamination. Soil contamination can lead to groundwater contamination in some situations.

With regard to the fifth factor, he states that market reactions to contamination differ according to whether the property is residential or commercial. And the sixth factor deals with the uncertainty of the level of cleanup that is required. The cleanup level is expressed as allowable levels of risk to the health of the nearby population, because of the contamination that remains in the soil after remediation.

Mundy (1992a) referenced Patchin's latter article and quotes seven criteria from another reference used to evaluate and determine the degree of stigma. Mundy says that stigma results from perceptions of uncertainty and risk. He noted that it may be relatively easy to quantify a simple contamination problem, but that as the complexity of the contamination increases, the level of uncertainty and perceived risk rises. Mundy then goes on to differentiate between real and perceived risk. Perceived risk is the risk envisioned by those who do not understand the true risk of the contamination.

Perceived risk could account for the differences that Patchin observed in stigma in residential vs. commercial properties. Very few homeowners are able to quantify environmental risk. Most buyers of commercial properties have environmental site assessments prepared. A buyer of a commercial property that did not have a study done to quantify the risk of contamination is not well informed.

Both Mundy (1992b) and Wilson (1994) discuss the variation in value (or lack of) at varying points in time. It is acknowledged that there may be no market for a contaminated property (and no value) until the seriousness and extent of the contamination is quantified. The contention is that a property increases in value while the site is being remediated and that the stigma may eventually disappear.

Mundy (1992b) and Chalmers and Roehr (1993) focus on quantifying the loss in value of improved property by using cash flow analysis that provides for a remedial cost estimate over a ten-year or so holding period. The discount rate that is used is supposed to reflect stigma by accounting for the "increased risk associated with the contaminated property," which the authors say is difficult to justify.

Lizieri, Scarlett and Finlay (1995) surveyed market participants in the United Kingdom in order to find out how they were dealing with the issue. They found a range of valuation methods that were used. The methods "range from their traditional all risks yield approaches and direct application of costs, through yield decomposition techniques to explicit discounted cash flow scenario modeling approaches and real option pricing models." They concluded that "the property industry is well able to identify problems, but is some way from establishing solutions."

Dixon (1995) concludes from his study of contamination issues in America that a systematic approach to valuation / appraisal of contaminated land is essential. Dixon refers to Wilson (1992) and his contention that a valuation "team" approach consisting of experts in such areas as appraisal and engineering be used and that an appraiser should be the manager of this team. Dixon also provides a quote from Campanella (1995) who sees the appraiser as a synthesizer of all relevant information, including remediation costs.

> The appraisal professional is both the beginning and the end of the valuation process, providing the unimpaired value opinion from which all of the adjustments to value are made and providing the market place insight and technical value adjustment skills required to arrive at the impaired value opinion.

Weber (1996) agreed with Wilson and Campanella and described how the techniques used to quantify environmental risk to human or other biologically valuable receptors could also be used to quantify the financial risk of the contamination. This work described the remedial investigation and feasibility study that is required in the United States for a seriously contaminated site. It also addressed the uncertainty that any one remedial method would be chosen and the Applicable and Relevant and Appropriate Requirements (ARARs) that govern which method is chosen.

More recently, Chalmers (1996) notes that the quantification of risk in light of particular, site-specific factors is the most challenging part of the valuation problem. Chalmers states that risk analysis and quantification must begin with the perceptions of market participants. If the potential buyers of a site are well informed, perceived risk would equal real risk, as defined by his earlier article.

Jackson, Dobroski and Phillips (1997) note that all real estate has risk, but the type of risk that keeps real estate from selling is the risk that cannot be defined or quantified. They have concluded that sellers, lenders and buyers need to understand all of the risks in contaminated real estate and that it is necessary to quantify the risks associated with a specific property. He states that this risk is "always dependent on that property's unique environmental, locational, market, regulatory, and other characteristics." This study deals specifically with a methodology for quantifying the above-described risk.

A Thesis for Investigation

A number of consultants, e.g., Patchin (1988), Wilson (1992, 1994) and Roddewig (1996) have taken issue with the use of comparable sales for the valuation of contaminated land.

This opinion is understandable since each site is unique relative to a number of attributes. References on hydrology and other soil sciences, such as Dragun (1988), Fetter (1994) and Freeze and Cherry (1979) show that, even if two sites otherwise identical (above grade) could be found with contamination, the type and extent of the contamination, the difference in subsurface conditions and proximity to an underground water supply could result in one site having one thousand times the environmental, and hence financial, risk of the other site. Travis and Doty (1990) note that some sites may not be capable of remediation.

Since comparable sales are not likely to be useful in valuing sites with a significant contamination problem, a different valuation thesis will be investigated. The thesis is that a development model that would take into consideration the uncertainty of the remedial cost and prospective future value upon completion of the remedial effort would provide a more reliable estimate of value. The model would make use of Monte Carlo sampling to quantify the financial risk of successfully remediating a site.

In order to illustrate this point, let us assume that three sites at three corners of the same intersection shown in Exhibit 1 have all been contaminated. One from a gas station, a second from a dry cleaner and the third from a car repair business.

