BENEFITS CHAPTER 4

In this chapter, we discuss in greater detail our proposed methodologies for measuring and characterizing benefits of the UST cleanup program. For each attribute, we first provide information on general attribute characteristics and potential benefits associated with this attribute. We then discuss each proposed method in terms of analytic steps and potential data sources. Finally, we compare the methods proposed for each attribute in terms of advantages and disadvantages, associated uncertainties, and potential methods for addressing uncertainty.[1]

In the first part of the section, we discuss methods for estimating human health benefits, principally reduction in cancer risk from contaminated drinking water sources.[2] In the second part of this section, we discuss ecological benefits (i.e., reduced surface water contamination and total groundwater use and non-use values). In the third part, we present our proposed methods for measuring avoided costs due to reduced contamination of drinking water sources and reduced vapor damages and fires and explosions. Part four discusses methods for using changes in property values as an alternative measure for a range of benefits. Finally, in the fifth part we present methods proposed to characterize long-term program benefits.

For attributes that are spatially driven and can be spatially measured (i.e., that vary with distance from a site), we propose simple benefits analyses, spatial analyses, and spatial analyses with multi-pathway modeling. These "spatial" attributes are reduction in health risk, ecological benefits from reduced surface water contamination, avoided costs of providing alternative water supplies, and property value proxies for benefits. For measuring avoided costs and reduced acute health effects from fires and explosion, we propose non-spatial approaches separate from the three primary methods. Finally, we use a mix of spatial and non-spatial approaches to characterize long-term, inter-generational benefits.

[1] The order in which we discuss methods for attribute characterization is not related to the importance of the attribute for the UST cleanup program.

[2] We discuss methods for measuring reduction in acute health effects from fires and explosions in the avoided cost section of this chapter.

4.1 REDUCTIONS IN HUMAN HEALTH RISK

One of the primary goals of the UST cleanup program is the reduction in health risks resulting from petroleum contamination of drinking water sources. Human health risks from well contamination is predominately the result of ingestion of contaminated well water, which is the primary pathway for exposure to petroleum contaminants present in the groundwater. We focus on quantifying cancer risk associated with benzene rather than cancer and non-cancer risks potentially incurred by other petroleum compounds.[3] Our rationale for focusing on benzene is that in previous analyses it has been shown to be the dominant cause of health risk. In addition, extensive information is available to characterize its carcinogenic potential and groundwater plume behavior. We have also simplified the analysis by not accounting for additional, but less significant, health risk incurred through dermal contact with and inhalation of contaminated water (e.g., during showering).

In addition to ingestion-related health effects, volatilized petroleum compounds may pose cancer risks when inhaled as well as acute health effects resulting from fires and explosions. These effects occur primarily when vapors enter buildings through basements or underground utility lines and accumulate in enclosed areas. Based on our literature review, exposure to vapors in buildings appears to be a less significant exposure pathway because it occurs less frequently than other types of exposure.[4]

Consequently, we do not develop methods for measuring human health benefits from reduced vapor damages and fires and explosions in the human health section but instead discuss these methods in the avoided costs section of this chapter. We note, however, that even though the number of incidents may be limited, fires and explosions could pose significant safety risks should they occur. To the extent that we are able to identify additional data on vapor-related human health effects and/or fatal and non-fatal injuries due to LUST-induced fires and explosions, it would be

---

[3] Petroleum products consist of a number of hydrocarbons with varying concentrations and toxicity. Particular hazardous constituents of petroleum products include benzene, and polynuclear aromatic compounds. The terms Total Petroleum Hydrocarbon (TPH) and BTEX (benzene, toluene, ethyl benzene, and xylenes) are frequently used to describe various compounds present in petroleum products. TPH analyses are widely used as a general measure of the presence of crude oil or petroleum product in soils.

[4] See, for example, *Policy for Investigation and Cleanup of Petroleum Discharges to Soil and Groundwater*. Draft. California State Water Resources Control Board, 1997. Vapor exposure appears to be less frequent in part because concentrations of volatile petroleum constituents typically attenuate rapidly within the soil as the vapors migrate upward from underlying residual petroleum constituents. In addition, installation of vapor barriers during new building construction (a common practice to prevent moisture transmission) may provide protection against vapor accumulation.

possible to expand our methods to develop quantitative estimates of human health benefits from avoided fire and explosion incidents.

