Measuring Future Liability of Ohio Brownfields as a Function of Site Cleanup Levels.

by

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ABSTRACT

Environmental liability of brownfields can be predicted by developing a model based on long-term effectiveness of proposed site cleanups. Remedial action technologies used in the cleanups reduce the quantity and hazardous characteristics of residual contaminants after treatment, thus lowering future liability. Proposed technologies were ranked on the basis of long-term effectiveness. Combinations of technologies, called alternatives, were ranked by averaging assigned liability values for the group of technologies for each site. Based on the projections from the Records of Decision (RODs): the alternatives to be used, the costs for cleanup, and the EPA mandated cancer risk reduction at each Superfund site, a plot and trend analysis defined a predictive model showing the relationship between the expenditure of dollars for cleanup, health risk reduction, and future liability. This model will help owners of contaminated property and developers to predict the expected costs of cleanup, and be encouraged to purchase, improve, and develop brownfields.

DEDICATION

I would like to dedicate this work to my family, for your encouragement and guidance during the time of working on this thesis project.

I want to thank my past and current teachers and professors for their help in reviewing the thesis and giving instruction on where to take the next step in research and development of key concepts.

I send a whole hearted thank you to the Cushwa family for the fellowship they provided at Youngstown State University.

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1.0 Introduction

Future liability of a brownfield site can be measured as a function of site cleanup levels in relation to a monetary value spent. The study's objectives were to compare Ohio brownfields based on site characterization and rank them according to levels of associated cancer risk. From this ranking, analysis of the sites' projected costs and types of remediation conducted were done in order to determine the liability value achieved for the particular price. Then using the data collected, a graph was constructed comparing cancer risk reduction with cleanup costs.

2.0 Brownfield Background

The term brownfield was first defined in section 101 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. A brownfield site is a realty property where the expansion, redevelopment, or reuse of the site may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant (U.S. EPA, 2006a).

Brownfields exist in almost all large industrial cities across the United States. They can be distinguished when driving through metropolitan areas by the abandoned factories or empty industrial lots. There are an estimated 450,000 brownfields existing in the United States (U.S. EPA, 2006a). With problems such as spreading contaminant plumes and contaminant releases that may be associated with a brownfield, investors look at using undeveloped real estate that doesn't have environmental problems.

In my opinion, abandoned industrial sites negatively impact future economic development in the immediate and surrounding areas. This impact affects property values and reliance on undeveloped land for future development.

2.1 Ohio's Voluntary Action Program

The Ohio Voluntary Action Program (VAP) is a program created to help mitigate the fiscal and environmental issues stalling brownfield redevelopment. Since 1996, property owners, lenders, and developers have investigated and cleaned up contaminated areas under the supervision of private consultants (Greene Environmental Coalition, 2001). Since it went into effect, the VAP has led to a large number of brownfields being redeveloped and is still used in cutting red tape and allowing sites to be cleaned up.

The stages of a VAP begin with a company wanting to clean up a brownfield hiring EPA-certified professionals to conduct Phase I and Phase II assessments of the site. The professionals then conduct the cleanup to the specific standards set by the Ohio EPA. After cleanup, the private consultant mails a No Further Action (NFA) letter to the Ohio EPA for review. The NFA outlines the site's hazards, how they were investigated, and what activities were implemented to reduce the hazards. If the director of the Ohio EPA agrees the standards under VAP have been met, a Covenant "Not to Sue" is issued releasing the owner from further site liability. The covenant stays with the land title and stipulates restrictions on how the property can be used in the future. Under VAP the public has the right to review any and all information provided to the Ohio EPA pertaining to the site. To ensure the VAP cleanups are being done correctly, about 25% of the properties cleaned up under VAP are audited by the Ohio EPA, allowing review of all records and on site sampling (Ohio EPA, 2001).

Using the same principles as the VAP is the Memorandum of Agreement (MOA) Track that was started in 2000. Ohio and U.S. EPA entered an agreement to allow sites cleaned up under Ohio's VAP to receive assurance that the U.S. EPA would not ask for additional cleanup. This assurance is documented in a MOA. In order to obtain this, site cleanup must be done or overseen directly by Ohio EPA personnel and include opportunities for public review and comment (Ohio EPA, 2001).

2.2 Comprehensive Environmental Response, Compensation, and Liability Act

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, was enacted by Congress on December 11, 1980 (Sullivan, 2005). A tax on chemical and petroleum industries was created by this law, which provided federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment. CERCLA also established requirements for closed or abandoned sites, placed liability on the persons responsible for the contamination of these sites, and created a trust fund that uses the funds for cleanup when a responsible party cannot be found.

The law incorporates two different actions toward cleanup of sites. The first is a short-term removal that promptly addresses releases or threats of releases. Long-term remedial response actions permanently and significantly reduce risk associated with hazardous substance releases that are serious, but not immediately life threatening. In order to perform a long-term removal a site must be listed on the EPA's National Priorities List (NPL) that lists the known or potential releases of hazard substances on a particular site in the US. The NPL helps guide the EPA on which sites will warrant further investigation (Sullivan, 2005).

CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) on October 17, 1986 (U.S. EPA, 2006b). SARA addressed certain areas of complexity in CERCLA and made additions to the program. SARA helped increase state involvement and citizen participation, increased focus on human health aspects, stressed the importance of permanent remedies in cleanup, expanded the trust fund budget, and required Superfund cleanup to incorporate standards and requirements found in other state and federal agencies (U.S. EPA, 2006b).

With CERCLA cleanup there are four steps in response to a hazardous substance or potential substance spill. The first step is site discovery through various means such as reports to the EPA, government authority investigation, or incidental discovery. After the spill is reported, then site assessment is done on the site. Site assessment includes a preliminary investigation of available information and possibly a site investigation if one is necessary. On site investigation includes minimal sampling in order to determine how much of a threat the site is to human/environmental health. The site's threat analysis will determine its placement (or not) on the NPL. The site assessment will also aid in determining the nature of cleanup being time sensitive or not. Once the site assessment is conducted a remedial investigation and feasibility study are done. Data collection is the primary goal of this step of CERCLA that will aid in determining site conditions, extent of contamination, possible site risks, and remediation options. The primary decision of this step is if the site requires remediation and what kind. This is stated in the Record of Decision (ROD) along with the cleanup standards that will be protective of human and environmental health. The cleanup standards for CERCLA sites are an Excess Level of Cancer Risk (ELCR) of 1.0×10^{-6}. With the ROD designated remedial design, remedial action can be conducted. After further remedy-specific site information is taken and analyzed, the remedial technology is designed and implemented. The site is then assessed to determine if the standards of cleanup set forth in the ROD have been met, or if they have not, what actions need to be done to achieve them (Sullivan, 2005).