Assume that Property A, the site discussed in the Introduction, is located at the northwest corner of the hypothetical intersection of X and Y streets. Property B is located at the northeast corner; Property C, at the southwest corner of the same intersection. These sites are identical except for the type and extent of their contamination. Each has a value of $20,000,000 if not contaminated, as indicated by the recent sale of Property D, located at the southeast corner of the same intersection. The remedial costs of the three sites have been simulated, and the resulting frequency distribution has been overlaid on the locations of each property on the map.

Relatively common forms of continuous distributions have been overlaid upon the simulation of each remedial cost. The assumption implicit in the lender's appraisal was that the probable remedial cost for Property A was normally distributed, similar to that of Property C. The risk analysis shows that the distribution of remedial cost for Property A is much more skewed. It is similar to a Weibull or Gamma distribution. Property C is identical to the sites on the other three corners of X and Y, with the exception of the type and extent of contamination. C's contamination is all near the surface. It will cost, at most, $8.6 million to dig it all up, move it all elsewhere, and fill in the excavation.

A geographic information system (GIS) was used as illustrated by Exhibit 2, to show that the contamination has seeped further into the soils at Property A. This GIS program can also calculate the environmental risk to humans from polluting the groundwater below the site—the only local source for drinking water. The minimal remediation cost is $8,000,000. If it does not work, a different action with a cost of $20,000,000 will be required. There is still a risk that a $43 million remedial cost might be required to remediate this site. How should the properties be valued?"

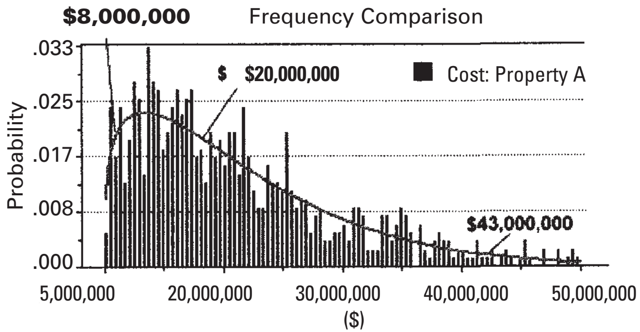
The Data for the Analysis of Property B

The prospects of incurring large financial losses led to the development of a method of quantifying the financial risk involved in acquiring a contaminated site. It applies to sites that have had a preliminary investigation, which concludes that contamination is likely. This financial risk stems from the possibility that a potential buyer of the site might have to pay for very expensive remediation.

Exhibit 1
Relative Financial Risks of Three Contaminated Sites

Risk Profile: Property A

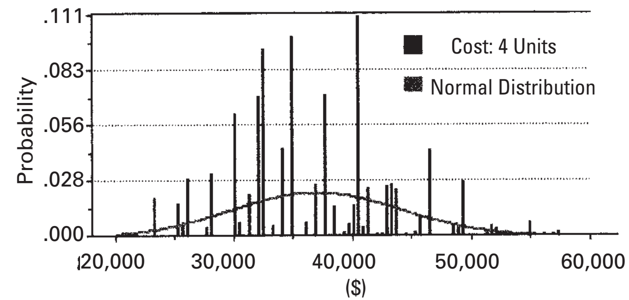
Frequency Comparison



X Street

Risk Profile: Property B

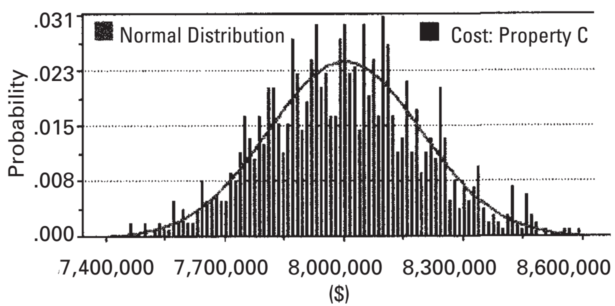
Frequency Comparison



Y Street

Risk Profile: Property C

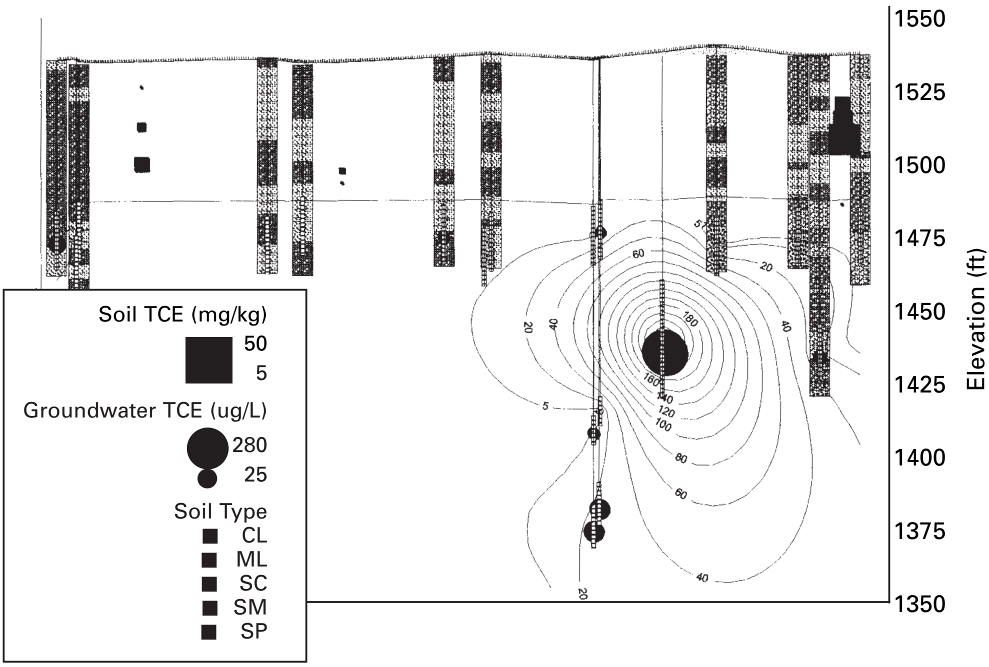
Frequency Comparison



Property D: No Contamination

Land Value is $20,000,000

Exhibit 2
Example of the Use of a Geographic Information System for the Characterization of Contamination