In evaluating human health benefits from reduction in contaminated drinking water sources, it is important to account for risk averting actions undertaken by households as a consequence of the discovery of leaks and/or unpleasant odors of contaminated water (see also Avoided Costs). In situations where contaminant levels exceed the taste/odor threshold, households may eliminate health risks from ingestion by securing other water supplies.[5] Risk averting actions are likely to reduce health risks in both the base case and the post-rule scenarios, defining a point in time when averting behavior is likely to begin will be an important aspect of the actual scenario development.

To measure potential human health benefits associated with cleanup activities, we propose methods for estimating reduced population risk, as well as reduction in the number of individuals exposed to the greatest cancer risk.[6] Typically, population risk is calculated using information on the concentration of contaminants in the drinking water sources, the amount of drinking water ingested, and the number of people exposed to contaminants. Risk to the most exposed individual (MEI) is a more conservative measure of risk that focuses on individuals at high cancer risk within each exposure scenario. MEI is important because it isolates the high end of the risk distribution, and delineates the number of people likely to be exposed to those risks.[7]

Exhibit 4-1 provides an overview of the three methods proposed for measuring reduction in cancer risk: the simple analysis which would use only existing data or a limited amount of state data; the spatial analysis which would involve spatial modeling to estimate the number of threatened wells; and the more refined spatial analysis with pathway modeling. In addition to quantitative estimates of cancer risks for each scenario, we would also provide qualitative descriptions types of other human health effects associated with contamination of drinking water with petroleum

---

[5] It is possible that responses to taste/odor thresholds would reduce ingestion-related health risks if taste/odor thresholds occur at levels lower than the level of contaminants associated with health risks. However, it is not clear that people routinely undertake averting behaviors in response to taste or odor, and it is likely that some types of exposure (e.g., dermal exposure through showering) would continue. Therefore, our approaches assume that people take averting actions when notified of a leak. However, if the proposed approach is implemented, it may be worth revisiting this baseline assumption about the potential impacts of risk averting behavior.

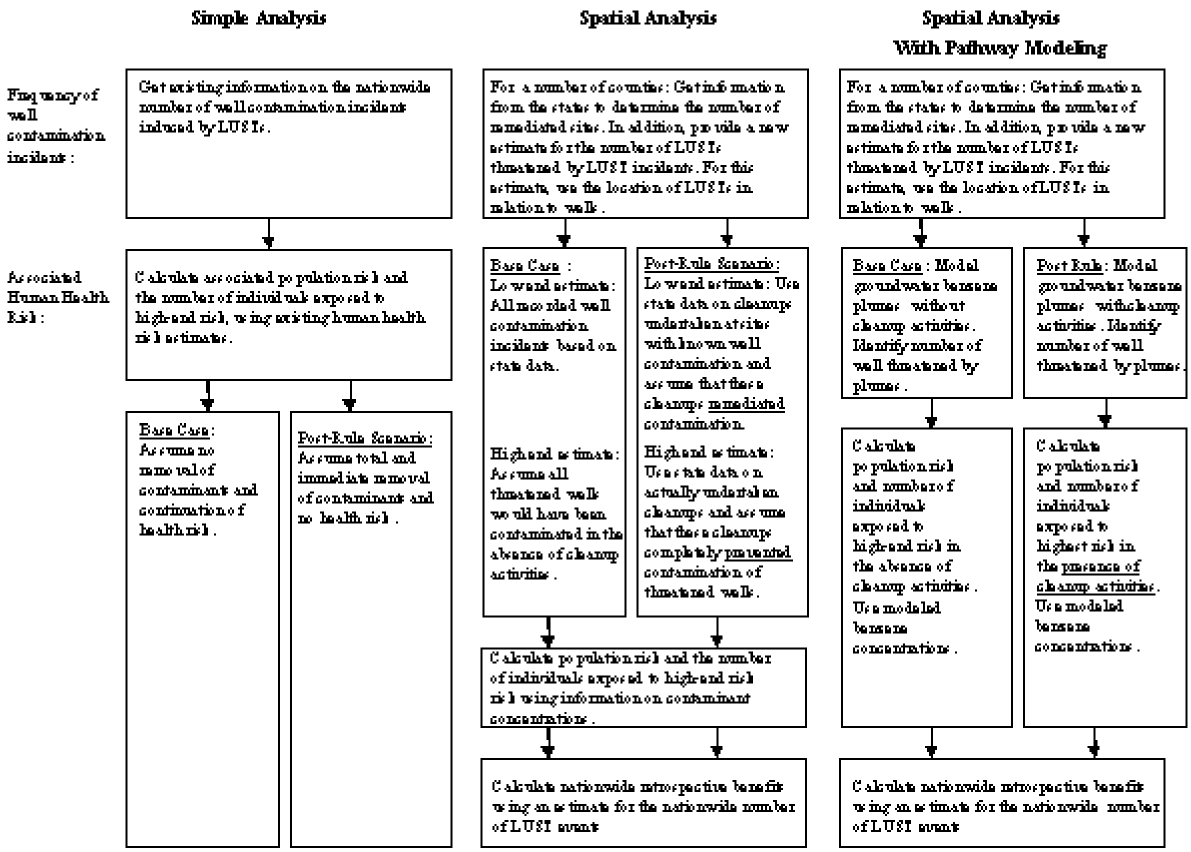
[6] The determination of the actual endpoint and metric for economic valuation of reduced cancer risk (e.g., statistical lives saved, cancer cases avoided) will be part of the implementation and we will revisit this issue at that point.