3.0 Site Analysis

The sites selected for analysis were confined to the National Priority List (NPL) superfund sites located in Ohio because of a focus on local brownfields. The data were acquired from the Records of Decision (RODs) for each site. The reason for this selection is that it was found after reviewing various VAP files that the necessary information for calculations of this study was not provided. The VAP files were then not used, but the VAP is a necessary program in the cleanup and redevelopment of brownfields. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 in comparison was able to provide the necessary analytical information for this study. The necessary information included:

- Site history
- Contaminants of concern (COCs)
- Excess level of cancer risk (ELCR)
- Remediation actions and cost

ELCR is the probability of developing cancer from exposure to contamination that has adverse health effects. Excess means beyond that of naturally occurring cancer in the population.

From the multiple sites originally reviewed only 14 were selected for use because they fulfilled the information criteria. The sites chosen were separated by the amount of cancer risk reduction that was projected. The amount of cancer risk reduction depends on the amount of cleanup needed in order to achieve the goal ELCR levels set by the U.S. EPA.

3.1 Level of Risk Reduction

The Level of Risk Reduction (LRR) is the amount of ELCR reduced during remedial actions of the site. The LRR was developed for this study and is calculated by using the current ELCR levels and the goal ELCR of the site. The goal ELCR is subtracted from the current ELCR producing a positive value. That value is then the LRR that was targeted for the site.

The LRR used at the bottom of Figures 1 through 4 and in Charts 1 through 3 was derived from using:

- LRR = log (current ELCR) – log (goal ELCR):

An example illustrating this formula using the current site ELCR value of 3.2×10^{-6} and goal ELCR of 1.0×10^{-6}:

- $\text{LRR} = \log(3.2 \times 10^{-6}) - \log(10^{-6}) = 0.51$

3.2 Risk/Liability Predictions

Future liability of the sites was determined by evaluating the long-term effectiveness of the remedial action. Effectiveness is a function of reduction in toxicity, mobility, and volume through treatment of the waste. In this way, waste can be rendered less hazardous, non-hazardous, or even considered as a resource for future use. For example, incineration transforms volatile hazardous constituents into mostly non-hazardous contaminants that cannot reappear to harm human health and the environment. On the other hand, if the waste is placed in a landfill without treatment it can, in the future, be released into the environment through breaching of the landfill containments. The effectiveness of the remedial action technologies is a function of the quantity and hazardous characteristics of the residual contaminant after treatment.

The various remedial action technologies have been ranked according to their effectiveness in reducing the quantity and hazardous characteristics of the residual contaminants after treatment.

The higher number indicates a higher liability and the lower number showing a low liability value. Table 1 outlines the remedial action technologies along with a corresponding future liability value. The future liability values were developed in this study, and assigned according to the remediation technology's effectiveness. Remedial alternatives (as defined for a feasibility study in Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)) are combinations of remedial action technologies (U.S.C., 1980). Alternatives can include more then one technology. For example, partial excavation and treatment, pumping and treatment of groundwater by air stripping, and capping of some areas of the site can constitute one alternative. Other alternatives for the same site can include some of these technologies plus others. According to CERCLA, two alternatives must be considered for comparison with others that are site specific, normally, no action and institutional controls (e.g. fencing and zoning). These two alternatives can be used to compare costs, effectiveness, risk to remediation construction workers, state and community acceptance, compliance with Applicable or Relevant and Appropriate Requirements (ARARs; that must be met during CERCLA cleanup), implementability, and overall protection to human health and the environment.

For each site, remedial action technologies were assigned values and then combined corresponding to the approved alternatives for cleanup. For example, if soil washing (future liability value 3) was combined with air stripping (future liability value 2) and each had equal importance in the cleanup strategy, an alternative future liability value of 2.5 was used.

Table 1 Future Liability Predictions

Remedial Action Technologies	**Future Liability Value (1-5)**
Natural Attenuation/Monitoring	5
Cap Area Landfill Excavated Waste	4
Soil Washing Interceptor Wells/Treatment Leachate Extraction/Treatment	3
Air Stripping In-situ Vapor Extraction Gas Scrubbing by Carbon Absorption Vapor Phase Carbon Treatment	2
Incineration (Thermal Treatment)/ Ash Disposal	1

3.3 Remedial Cost Calculations

The values used for cost calculations are the present worth values provided in the brownfield Record of Decision (ROD). A ROD is the final decision on the goals of cleanup and types of remediation to be used on the brownfield (U.S. EPA, 2006a). The present worth value given in each ROD represents the estimated cost over the entire period for site remediation that would achieve the goal ELCR levels established by the EPA. In essence it is the total cost of the site's remediation over a given time frame, in this case present time.

For cost comparisons on an equal basis, the values were adjusted to 2006 dollars by using Consumer Price Index (CPI) to establish inflation rates. CPI is a statistical measure of a weighted average of prices on certain goods purchased during a given year providing a measure of inflation (Federal Reserve Bank of Minneapolis, 2006). The CPIs are time sensitive. For example:

- A brownfield in 1988 was estimated to cost $63,200.00 for remediation. How much would the same Brownfield's remediation practices cost in 2006?
  This is done by using the formula:
  2006Price = 1988 Price x (2006 CPI / 1988 CPI)
  1988 CPI=118.3 and 2006 CPI=201.7
  2006 Price = $63,200 x (201.7/118.3)
  2006 Price = $107,755.20
- CPI values can be found at the Federal Reserve Bank of Minneapolis website (http://www.minneapolisfed.org/Research/data/us/calc/#calc).

By adjusting all values to the current year, the costs can be compared to one another without bias.

3.4 Level of Risk Reduction Unit Cost Calculations

By taking the present worth values and dividing by the Level of Risk Reduction (LRR) log value, a value expressing the cost per unit of risk reduction was achieved. This value represents the cost for reducing risk by one unit.