Source: EMAGIS, Market Foresight

The data for the analysis of hypothetical Property B came from actual cost estimates for another "test" property. The reversionary value in the example is also from the other property. The distribution of uncertain cost is the only item from the analysis that follows that is used to illustrate the risk in purchasing Property B in Exhibit 1.

Property B is representative of a number of sites that contain underground storage tanks and connecting lines for filling and dispensing material. The material could become a hazardous waste if it were to leak from its container. The financial risk stems from the likelihood that a leakage could have occurred anywhere in the underground system. This leakage could result from improperly pouring toxic chemicals down drains in the past. If so, the chemical could endanger the health of the surrounding population and would require removal.

The possible sources of contamination are described in terms of four units:

- Unit I the underground tank and filler / dispenser lines;
- Unit II an oil drain pit;
- Unit III a waste oil tank;
- Unit IV a clarifier.

An engineer performed a Phase II Environmental Site Assessment in order to confirm the presence of contaminants. It revealed oily residue in the surface soils over most of the site. Tests showed that metals and petroleum hydrocarbons were present at a variety of locations and depths. There were three locations where gasoline components were present and there was some hazardous waste in the clarifier unit.

The process requires that each unit be analyzed to determine the risk of the buyer having to incur extensive cleanup cost. The risk analysis involved:

- breaking the in-ground construction into logical components;
- identifying major events (listed in the exhibits as Remedial Uncertainties);
- estimating the likelihood and cost of each event; and
- deriving a probability distribution of potential costs.

The risk analysis goes beyond traditional single-point engineering estimates of the most likely, optimistic and pessimistic costs. Environmental engineers are surveyed. These engineers develop a range of possible outcomes from the remedial investigation and the cost of each outcome. The experts also provide the probability of incurring each cost. An event tree lists each of the units. The tree shows the possible remedial requirements and the resultant cost of each one.

The Conceptual Model

The solution to the problem was to structure it as a land development model. There are five sections in Exhibit 3: one section for each of the units and one section for the reversionary value of the remediated site. The reversion is an estimate of the prospective future value of the site.

Exhibit 3
Land Development Model Analogy

		Remediate Unit I			
	A	Cost 1×P(Cost 1)	+ Reversion @ Time=2?		
	B	Cost 1×P(Cost 1)	+ Cost 2×P(Cost 2)	+ Reversion @ Time=3?	
		etc . . .			
		plus			
		Remediate Unit II			
	A	Cost 1×P(Cost 1)	+ Reversion @ Time=2?		
Present Value of Periodic Expenses and Reversion (Future Land Value)	B	Cost 1×P(Cost 1)	+ Cost 2×P(Cost 2)	+ Reversion @ Time=3?	
		etc . . .			
		plus			
		Remediate Unit III			
	A	Cost 1×P(Cost 1)	+ Reversion @ Time=2?		
	B	Cost 1×P(Cost 1)	+ Cost 2×P(Cost 2)	+ Reversion @ Time=3?	
		etc . . .			
		plus			
		Remediate Unit IV			
	A	Cost 1×P(Cost 1)	+ Reversion @ Time=2?		
	B	Cost 1×P(Cost 1)	+ Cost 2×P(Cost 2)	+ Reversion @ Time=3?	
	C	Cost 1×P(Cost 1)	+ Cost 2×P(Cost 2)	+ Cost 3×P(Cost 3)	+ Cost 4×P(Cost 4)
		etc . . .			
		plus taxes, etc . . .			
		Total Cost: Sum (Cost 1)	Sum (Cost 2)	Sum (Cost 3)	Reversion @ Time X
		Time: *T*=1	*T*=2	*T*=3	*T*=4, etc.

Starting with Unit I, there is a chance that remediation of the underground tank might be complete in step A by simple excavation. The reversion might occur at Time $T=2$, if step A in each section resolves all of the potential problems.

Chances are that at least one of the units will require steps B or C, etc. If this happens, it will both add an additional "development cost" to the timeline and push the reversion further into the future. This is because regulators will not provide a letter of No Further Action (NFA) until all of the units are satisfactorily remediated.

The probability of each of the steps having to be taken quantifies the "Chances" referred to above. Multiply each cost by its probability to determine the subtotal for each cost. The next step adds the subtotal cost. The bottom line of Exhibit 3 shows the total remedial costs for all of the units, followed by the reversion.

This model simulates the process thousands of times, collecting the present value that results from each iteration. The model takes all of the value estimates and creates a probability distribution of the value. Exhibit 4 provides more detail on the probabilities for one of the units.