[7] Reduction in the number of MEIs would not represent a separate, additive health benefits to reduction in population cancer risk, although it may affect the choice of economic values for avoided cases.

substances. We note that although we do not address methods for valuing reductions in cancer risk, the quantitative estimates that our approaches provide could be used as the basis for a monetary estimate of benefits.

Exhibit 4-1

PRELIMINARY METHODS FOR ESTIMATING BENEFITS FROM REDUCTION IN CANCER RISK



4.1.1 *Simple Benefits Analysis for Cancer Risk*

We would base this analysis on 1988 RIA data on the frequency of LUST incidents that lead to well contamination and associated human health risk. In its simplest form, this approach relies on projected data from the 1988 RIA. However, it would be possible to augment this analysis with empirical data from the states. We propose approaches based on existing national data and identify areas in which available state-level data may improve the analysis. Note that in all of our proposed approaches, this report has been prepared using data that we have identified as available; at the point of implementation, additional data may be available that could be substituted for identified sources.

Approach: For the base case scenario, we first would estimate the total number of LUSTs which existed over the time frame of the retrospective analysis.[8] Then, using the 1988 RIA information on the percentage of LUSTs leading to well contamination, we would estimate the total number of associated well contamination incidents. For the purpose of estimating associated human health risk, we propose to scale population risk and MEI estimates from the 1988 RIA to the number of identified well contamination incidents. This is done by calculating the portion of health risk posed by a single well contamination incident and multiplying this ratio by the total number of contaminated wells. For the post-rule scenario we propose to assume that all LUSTs have been cleaned up in the past and that human health risk prior to completion of cleanup efforts is negligible compared to benefits.

To estimate prospective benefits, we would multiply the average risk posed by a LUST in the absence of cleanup activities by the number of expected tank failures assuming that all LUSTs have been found and remediated and that all tanks have been upgraded. This would provide an estimate of future human health risk in the absence of cleanup activities.

Data Sources: The 1988 RIA would provide most data required for the simple benefits analysis. However, these data are derived from modeling efforts and using these data would be associated with significant uncertainties.[9] It is possible to address some uncertainties about the 1988 RIA data by substituting empirical data from the states. Below we summarize the types of data that may be available from the states and the major effects using these data would have on the simple benefits analysis.