4.0 Site Research

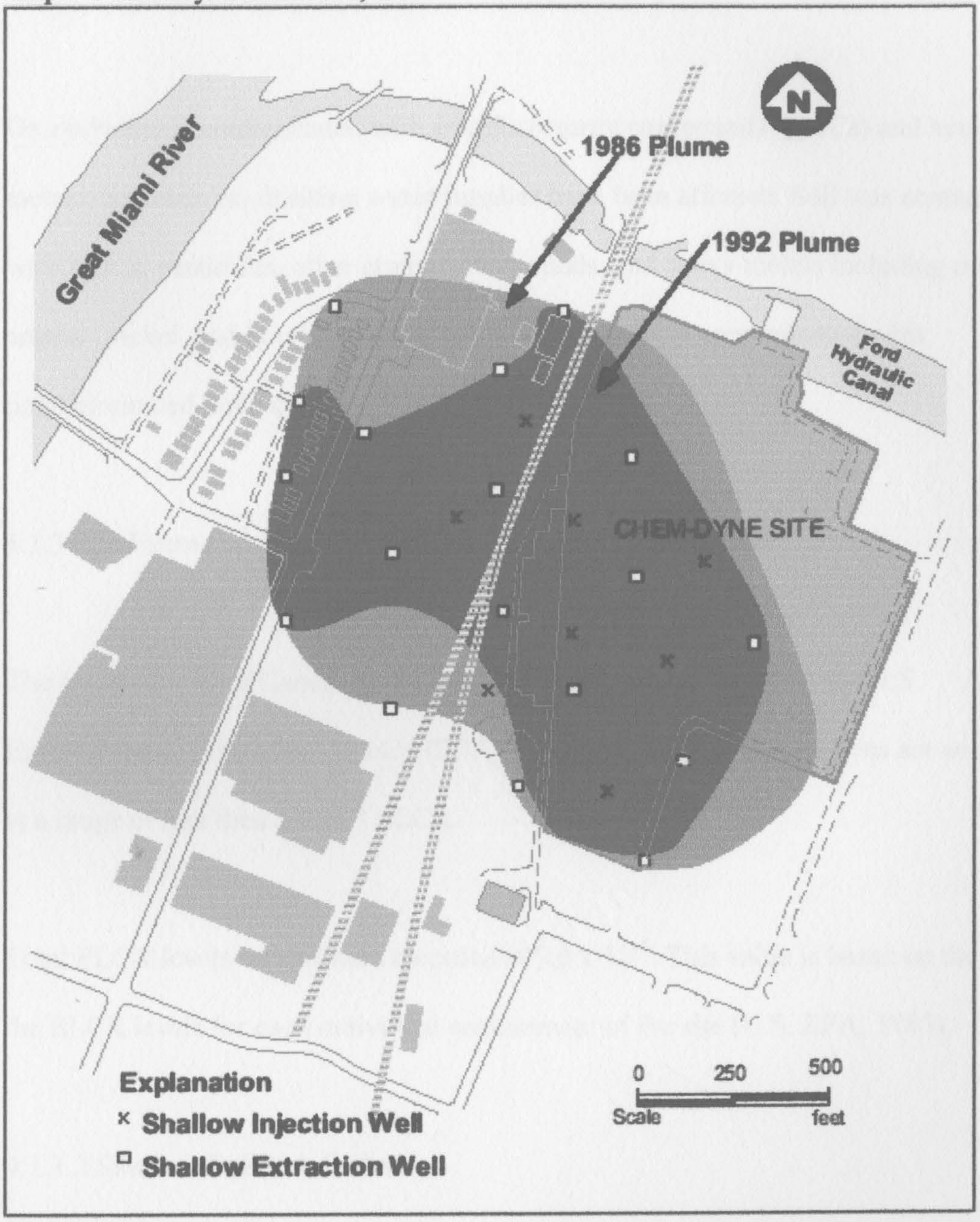
From the 14 sites selected, 2 of them were selected for detailed analysis. These sites are Chem-Dyne of Hamilton, Ohio and Wright-Patterson Air Force Base in Dayton, Ohio.

4.1 Chem-Dyne (Hamilton, OH)

4.1.1 Site History

The ten-acre Chem-Dyne site (Map 1) operated as an industrial chemical waste transfer, disposal, and storage facility located in the city of Hamilton. Hamilton has a population of approximately 87,000 and is located less than 1,000 feet from the site (U.S. EPA, 1985). Other adjacent land uses include a recreational park and industrial facilities. Chemical wastes may have been trucked to the site beginning in 1974. In 1975, Spray-Dyne produced anti-freeze from recycled chemical wastes. Chem-Dyne Corporation was formed in 1976. Wastes that were unsuitable for recycling were stored in drums and tanks on the site or shipped to other disposal sites. More than 30,000 drums of waste and 300,000 gallons of bulk waste materials were left on site when operations ended in 1980 (U.S. EPA, 1985).

Map 1 Chem-Dyne Hamilton, OH



4.1.2 Site Contaminants of Concern

Groundwater is contaminated with volatile organic compounds (VOCs) and heavy metals; however, no drinking water supplies have been affected. Soil was contaminated with VOCs, pesticides, other organic compounds, and heavy metals including mercury, arsenic, nickel, and beryllium. The onsite buildings were contaminated with polychlorinated biphenyls.

4.1.3 Site Excess Level of Cancer Risk Level and Cleanup Goal

The Excess Level of Cancer Risk (ELCR) cleanup goal is based on the U.S. Environmental Protection Agency (EPA) acceptable ranges. Carcinogens are acceptable at a range of less then 1×10^{-6} ELCR.

Total ELCR levels on site were recorded at 9.0×10^{-5}. This value is based on the sum of the ELCR levels for each individual contaminant of the site (U.S. EPA, 1985).

4.1.3.2 Site Level of Risk Reduction

Given the site's ELCR value of 9.0×10^{-5} and a goal ELCR cleanup level of 1.0×10^{-6}, the Level of Risk Reduction (LRR) is:

- $[\log(9.0)+\log(10^{-5})] - \log(10^{-6}) = 1.95$

This would give the site a total ELCR cleanup level of 8.9×10^{-5}. This illustrates that the site was at the lower amount of cleanup required to achieve EPA standards for ELCR levels.

4.1.4 Site Selected Remedial Action

The remedial actions projected in the Record of Decision (ROD) at the Chem-Dyne site were extensive. Excavation and demolishing of contaminants and onsite debris and structures would occur along with placement of a multilayer clay cap consisting of clay, permeable layer, synthetic liner, and vegetative cover. Extraction wells were to be emplaced for groundwater removal, treatment, and then re-injection. VOCs would be air stripped from the extracted water and absorbed through carbon for removal until remedial goals were met. All structures and underground storage tanks (USTs) can then be removed. All drainage systems would need upgraded and/or repaired and a monitoring system emplaced (U.S. EPA, 1985).