The appraiser uses the range and probability distributions of the major costs that were provided by the engineers and assigns the likelihoods to the potential outcomes for the construction of the event trees. The decision tree for Unit IV, the clarifier and leach field, is shown in Exhibit 4.

A detailed description of the simulation and its inferences may be noted by reference to the Addendum. Exhibit A1 therein shows the simulation of the remedial process for each of the units. Exhibit A2 shows the resulting probability distribution for remediating Unit IV and Exhibit A3 shows the probability distribution for the total remedial cost.

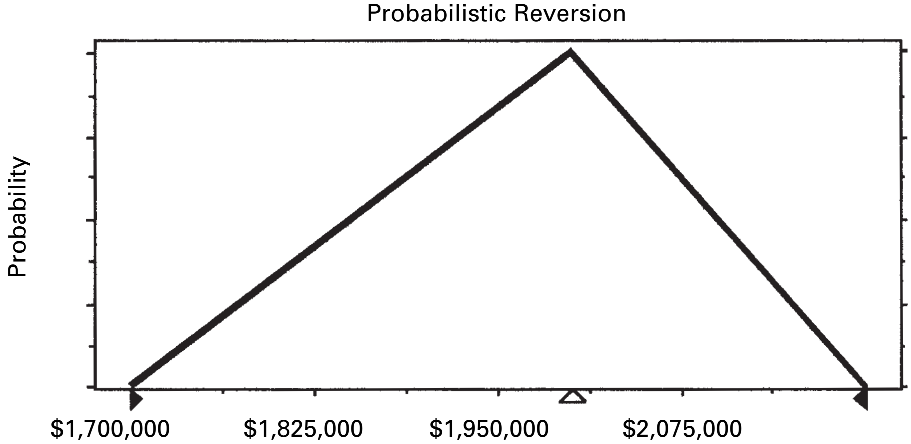
A number of papers were presented on business cycles at the first meeting of the International Real Estate Society. Real estate researchers from Australia, Great Britain, Stockholm, and other parts of the world have noted declines in property values resulting from overbuilding as a result of the business cycle. Jeffries (1996), The Royal Institute of Chartered Surveyors (1995) and Born and Pyhrr (1995) noted the problems in assuming constant trends in values. The method described here can also be used separately from a valuation model for improved property that takes into consideration business cycles. In

Exhibit 4
Decision Tree for Risk Analysis of Operable Unit IV

IV Clarifier & Leach Field

	Column:	1	2	3	4	5	6
	Remedial Uncertainties		NFA				Joint Probability
A	Only have to remove clarifier	20%		NFA			20.0% (Col 1, row A)
B	Find contamination, further tests req'd	80%	80%		NFA		64.0% (Col 1×col 2)
C	Tests find dichlorobenzene	80%	20%	99%		NFA	15.8% (1×2×3)
D	Tests find PCE	80%	20%	1%	99.90%		0.15984% (1×2×3×4)
E	PCE threatens drinking water	80%	20%	1%	0.10%		0.00016% (1×2×3×4)

Exhibit 5
Relative Financial Risk: A Site with a Lower Value



other words, a property could be valued by the use of business cycle analysis as described by Weber (1997) instead of having to rely on the Ellwood Technique for the income approach, which is recommended in a number of articles.

Again, for longer remediation periods, the risk of a differing highest and best use upon completion of remediation should also be considered for the valuation of undeveloped land. Fanning (1994) provides a number of reasons why this market analysis is so important in estimating future values. If another shopping center had been developed within the trade area of Parcel A (as was actually planned), it could have resulted in Parcel A losing half its value from this factor alone.

A probability distribution was also used to estimate the value of the property upon the completion of remediation. A triangular distribution (for the "test" property) with pessimistic, most likely and optimistic estimates were chosen as shown in Exhibit 5.

Probabilistic Present Value Analysis

The results of each of the simulations of the remedial process are used in the spreadsheet shown in Exhibit 6 for a present value analysis that quantifies the uncertainty of the future value. An explanation of the process follows.

Simulated Cost and Time for Remediation

This section contains a summary of the results of each spreadsheet simulation. The sum of the individual remedial costs for this iteration is labeled Total Remedial Cost.

Most Likely Value after Remediation

This reversionary value was derived from this iteration of the sampling of the triangular probability distribution that was used to estimate the value of the reversion after remedi-

Exhibit 6
Present Value Analysis
DCF Iterations

Iterations Resulting from Sampling the Probability Distributions

Simulated Cost and Time for Remediation

Area Contaminated	Est'd Cost	Periods
Operable Unit I	$6,890	1.00
Operable Unit II	$4,815	1.00
Operable Unit III	$17,910	7.00
Operable Unit IV	$16,815	1.00
Total Remedial Cost	$46,430	
Remediation Period	7.00	
Periods/Year	4	