- **Total number of LUSTs and number of cleanup activities:** State or commercial data would address uncertainties about the actual number of LUST incidents and would account for the number of actual cleanups. Consequently, the retrospective analysis would not require assuming immediate and complete cleanups of all contamination incidents. For the prospective analysis, it would be possible to provide two scenarios, one assuming future compliance rates with UST cleanup rules similar to those encountered in the past and one assuming full compliance.

---

[8] One potential source of information on the number and location of LUST events is the Starview database of real estate features; the Office of Underground Storage Tanks also tracks annual LUST reporting statistics (though specific LUST locations are not recorded).

[9] The *1988 Regulatory Impact Analysis of Technical Standards for Underground Storage Tanks* used the UST computer Model (created for EPA by ICF, Inc. in April 1988) to calculate plume characteristics and risk estimates. The RIA analysis assumes that the universe of tanks reflects the pre-regulatory tank population (e.g., many older steel tanks with bare steel piping systems) and distributes the tanks randomly among three soil types ("sand," "sandstone," and "clay").

- **Frequency of LUSTs leading to well contamination incidents:** We could employ available state on the frequency of well contamination incidents to address uncertainties about projected 1988 data.

- **Concentration of contaminants:** Using state data on the concentration of benzene found in contaminated drinking water sources may allow for new and more certain estimates of cancer risks in both the base case and the post - rule scenarios.

- **Number of not yet cleaned up LUSTs:** State data on the number of detected but not yet cleaned up LUSTs (and estimates states may be able to provide on the number of not yet detected LUSTs) would allow us to account for benefits associated with these LUSTs in the prospective analysis and would eliminate the assumption that all LUSTs have been detected and cleaned up.

- **Mix of upgraded and substandard tanks:** State data on the current mix of upgraded and substandard tanks and their specific failure rates would provide more certain estimates of future LUST incidents and would eliminate the assumption that all tanks have been upgraded.

While we note that state data would address uncertainties about the 1988 RIA data, obtaining and employing certain state data could significantly increase the level of effort required to conduct the simple benefits analysis. Our efforts to determine state data availability indicate that quality and quantity of available data vary widely among the states.[10] Consequently, although results derived from state data would address some of the uncertainties associated with 1988 RIA data, uncertainties related to data collection, representativeness, and comparability of these data may increase. Also, collection of state data from more than nine states may require an ICR.[11] There is, however, some flexibility in selecting which parameters to replace with state data depending on data availability and expected effects on the certainty of the analysis.[12] To the extent that the two other approaches

---

[10] As noted above, to identify data potentially available from states, we conducted interviews with UST program representatives in Arizona, New Hampshire, New Jersey, Tennessee, and Texas.

[11] If state data are in a prepackaged form readily available to the public, then an ICR would not be required to collect these data from multiple states. However, if data collection requires that state personnel perform database queries or provide file information, then an ICR may be necessary. Our interviews with state UST programs indicate that data formats and availability vary.

[12] Data availability varies depending on the data type. Specifically, certain basic data (e.g., the number of detected LUSTs) are likely to be more easily accessible than data that require

(spatial analysis and spatial analysis with modeling) also rely on the use of state data, these uncertainties also apply.

We describe potential sources for both 1988 RIA and empirical state data in more detail in Exhibit 4-2; we summarize uncertainties related to the proposed methods below in Exhibit 4-8.

Exhibit 4-2

DATA SOURCES FOR THE SIMPLE BENEFITS ANALYSIS (REDUCTION IN CANCER RISK)

Data Type	Data Source (1988 RIA)	Data Sources (States)
Total Number of LUSTs and Number of Cleanup Activities	The 1988 RIA contains data on the total number of LUSTs and estimates of the number of tank failures of substandard and upgraded tanks. It does not provide information on the number of cleanup activities. Using 1988 RIA data would therefore require additional assumptions about the number of cleaned up sites.	Many states maintain databases that contain information on the number of detected incidents and number and types of cleanup activities.
Frequency of LUSTs Leading to Well Contamination Incidents	The 1988 RIA provides estimates of the frequency of LUST-induced well contamination incidents for both upgraded and substandard tanks.	Some states record well contamination incidents, in either digital format or case files. Digital data would be readily available; case files access would require additional resources.
Cancer Risk Estimates[13]	The 1988 RIA estimates population and MEI risk associated with well contamination incidents, and provides information on the range of benzene concentrations in contaminated wells, as well as the frequency at which these concentrations occur.	Some states record concentrations of benzene found in contaminated wells. We could use this information to estimate associated cancer risk assuming life time exposure in the absence of cleanup activities.