4.1.4.1 Site Future Liability

Given the site's expected remedial actions and the values assigned to each of these actions (excavation of contaminants future liability value of 4, clay cap covering value of 4, ground water extraction wells value of 3, air-stripping value of 2, and gas scrubbing by carbon absorption value of 2) the average future liability is a value of 3. A value of 3 places this site in the mid range of future liability.

4.1.4.2 Selected Remedial Action Costs (2006 values)

Remedial actions totaled to an estimated present worth cost of $15,100,000.00 in 1985 (U.S. EPA, 1985). The total present worth cost of the Chem-Dyne remedial actions in 2006 is $28,417,750.93 (Federal Reserve Bank of Minneapolis, 2006).

4.2 Wright-Patterson Air Force Base Dayton, OH

4.2.1 Site History

Wright-Patterson Air Force Base (WPAFB; Map 2) is located in southwestern Ohio between the cities of Fairborn and Dayton. Wright Field consists of 2,300 acres and three old runways, and Patterson Field is 4,900 acres in size and contains the active runway complex, warehouses, offices, industrial facilities, and flight line support (U.S. EPA, 1999). WPAFB overlies the Mad River Buried Valley Aquifer, which is a sole-source aquifer providing drinking water for approximately 500,000 people (U.S. EPA, 1999). The Installation Restoration Program at WPAFB consists of 65 sites or source areas (including thirteen landfills, twelve earth fill disposal zones, nine fuel or chemical spill sites, six coal storage piles, five fire-training areas, four chemical burial sites, two underground storage tanks, and miscellaneous other sites).

Map 2 Wright Patterson Air Force Base Dayton, OH

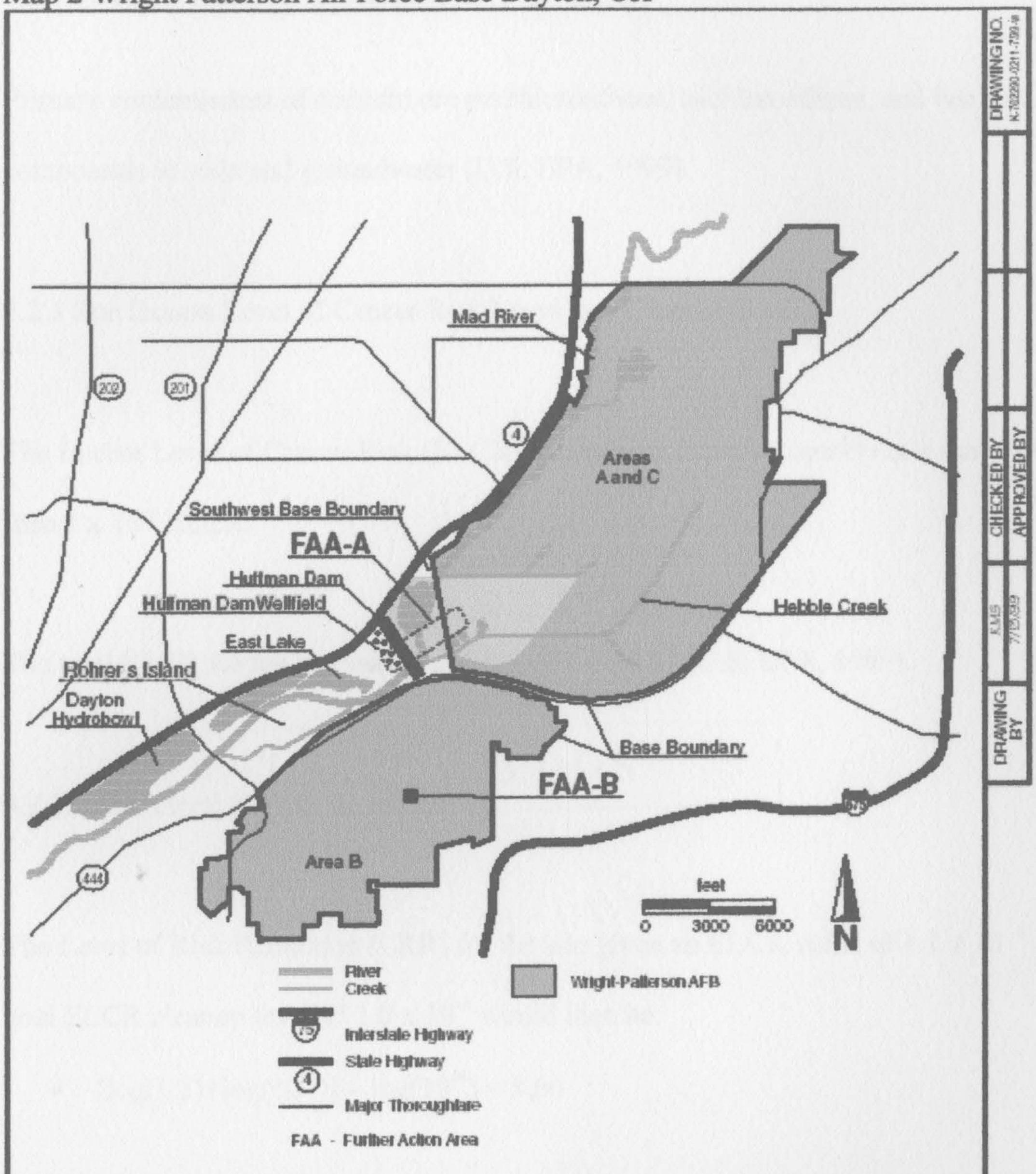


Figure 2. Site Location.

4.2.2 Site Contaminants of Concern

Primary contaminants of concern are perchloroethene, trichloroethene, and benzene compounds in soils and groundwater (U.S. EPA, 1999).

4.2.3 Site Excess Level of Cancer Risk Level and Cleanup Goal

The Excess Level of Cancer Risk (ELCR) cleanup goals are acceptable at a range of less then 1×10^{-6} ELCR.

The total ELCR for the site was at a value of 1.1×10^{-1} (U.S. EPA, 1999).