Probabilistic Present Value Analysis

Holding Period	1	2	3	4	5	6	7	8	9	10
Annual Discount Rate:	12.00%									
Most Likely Value after Remediation:	$1,950,000									
Remediation Expense										
Operable Unit I	($6,890)									
Operable Unit II	($4,815)									
Operable Unit III	($2,559)	($2,559)	($2,559)	($2,559)	($2,559)	($2,559)	($2,559)			
Operable Unit IV	($16,815)									
Total Remedial Cost	($31,079)	($2,559)	($2,559)	($2,559)	($2,559)	($2,559)	($2,559)			
Real Estate Expense										
Real Estate Tax	($536)	($536)	($536)	($536)	($536)	($536)	($536)			
Total Outflow	($31,615)	($3,095)	($3,095)	($3,095)	($3,095)	($3,095)	($3,095)			
Reversionary Value								**$1,950,000**		
Cash Flow:	($31,615)	($3,095)	($3,095)	($3,095)	($3,095)	($3,095)	($3,095)	$1,950,000		
3% Discount Rate/Qtr.:	.9708738	.9425959	.9151417	.8884870	.8626088	.8374843	.8130915	.7894092		
Discount Amount:	($30,694)	($2,917)	($2,832)	($2,750)	($2,670)	($2,592)	($2,516)	$1,539,348		
Cumulative Present Value:	($30,694)	($33,611)	($36,443)	($39,193)	($41,863)	($44,455)	($46,971)	$1,492,377		
Estimated Value "As–Is"	$1,492,377									

ation. Estimates are made of the most likely, optimistic and pessimistic reversions for cash flow studies. A pessimistic scenario could reflect the loss in value in the event the site loses its highest and best use by the time that remediation has been completed.

Remediation Expense

Each estimated cost of remediation is spread out evenly over the time (in this case, quarters of a year) that is estimated to be required to complete the remediation of each Operable Unit. Again, the time estimate has been tailored to suit the specific outcome of the remedial sampling of the tasks to be done.

Real Estate Tax

This annual expense is estimated based upon the results of the most likely value estimate after remediation. It also has to be allocated over time based upon the periods that are chosen for the analysis. Other items such as entrepreneurial profit could be structured appropriately and deducted over time in this section of the model.

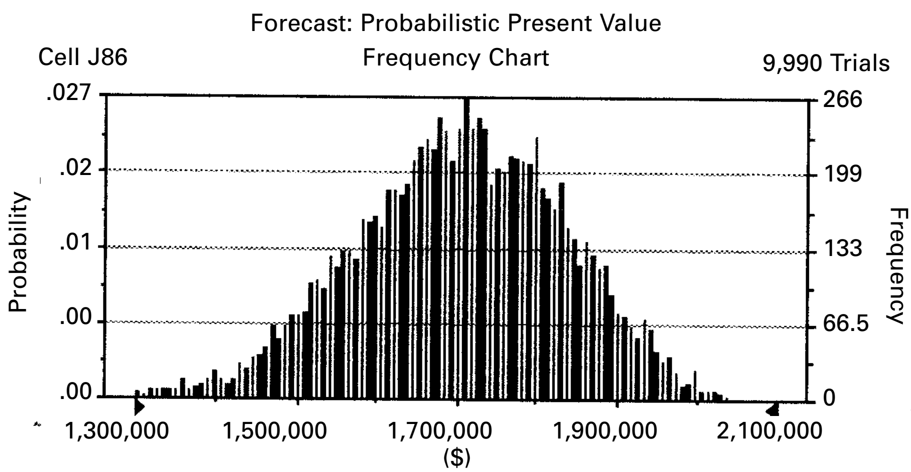
Cash Flow

The cash flow analysis discounts (at a 3% quarterly discount rate in this example) the cash flow after total remedial cost, real estate taxes, etc., and the reversionary value.

Estimated Value "As-Is"

This value indication is based upon the results of this iteration of the remedial process. The value indications for all 10,000 iterations of the spreadsheet have been plotted in the frequency distribution shown in Exhibit 7. The resulting mean value of the "test" property prior to the remediation amounts to about $1,700,000.

Exhibit 7
Probabilistic Present Value—Prior to Remediation



Calculating Stigma

The model can also be used to quantify stigma, if stigma is defined to include the financial risk of remediation. An appraiser can communicate the financial risk of a site as part of the process of confirming sales, once the risk of cost overrun is quantified by a probability distribution.

Reference to the probability distribution of remedial cost for Property C shows that it will cost, at most, \$8,600,000 to remediate this site due to the complete removal of the contamination. Survey research can be used to find out what level of risk potential buyers would take to remediate this site in light of the certainty of its profit potential if redeveloped. If, for example, it was found that the most likely buyers wanted a 95% certainty of covering remedial cost, it is a simple process to find the cost that will provide this level of certainty by finding the point on the X-axis that represents 95% of the area under the leftmost portion of the curve.

Let us say that \$8,400,000 is the cost on the X-axis that corresponds to a 95% confidence level. Stigma would be reflected by the difference between \$8,400,000 and the most likely remedial cost estimate of \$8,000,000. It amounts to \$400,000, which is only 5% of unimpaired land value.

Application of the risk analysis to Property B shows that mean remedial cost is just \$35,000. A 95% confidence level for remedial cost here would only suggest stigma amounting to \$20,000, or .1% of the value of a \$20,000,000 site. If the site were only worth \$20,000 after remediation, the stigma would amount to 100% of the land value. This exemplifies why the calculation of stigma as a percentage of value is not considered to be an appropriate methodology.

Probabilistic analysis can also be applied to Property A to determine how much the value of the property should be discounted over and above the \$8 million "most likely" remedial cost in order to satisfy the maximal risk requirements of the market for this specific site. It may be that the probability of having to incur the \$43,000,000 cost will be great enough to render the property valueless. At least the risk will be quantified so it can be more readily communicated to others. Potential purchasers can now be well informed about the financial risk of the site and perceived risk will equal real risk by the use of this methodology.