extensive site assessments and/or monitoring (e.g., concentrations of contaminants in private wells). In addition, EPA is preparing to issue a proposed rule under the Toxic Substances Control Act section 6 to address the potential methods of better regulating MTBE. This rule may contain data which could be use to estimate the number of tanks containing MTBE.

[13] Note that this approach does not address reductions in baseline risk due to averting actions taken when contaminants are below levels posing risks to human health. This assumption may be revisited if new information indicates that averting behaviors are more (or less) protective of health.

Exhibit 4-2

DATA SOURCES FOR THE SIMPLE BENEFITS ANALYSIS (REDUCTION IN CANCER RISK)

Data Type	Data Source (1988 RIA)	Data Sources (States)
Number of Detected But Not Yet Cleaned Up LUSTs and Number of Not Yet Detected LUSTs	In absence of information on the number of detected and not yet cleaned up LUSTs and the number of not yet detected LUSTs, we would base our prospective estimate on future tank failures of upgraded tanks, assuming that all LUSTs have been detected and cleaned up and all tanks have been upgraded.	Information on the number of not yet cleaned up LUSTs is available from state data in digital format or in case files. Estimates of the number of not yet detected LUSTs could be elicited from representatives of state UST cleanup programs.
Number of Future LUSTs	The 1988 RIA provides estimates of the failure rates of upgraded tanks.	We would estimate the number of future leaking tanks using information on the number of existing USTs, the current mix of substandard and upgraded tanks, and projected failure rates of substandard and upgraded tanks. Estimates of the current mix of upgraded and substandard tanks is available from the states and estimates of failure rates of substandard tanks are in the 1988 RIA.[14]

4.1.2 *Spatial Analysis for Cancer Risk*

This approach would employ available empirical information on the extent of LUST groundwater plumes to estimate the number of wells threatened by LUST incidents. Empirical data on the extent of LUST benzene plumes are available for California (Rice et al., 1995) and Texas (Mace et al., 1997).[15] Both studies conclude that LUST incidents lead to the formation of similarly sized, stabilized benzene plumes, which cease to increase in size at some point in time after the

[14] EPA currently estimates that 85 percent of tanks have already been upgraded. We also note that information on failure rates of upgraded tanks is currently being obtained by UC Davis in conjunction with EPA (http://cee.engr.ucdavis.edu/faculty/young/ldstudy/ld-study.htm).

[15] Rice, D.W., R.D. Grose, J.C. Michaelsen, B.P. Dooher, D.H. MacQueen, S.J. Cullen, W.E. Kastenberg, L.G., Everett, and M.A. Marino, 1995. *California Leaking Underground Fuel Tank (LUFT) Historical Case Analysis*. Environmental Protection Department, Environmental Restoration Division. Mace, R.E., R.S. Fisher, D.M. Welch, and S.P. Parra, 1997. *Extent, Mass, And Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites In Texas*. Bureau of Economic Geology, University of Texas at Austin.

incident.[16] The key advantage of this method is that it would provide both a low end estimate of benefits based on empirical data (which do not identify cleanups that prevented contamination) and a high end estimate based on the GIS approach. The method would, however, be significantly more costly than the simple benefits approach, and would also be more costly than any augmented simple benefits approach that did not require significant state data collection efforts.