4.2.3.2 Site Level of Risk Reduction

The Level of Risk Reduction (LRR) for the site given an ELCR value of 1.1×10^{-1} and a goal ELCR cleanup level of 1.0×10^{-6} would then be:

- $[\log(1.1)+\log(10^{-1})] - \log(10^{-6}) = 5.04$

Given the same values the total amount of ELCR cleanup would be a value of 1.09×10^{-1}. The level of cleanup required for the Wright-Patterson Base places this site toward the higher end of cleanup to achieve EPA standards.

4.2.4 Site Selected Remedial Action

The remediation of the site was expected to include continuation of groundwater treatment by an extraction and treatment system that is already in operation. Chemical oxidation treatment on site with monitoring was to aid in groundwater cleanup. Access restrictions to areas were to be emplaced because military base is still active in various sectors. Due to the restrictions, new private wells were then to be required for the base's drinking supply (U.S. EPA, 1999).

4.2.4.1 Site Future Liability

Given the site's projected remediation activities, the average future liability value would be 2. The corresponding values for air-stripping is a future liability value of 2, in-situ chemical oxidation is a value of 2. These values averaged give a future liability value of 2. This average future liability value places this site toward the lower end, making it a lower liability for future usage.

4.2.4.2 Selected Remedial Action Costs (2006 values)

The total estimated present worth cost for remediation in 1999 was at $14,444,000.00 (U.S. EPA, 1999). The remediation costs in 2006 are at $17,556,482.59 (Federal Reserve Bank of Minneapolis, 2006).

5.0 Data Analysis

The data collected from the 14 study sites were compiled and analyzed using the methods discussed in previous sections.

5.1 Site Summaries

The remaining sites that were selected for this study have been compiled in Table 2 that highlights each site's key areas used in calculations. The table displays each site's ELCR level when the site was first assessed. Each site's projected remedial actions taken are listed along with the estimated present worth costs associated with the remediation. The sites' LRR and future liability values are given as well to allow for predictive capabilities.

Table 2 Site Analysis Summaries

Site	Current ELCR	Remedial Actions	Present Worth Costs (2006)	Log LRR	Future Liability
Bower Landfill	1.2×10^{-5}	Ground water monitoring and clay cover cap on landfill.	$6,969,102.82	1.07	4.5
Chem-Dyne	9.0×10^{-5}	Excavation of contaminants in soil. Clay cap covering. Extraction wells for GW monitoring. Airstipping and gas scrubbing.	$28,417,750.93	1.95	3
Republic Steel Quarry	1.1×10^{-4}	Soil Excavation and soil disposal in RCRA landfill.	$108,182.59	2.04	4
Zanesville Well Field Site	3.9×10^{-3}	Monitoring wells, In-situ vapor extraction of VOCs, air stripping, soil washing, GW pumping and cleaning	$4,419,391.52	3.59	3
Fields Brook	1.6×10^{-3}	Monitoring wells installed and incineration of excavated waste.	$8,705,607.48	3.2	3
Miami County Incinerator	2.0×10^{-3}	Monitoring of area, cap landfill, vacuum extraction of VOCs, pump and treat, and vapor phase carbon treatment.	$8,655,242.69	3.301	3.2
Reilly Tar & Chemical	2.1×10^{-3}	Excavation and incineration of wastes, cap over area, and natural attenuation.	$3,545,705.61	3.32	2.5
Powell Road Landfill	2.0×10^{-3}	Cap landfill with clay liner, waste excavation GW monitoring, and leachate extraction.	$28,742,387.54	3.301	4
Alsco Anaconda	1.0×10^{-3}	Natural flushing and attenuation with GW monitoring.	$728,307.20	3	5
Ormet Corp.	1.8×10^{-2}	Interceptor wells and treatment, leachate extraction and treatment, cap area, in-situ soil flushing, dredging, and land filling.	$23,775,303.64	4.255	3.25
Laskin/Poplar Oil Co.	2.4×10^{-2}	Drain and treat retention ponds, incineration of contaminated soil, GW diversion trenches, multi-layer cap, and monitoring.	$17,963,709.68	4.38	2.6
Big D Campground	1.6×10^{-2}	Removal of waste, incineration, onsite GW treatment, and monitoring.	$63,689,516.13	4.2	2
Wright-Patterson Air Force Base	1.1×10^{-1}	Extraction and treatment through airstripping, GW monitoring, and in-situ chemical oxidation.	$17,556,482.59	5.04	2
Pristine Inc.	1.1×10^{-1}	Excavation, incineration of waste, and soil vapor extraction.	$19,291,420.12	5.04	1.5

5.2 Results

Upon compilation of the data from Table 2, Figure 1 was created to show the relationship between the amounts of cancer risk reduction projected for each site and their estimated costs. That relation is then paired with the resulting future liability of the site, after goal ELCR levels are reached.