The methodology presented here was described to a speaker from an insurance company that provides insurance for contaminated sites. The speaker noted that the company estimators performed similar analysis in order to determine an appropriate premium when they consider providing insurance for seriously contaminated sites. The technique then passes one of the initial requirements of the *Daubert* factor, which calls for general acceptance of the technique, although it is no longer a precondition to admissibility. The technique could also be used to calculate stigma for an income-producing property, by quantifying the annual "premium" that should be deducted from income due to the financial risk of contamination.

Summary and Conclusions

The valuation of contaminated land can be among the most challenging appraisal assignments. One could argue that it requires that the appraiser have a number of atypical skills, such as a good understanding of environmental site assessment and remediation, the use of GIS systems, and significant experience in market and marketability analysis. Weber (1998) provides a number of examples of the use of GIS for dealing with environmental problems and for market analysis as part of the appraisal process. The literature suggests that appraisers are the logical ones to coordinate the efforts of other professionals.

Probability distributions can be a very effective method of communicating risk. An appraisal may be a waste of time and money if a remedial investigation that quantifies the risks involved has not been done. It also does not do an appraiser much good to simply know that a site has been contaminated and that somebody estimated that it would cost $8 million to remediate it. The implications of the cost simulations in the addendum are that percentage adjustments and risk rates are not appropriate for the quantification of stigma, if stigma is defined to include uncertain remedial costs.

Comparable land sales with some form of contamination could be used as part of the valuation process, but they might only show one thing. This is that buyers do not refer to other land sales that also have contamination in order to decide what they will pay for a contaminated site. A number of environmental engineers such as Swaroop (1987) have provided risk analyses, not unlike the one discussed in this study, to clients who are making purchase decisions.

Textbooks such as the one by Covello and Merkhofer (1994) describe the use of Monte Carlo for environmental risk assessment. This study demonstrates that the same techniques can be used for financial risk assessment. The use of these techniques can result in a much better idea of the financial risk involved in the acquisition of contaminated land due to uncertain remedial costs and a better indication of its value.

Finally, Hoyt (1997) notes that the 1993 Supreme Court case known as *Daubert* has changed the admission requirements of scientific evidence by expert witnesses. He concludes that is imperative that real estate appraisers who testify be sure that their scientific evidence will stand up to the scrutiny of *Daubert*, or their testimony may be rejected. If there are tools such as the ones described in this study that are acknowledged to be useful in the quantification of environmental risk, it makes sense that appraisers should also use these tools in the valuation of contaminated land.

Addendum
A Detailed Description of the Model

Investigations have to be made in order to get a letter from regulators stating that no further action (NFA) is required. Each remedial action for Unit IV (that is shown in Exhibit 4) and its corresponding probability of being required is as follows.

- Event A: There is a 20% chance of getting by with only having to remove the clarifier and thereby receiving approval by the regulatory authorities (letter of NFA).
- Event B: There is an 80% chance of finding more serious contamination upon removing the clarifier. This would result in having to incur additional cost by having to do more testing. There is an 80% chance of getting an NFA letter after added testing. This is a joint probability, resulting in a .8 times .8 or 64% chance of not having to do more.
- Event C: IF event B occurs after A (80% chance), there is a 20% chance of finding dichlorobenzene. If it is found, there is an 99% chance of NFA after an additional small remediation cost. This results in a .8 times .2 times .99, or 15.8% chance of incurring this expense.

- Event D: This event assumes that the original testing (80% chance) and the added testing (20% chance) is required and that PCE is found (1%) but it has not migrated to the drinking water (99.9%), resulting in a probability of .8 times .2 times .999, or .1598%.
- Event E: Event E is the scenario where everything goes wrong. The probability of PCE being found in the drinking water below the site is .8 times .2 times .1 times .001, or somewhat over one chance in one million.

Analysis of Units I-IV
Exhibit A1 shows Units I-IV along with their corresponding event trees. This is the section of the spreadsheet that provides each estimate of the total remedial cost that might be required for closure of the site.

Column Headings
Remedial Uncertainties are the individual events that might be required to be done in order to attain closure. They are followed by the probabilities of the individual remedial tasks being required.

Joint Probabilities lists the probability that the individual task and all of its preceding tasks will be required. The joint probabilities are the ones that are incorporated in the model for sampling. For example, in order for event E under "Unit IV - Clarifier & Leach Field" on the second page of Exhibit A1 to happen, it must be preceded by the failure of items A through D to solve the problem. The experts estimate that the chance of this happening is less than 2 in a million. Therefore, it is highly unlikely that the simulation will result in selecting this level of remediation as being required.

Remedial Cost is listed in the next column. It contains cost for each of the remedial tasks that might be required for each of the units.

Cumulative Remedial Cost lists the total remedial cost for each event A-E and all of the events that have to be completed prior to the sampled event. In other words, if the result of the sampling for "Operable Unit I - Tank & Lines" is that steps A through E have to be completed before a letter of NFA is granted, the total cost of the remediation would be $27,360.

Expected Cost. This item is calculated by multiplying the Cumulative Remedial Cost by the probability of the cost having to be incurred. It is used to show the most likely cost of remediating the unit from a statistical standpoint.