Approach: For the base case scenario we would first identify all wells threatened by LUSTs in the absence of cleanup activities. For this purpose, we would create GIS maps with information on drinking water well and UST locations and superimpose a stabilized benzene plume over each UST. Using state data, we would then scale the estimate to the number of LUST incidents affecting groundwater, and impose elliptical plume shapes reflecting plumes affected by groundwater flow.[17] Finally, using census data on the number of potentially affected individuals and information on benzene concentration found in contaminated wells, we would estimate population risk and MEI risks (i.e., the highest 10 percent of estimated risks). This estimate would provide a high end estimate of risks in the absence of cleanup activities. To obtain a low end estimate, we would obtain state data on the number of actually recorded well contamination incidents.

For the post-rule scenario we would use information from the states on the number of completed soil and soil/groundwater cleanups to develop high and low end estimates as follows:

- For the high end estimate, we would employ our high end estimate of the number of well contamination incidents in the base case derived from the GIS. We would then assume that all soil and soil/groundwater cleanups completely prevented well contamination incidents and associated health risk.

- For the low end estimate, we would employ our low end estimate of contaminated wells derived from state data. We would then use state data on the number of groundwater cleanups at sites with known well contamination

[16] Both studies find similar benzene plume lengths: Texas found that most plumes were less than 300 ft long, and have a median length of 180 ft. California found that plume lengths are frequently below 250 ft. Only in the case of limestone geological formations or in cases where plumes travel along preferential pathways created by underground utilities do plumes appear to get much bigger (Mace et al., 1997). Plumes may stabilize when biodegradation of petroleum compounds occurs at a rate equal to movement of contaminants at the plume's outer edges.

[17] In the absence of data on groundwater flow direction, we would define groundwater plumes as circular areas using empirical plume sizes to estimate radii. To remove the additional area captured by these hypothetical circular plumes, we would scale estimates to areas captured by typical elliptical plume shapes. For a more detailed description of this approach see Appendix A.

to estimate the number of remediated wells. Finally, we would assume that remediation reduced exposure duration to negligible levels.[18]

[18] The low end estimate of the post-rule estimate may underestimate cancer risk in cases where cancer risk existed prior to the completion of the cleanup (i.e., prior to the initiation of cleanup activities and during cleanups). It may be possible to estimate risks that existed prior to the completion of the cleanups by adjusting cancer risk estimates for longer times of exposure.

For the prospective analysis, we would provide two benefits estimates: the first assumes future compliance with the UST cleanup program similar to compliance behavior encountered in the past and the second assumes full compliance. For the first prospective estimate, we would multiply the average risk posed by a LUST incident encountered in the past by the number of expected future incidents.[19] For the post-rule scenario assuming full compliance, we would assume no cancer risk in the presence of cleanup activities. Finally, we would repeat this analysis for a set of representative counties and extrapolate to the national level.[20] Below in Exhibit 4-3 we summarize major characteristics of our low and high end estimates for both the base case and the post-rule scenarios.

Exhibit 4-3

COMPARISON OF BASE CASE AND POST-RULE SCENARIOS (REDUCTION IN CANCER RISK - PROSPECTIVE ANALYSIS)

	Number of Contaminated Wells		Cancer Risk*	
	High End Estimate	**Low End Estimate**	**High End Estimate**	**Low End Estimates**
Base Case	All wells threatened by LUST incidents based on the GIS analysis.	All known well contamination incidents based on state data.	All threatened wells posed cancer risk assuming life time exposure.	All known incidents posed cancer risks assuming life time exposure.
Post-rule Scenario	Accounts for prevented and remediated contamination incidents. Uses state data on completed and in progress soil and soil/groundwater cleanups and assumes that these cleanups completely prevented contamination of threatened wells.	Accounts only for remediation of known well contamination incidents. Uses state data on cleanups at sites with known well contamination and assumes that these cleanups remediated contamination.	Assumes that all prevented or remediated contamination incidents completely prevented cancer risk from threatened wells.	Assumes that remediated contamination incidents limited the duration of exposure to contaminants to levels negligible compared to benefits derived from cleanups.

* Note that this approach does not reflect potential reductions in baseline risk due to averting actions taken when contaminants are below levels posing risk to human health. This assumption may be revisited if new information indicates that averting behaviors are more (or less) protective of health.