Figure 1 Combined Figures A-2, A-3, and A-4

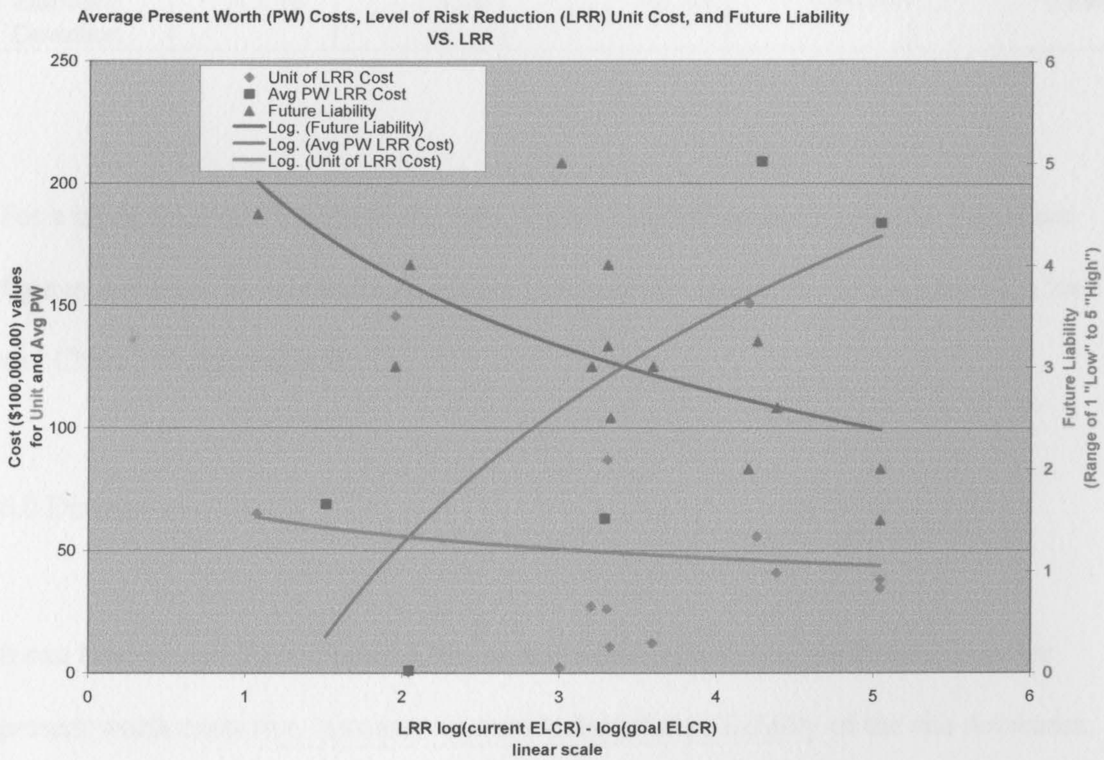


Figure 1 was constructed using Microsoft Excel. The data points of the graph correspond to the information found in Appendix B, Chart 1, Chart 2, and Chart 3. Trendlines were used in the figure to illustrate the missing data gaps. A logarithmic trendline was used because of the logarithmic formulas utilized in the calculations.

The table below does an analysis on the data used in Figure 1.

Table 3 Site Data Analysis

Calculations	LRR Values	LRR Log Values	Remediation Costs($100,000)	Per Unit LRR Costs	Future Liability Values
Average	2×10^{-2}	3.41	166.20	49.90	3.11
Standard Deviation	4×10^{-2}	1.16	167.04	48.24	0.994

For a more detailed viewing of the data, Figure 1 is broken down into the 3 separate figures displayed in Appendix A. Each figure uses the data compiled in Chart 1, Chart 2, and Chart 3 of Appendix B.

6.0 Discussion

It can then be seen from Figure 1 that as more risk reduction is performed, average present worth costs rise. As more cleanup is done future liability of the site decreases. The two curves, future liability and average present worth, appear as mirror images of the other showing that increase in a unit of cost decreases liability by an equal amount.

Figure 1 also shows that the unit cost of risk reduction decreases as more risk reduction is performed. The decrease is only minimal, but when quantified into millions of dollars could save large amounts of money in remediation costs. As more risk reduction is performed the dollar stretches further.

The working version of Figure 1 can be utilized to aid in the prediction of the future liability of a brownfield site. Estimation of the amount of cancer risk reduction that will be needed for a site or the amount of money that will be required leads to prediction of site liability.

By assessing the average amount of money spent in relation to the risk reduction achieved for the monetary sum, an estimated point on the chart can be established. This can evaluate cost effectiveness of remediation plans compared to other sites in Ohio. From that point a similar level of liability is estimated, and a business or potential brownfield buyer can potentially see what liability they might have in the future.

Using the diagram, an insurance company can justify their claims of high payments in response to a high liability of the site. Conversely, if the liability were low, insurance should be cheaper.

6.1 Uncertainties/ Assumptions

There is uncertainty in future liability from the ranking system of the remedial actions. The feasibility study criteria were used to determine the ranking system. This creates bias in discussions of which remedial action presents the lowest form of liability. As an example capping a site was ranked with higher liability, but sometimes capping an area presents lower liability. Opening a site up and exposing contaminants can potentially be worse than if the site were left untouched and capped with a new liner.

The monetary calculations using values for 2006 present a slight uncertainty because estimates of CPI values can vary from day to day. The variation is only slight but does leave some level of uncertainty in the calculations. Actual costs of remediation could also increase after the time when the Record of Decision (ROD) was approved.

The data points on the graphs are widely scattered, but trend-lines estimate the location on the graph of data gaps.

The data used from the RODs were based on projected costs and remedial alternatives. The actual costs and remediation techniques could have differed from that of the initial plan set forth in the site's ROD.

7.0 Conclusions

In conclusion, the prediction of future liability for an Ohio brownfield can be achieved when comparing similar sites. The capabilities of the methods presented here are limited due to scattered data, but can give a comparable scenario when assessing Ohio brownfields. The predictive capabilities could be strengthened given a broader study base outside of the state of Ohio, encompassing larger areas, and different remediation practices. A larger study base would also provide more data points, making the curves in Figure 1 more precise and less circumstantial. The figure does give the possibility that future liability can be predicted, making it a great asset to the future of brownfield redevelopment.

8.0 Recommendations for Future Studies

Future studies should incorporate a broader site selection. Site selection should not be only focused in Ohio or strictly on Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites; Voluntary Action Program (VAP) should be considered if necessary data can be provided. This would increase the number of data points and strengthen the predictive capabilities of the model.

Further site investigation could be done to acquire the final site remediation technologies implemented along with the final site costs. This would eliminate the uncertainty presented in using the Records of Decision (RODs) for this study.

The Hazard Index (HI) also should be incorporated into future studies. HI levels indicate the risk of non-carcinogenic adverse health effects. The HI equals the total human exposure of contaminants from all sources divided by a maximum dose that would not cause adverse health effects. A value of 1.0 or less means it is unlikely to cause adverse health effects. For example a value at 2.0 means it is more likely to happen. By incorporating HI levels another form of risk can be calculated and compared with costs and future liability. This would allow this model to be used for sites whose contaminants are not carcinogenic.