Time to Closure. It can also be important to estimate how long it could take to remediate the site in the event significant contamination is found. Regulators may be present to test the soil when sub-surface components are excavated. Certain types of contamination can take a very long time to remediate and building permits might not be allowed until remediation targets are met. The discounted present value of the land should be considered as part of a possible loss in value resulting from the contamination. The opportunity cost of carrying the land could result in a greater loss in value than the total cost of remediating the contamination.

Cumulative Time lists the total time required to remediate the site, in the event more than one of the remedial steps are required. The cumulative time is used to estimate the value of the property at the time remediation has been completed.

Row Headings: Results of Sampling (Operable Unit IV as the Example)
Simulated Remedial Cost (IV). A custom probability distribution can be created to reflect the relative probabilities of each of the remedial uncertainties A-E. The distribution that was created for Unit IV is shown in Exhibit A2.

It shows the probabilities of outcomes A, B and C. The probabilities of Event D at .16% and Event E, with a likelihood of about 1 in 1,000,000, are so unlikely that they are only noticeable as dots on the X-axis. The statistical sampling process retrieves cost for spreadsheet analysis from cost distributions such as the above that are created for each of the Operable Units.

Exhibit A1
Risk Analysis per Operable Unit
Remedial Interactions

Analysis of Operable Units I - II

	Remedial Uncertainties						Joint Probability	Remedial Cost	Cumulative Remedial Cost	Expected Cost	Time to Closure (quarters)	Cum'ive Time (quarters)
I	**Tank and Lines**											
			NFA									
A	Only have to excavate & remove	40%					40.00000%	$4,100	$4,100	$1,640	0.05	0.05
				NFA			(col 1, row A)					
B	Samples required at tank ends	60%	99%				59.40000%	$2,790	$6,890	$4,093	0.3	0.35
					NFA		(col 1×col 2)					
C	Contamination found-R A req'd	60%	1%	40%			0.24000%	$3,000	$9,890	$24	1.25	1.6
						NFA	(1×2×3)					
D	Borings to determine extent	60%	1%	60%	90%		0.32400%	$12,420	$22,310	$72	1.5	3.1
							(1×2×3×4)					
E	Additional investigation req'd	60%	1%	60%	10%	99.9%	0.03600%	$5,050	$27,360	$10	2.5	5.6
							(1×2×3×4)					
F	Soil vapor extraction req'd	60%	1%	60%	10%	0.1%	0.00004%	$60,000	$87,360	$0	11	16.6
	Simulated Remedial Cost I:									$6,890		
	Simulated Time I | Cost A-E:											0.35
II	**Oil Drain Pit**											
			NFA									
A	Dig up concrete/dispose of soils	80%					80.00000%	$4,815	$4,815	$3,852	0.6	0.6
				NFA			(col 1, row A)					
B	Regulators observe/require samples	20%	90%				18.00000%	$2,275	$7,090	$1,276	1.25	1.85
					NFA		(col 1×col 2)					
C	Contamination found-determine extent	20%	10%	99%			1.98000%	$8,360	$15,450	$306	2.5	4.35
					NFA		(1×2×3)					
D	Deeper borings req'd	20%	10%	1%	99.9%		0.01998%	$5,220	$20,670	$4	3.125	7.475
							(1×2×3× 4)					
E	PCE Found - Remediation req'd	20%	10%	1%	0%		0.00002%	$1,000,000	$1,020,670	$0	18	25.475
							(1×2×3×4)					
	Simulated Remedial Cost II:								$4,815			
	Simulated Time II | Cost A-E:											0.60

Analysis of Operable Units III - IV

III	**Waste Oil Pit**										
			NFA								
A	Excavate tank and dispose	30%				30.00000% (col 1, row A)	$4,270	$4,270	$1,281	0.1	0.1
				NFA							
B	Regulators observe/require samples	70%	40%			28.00000% (col 1×col 2)	$2,120	$6,390	$1,789	1.25	1.35
					NFA						
C	Borings for additional tests	70%	60%	80%		33.60000% (1×2×3)	$5,870	$12,260	$4,119	2	3.35
						NFA					
D	Deeper borings for additional tests	70%	60%	20%	99.0%	8.31600% (1×2×3×4)	$5,650	$17,910	$1,489	2.7	6.05
E	Remediation of oil residue req'd	70%	60%	20%	1%	0.08400%	$50,000	$67,910	$57	10	16.05
	Simulated Remedial Cost III:							$17,910			
	Simulated Time III | Cost A-E:										6.05
IV	**Clarifier & Leach Field**										
			NFA								
A	Only have to remove clarifier	20%				20.00000% (col 1, row A)	$10,145	$10,145	$2,029	0.1	0.1
				NFA							
B	Find contamination, further tests req'd	80%	80%			64.00000% (col 1×col 2)	$6,670	$16,815	$10,762	0.75	0.85
					NFA						
C	Tests find dichlorobenzene	80%	20%	99%		15.84000% (1×2×3)	$8,650	$25,465	$4,034	2	2.85
						NFA					
D	Tests find PCE	80%	20%	1%	100%	0.15984% (1×2×3×4)	$25,290	$50,755	$81	3	5.85
E	PCE threatens drinking water	80%	20%	1%	0.10%	0.00016% (1×2×3×4)	$250,000	$300,755	$0	16	21.85
	Simulated Remedial Cost IV:							$16,815			
	Simulated Time IV | Cost A-E:										0.85