APPENDIX A Figures

Figure A-1 Combined Charts

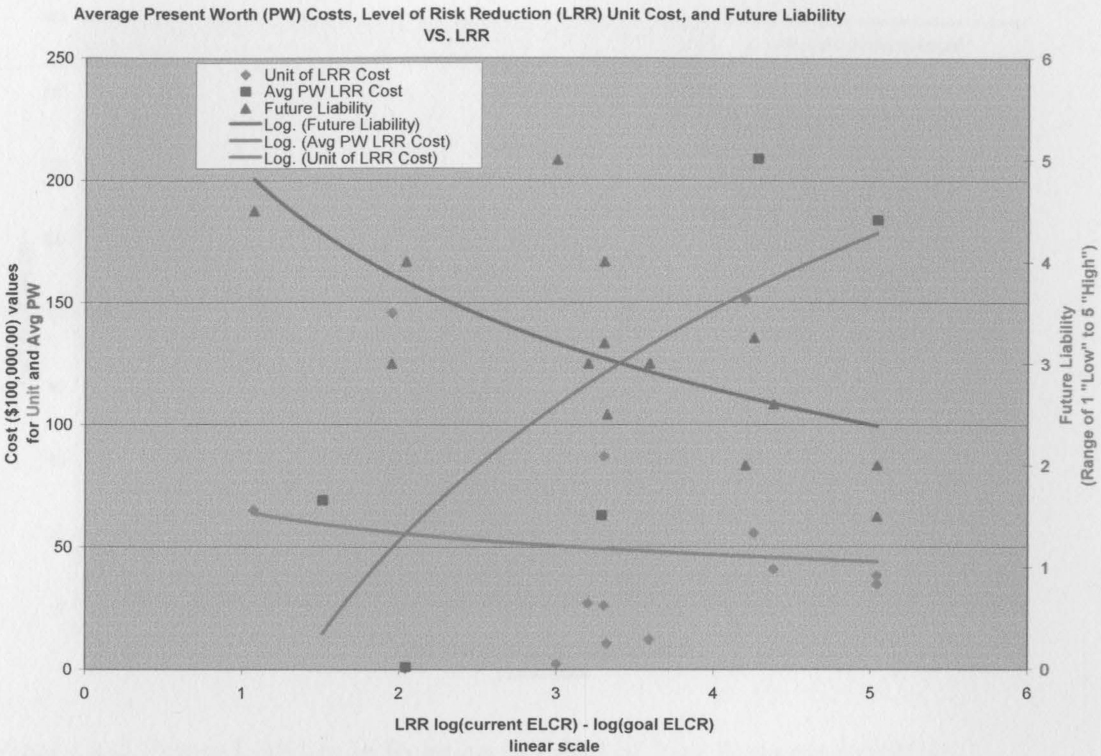


Figure A-2 Average Present Worth Values

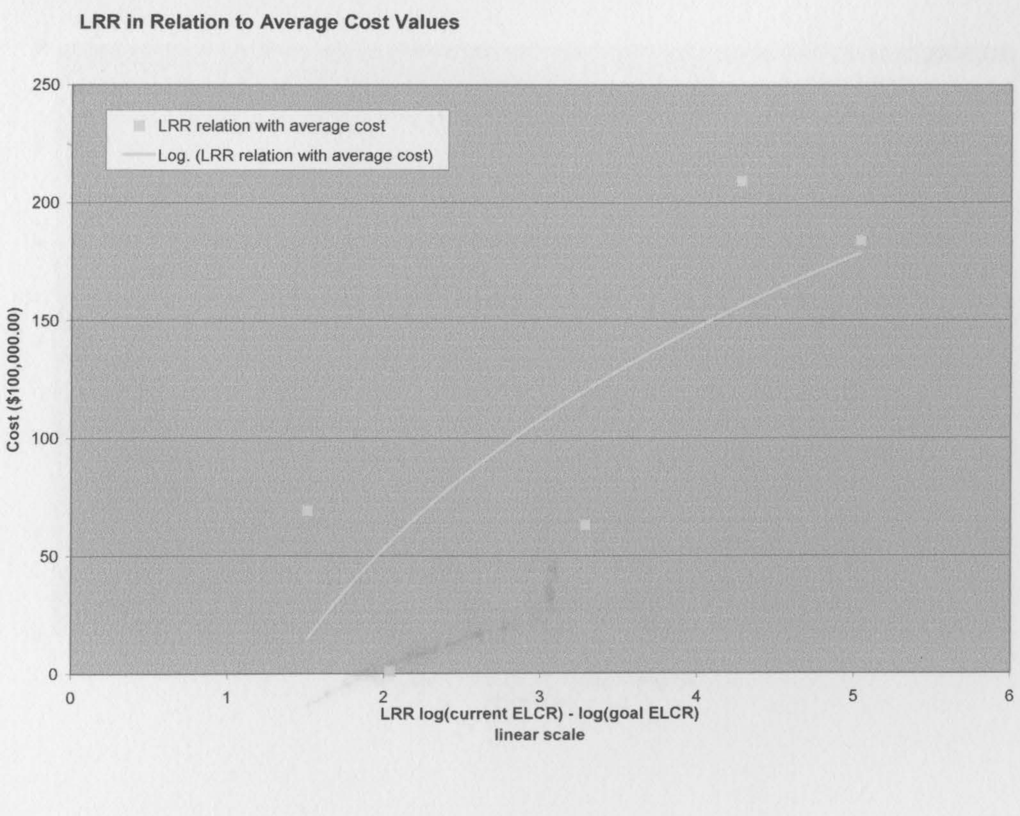


Figure A-3 Unit Cost of Level of Risk Reduction (LRR)

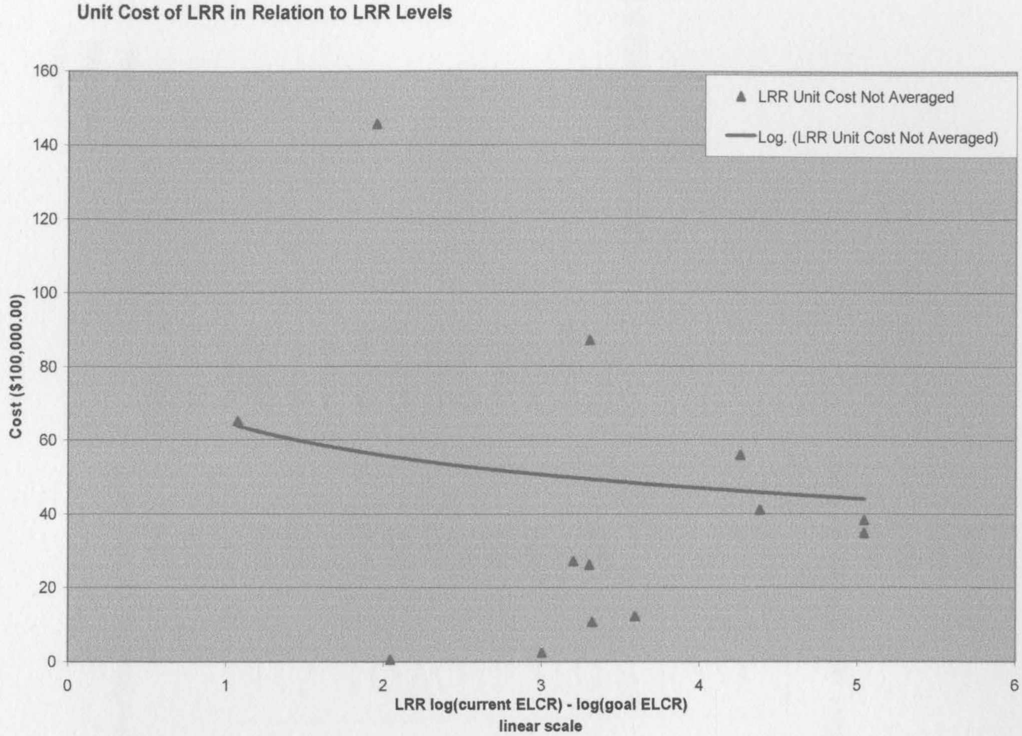
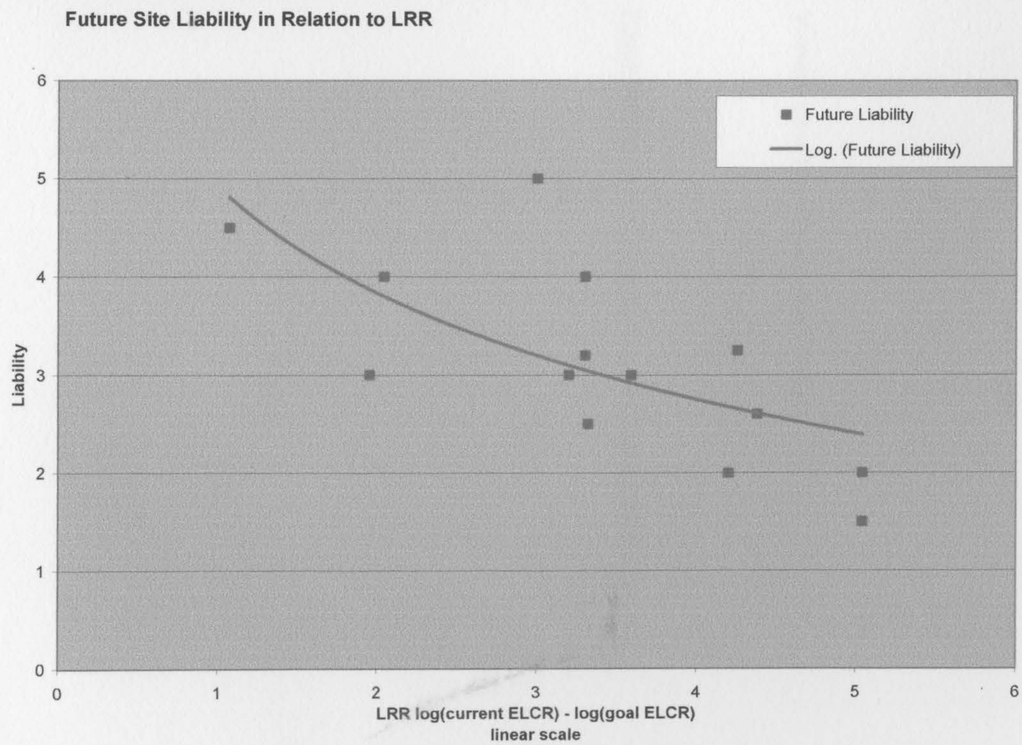


Figure A-4 Future Liability In Relation to Level of Risk Reduction (LRR)



APPENDIX B Charts

Chart 1 Average Present Worth Values

Level of Risk Reduction (LRR):		Present Worth Cost of Remediation 2006 Values ($100,000):		
1	1.51	69	OR	177
2	2.04	1		1
3	3.285	63		110
4	4.278	209		351
5	5.04	184		184
	Avg log(current ELCR)- log(goal)			

Average value from Present Worth Costs

Level of Risk Reduction (LRR):			Present Worth Cost of Remediation 2006 Values ($100,000):
1	1.07E-05	1.07	70
1	8.90E-05	1.95	284
2	1.09E-04	2.04	1.1
3	3.89E-03	3.59	44
3	1.59E-03	3.2	87
3	1.90E-03	3.301	87
3	2.09E-03	3.32	35
3	1.90E-03	3.301	287
3	9.90E-04	3	7.3
4	1.79E-02	4.255	238
4	2.39E-02	4.38	180
4	1.59E-02	4.2	637
5	1.09E-01	5.04	176
5	1.09E-01	5.04	193
*Risk Reduction Value		log(current ELCR)- log(goal)	

Chart 2 Unit Cost of Level of Risk Reduction (LRR)

Level of Risk Reduction (LRR):	Cost for One Unit of LRR ($100,000):		
1	69	OR	177
2	1		1
3	21		37
4	52		88
5	37		37

Average Present Worth value divided by the Level of Risk Reduction

Level of Risk Reduction (LRR):			Cost for One Unit of LRR ($100,000):	
1	1.07E-05	1.07	69.7	65.1
1	8.90E-05	1.95	284.1	145.7
2	1.09E-04	2.04	0.54	0.53
3	3.89E-03	3.59	14.7	12.3
3	1.59E-03	3.2	29.1	27.2
3	1.90E-03	3.301	28.9	26.2
3	2.09E-03	3.32	11.8	10.7
3	1.90E-03	3.301	95.8	87.1
3	9.90E-04	3	0.24	2.4
4	1.79E-02	4.255	59.4	55.9
4	2.39E-02	4.38	44.9	41.1
4	1.59E-02	4.2	159.2	151.2
5	1.09E-01	5.04	35.1	34.8
5	1.09E-01	5.04	38.6	38.3
*Risk Reduction Values		log(current ELCR)- log(goal)		*new unit cost values

Average Present Worth value divided by the Level of Risk Reduction

Chart 3 Future Liability In Relation to Level of Risk Reduction (LRR)

Level of Risk Reduction (LRR):			Liability:
1	1.07E-05	1.07	4.5
1	8.90E-05	1.95	3
2	1.09E-04	2.04	4
3	3.89E-03	3.59	3
3	1.59E-03	3.2	3
3	1.90E-03	3.301	3.2
3	2.09E-03	3.32	2.5
3	1.90E-03	3.301	4
3	9.90E-04	3	5
4	1.79E-02	4.255	3.25
4	2.39E-02	4.38	2.6
4	1.59E-02	4.2	2
5	1.09E-01	5.04	2
5	1.09E-01	5.04	1.5
*Risk Reduction Values		log(current ELCR)- log(goal)	

*Values for liability derived from Future Liability Chart model values. Remedial actions were added and then averaged for each site.

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