Operable Unit:		I	II	III	IV	
Cumulative Cost		$6,890	$4,815	$17,910	$16,815	
Total Cost:		$43,640				
Time:		0.35	0.60	6.05	0.85	(quarters)
Maximum Time:		6.05	(quarters)			
Worst Case Scenario:		$1,476,695			25	
		Pessimistic	M. Likely	Optimistic	Forecast	
Value after Remediation (1,000's)		$1,700,000	$2,000,000	$2,200,000	$1,950,000	
Simulated Present Value	$1,492,377					

Exhibit A2
Probability Distribution of Total Remedial Cost for Unit IV

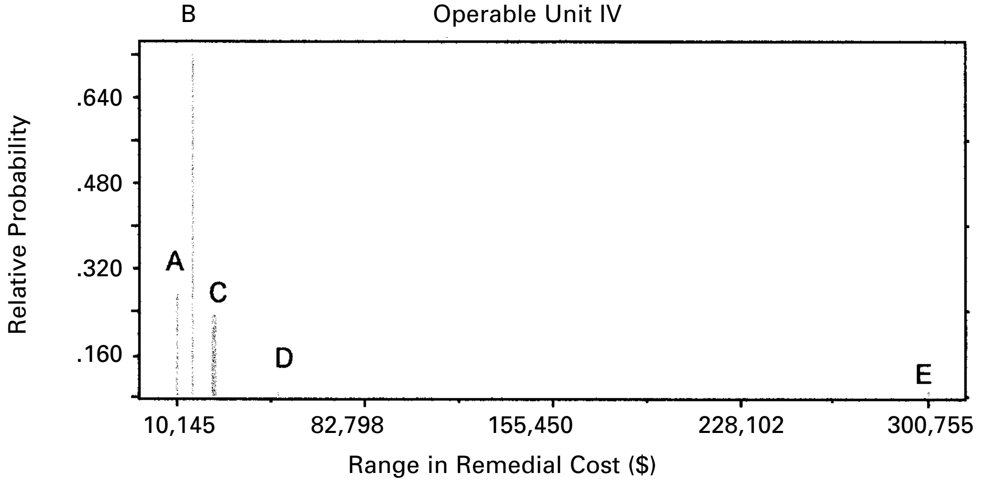
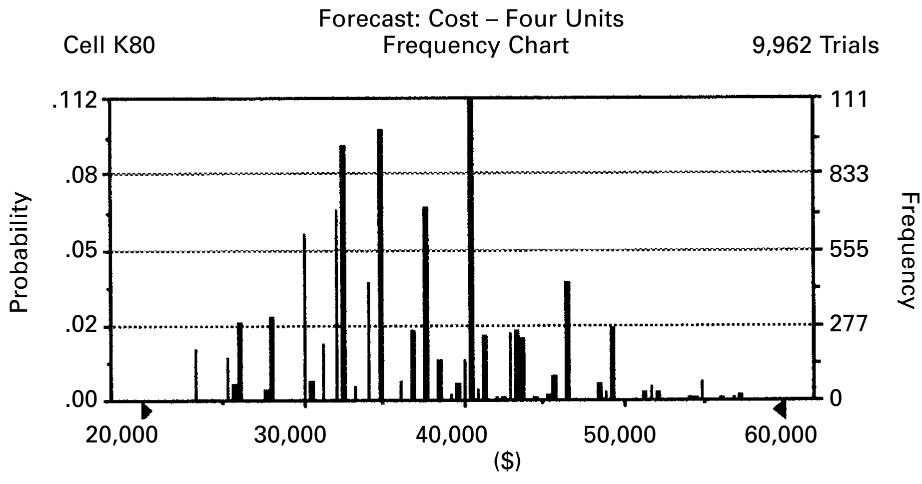


Exhibit A3
The Range of Uncertainty in Remedial Cost



Simulated Time IV | Cost A-E. Contains the result of sampling the time function for the unit, given the number of steps (Costs) required (two, in this iteration).

Cumulative Cost (at the bottom of Exhibit A1). Refers to the sampling results for the cost of each of the units (I-IV) required to successfully remediate the site.

Total Cost. This item refers to the summation of the sampled cumulative cost of each of the units.

Time. A vector containing the sampled time requirements for remediating each of the units.

Maximum Time. The simulated time required for remediation is the longest time required to remediate any of the units, based upon the outcome of a given iteration. In this iteration, the longest time that is required is 6.05 quarters for Unit III.

Simulation of Cumulative Remedial Cost

A computer-generated spreadsheet is used to simulate the remedial process 10,000 times for each of the units. The graph in Exhibit A3 shows the probability distribution of total cost. The mean remedial cost ended up being about $35,000.

Implications of the Cost Simulation

The costs shown above were actual estimates for a contaminated property. They were used to help explain the process and to show that financial risk resulting from remedial uncertainty is relative. The resulting risk is significant if the property without contamination is just worth $50,000, but this risk would only have a nominal effect on the value of a $20 million site. The example shows why percentage adjustments applied to value or risk rates are not considered to be appropriate for quantifying stigma, if contaminated real estate is valued prior to remediation and stigma is defined to include uncertain remedial costs.

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