---

[19] Estimating the number of expected future incidents would involve obtaining data from the states on the number of detected and not yet cleaned up LUSTs and estimates of the number of undetected LUSTs, and the number of future LUST incidents.

[20] For the spatial analysis, we would select counties representing a range of environmental conditions (e.g., subsurface conditions, percentage of private well users) and UST cleanup programs (i.e., varying RBDM approaches and cleanup requirements) for which digital information on UST locations are available.

Data Sources: For this analysis, we would use a number of data types from various sources in addition to those needed for the simple benefits analysis using state data (see Exhibit 4-4).

Exhibit 4-4

DATA SOURCES FOR THE SPATIAL ANALYSIS (REDUCTION IN CANCER RISK)

Data Type	Potential Sources
Location of USTs	Digital maps of USTs are available for many counties in the U.S. from public and private sources. Some state agencies have established digital spatial databases of USTs (e.g., for the purpose of risk-based decision-making). Alternatively, digital maps are offered by private providers for most U.S. counties. These maps are frequently used by real estate agencies for the purpose of identifying potentially contaminated properties.[21]
Location of Wells	Digital maps of private and public wells are available from a variety of public sources including EPA's Safe Drinking Water Information System (SDWIS). Publicly available census block group data contain digital information on the number of private wells per census block group.[22] While these data do not provide the exact location of private wells, they do provide good spatial resolution for private well densities within census block groups.[23]
Spatial Extent of Benzene Plumes	As mentioned above, empirical data on the spatial extent of benzene plumes are available from studies from California and Texas. In these studies, the extent of benzene plumes is defined by a concentration contour line (i.e., 10 ppm) which could be used to define plume impact radii (see Appendix).
Location of Public Drinking Water Sources	Digital data on the location of public drinking water sources are more frequently maintained by state agencies, which often use GIS for environmental decision making purposes.

---

[21] Our methods focus on the characterization of geographic patterns (i.e., typical location of USTs in relation to geographic entities such as wells) and do not require information on the location of LUSTs or complete data sets on the locations of USTs. In the absence of information on the LUST locations, we would estimate the number of wells threatened by USTs in case of leakage using the location of USTs in relation to wells and would then adjust this estimate for the actual number of LUSTs in the past. In the case where only a sub-set of the UST locations is known, we would scale estimates derived from the GIS using information on the total number of USTs in the county.

[22] A census block group is typically defined as an area containing housing units of approximately 1000 people. Census block groups are therefore smaller in high density areas than in areas with lower densities.

[23] These sources were used in a study on the impact of MTBE on private drinking water sources Happel, A., B. Dooher, and E. Beckenbach, 1999. *Methyl Tertiary Butyl Ether (MTBE) Impacts to California Groundwater.* USEPA Blue Ribbon Panel Presentation, March 25, 1999.

Exhibit 4-4

DATA SOURCES FOR THE SPATIAL ANALYSIS (REDUCTION IN CANCER RISK)

Data Type	Potential Sources
Concentrations of Benzene In Drinking Water Wells	The 1988 RIA estimates the range of benzene concentrations in contaminated wells, as well as the frequency at which these concentrations occur. Alternatively, we can base benzene concentrations on empirical data from the states or typical concentration gradients in benzene groundwater plumes.[24]
The Number of People Exposed To Contamination	We can derive this information from census block group data by calculating the number of households per block group deriving water from private wells. Since the number of affected wells would be based on well densities within census block groups, the number of affected households would constitute a statistical average rather than the exact number. The census block group data also provide information on the number of households using public water supplies. Information on the number of households using public water supplies is also likely to be available from the states.

Exhibit 4-5 provides a schematic summary of the use of geographic information in the spatial analysis. As noted earlier, to analyze the number of wells threatened in the absence of cleanup activities, we would first impose circular stabilized benzene plumes on each UST to estimate the geographic extent of potential impact zones. We would then superimpose this map on well densities to estimate the number of wells threatened in case of a LUST incident and on spatial census data to identify the number of people potentially affected by well contamination. Finally, we would scale this estimate to the number of LUST incidents likely to affect the groundwater and to elliptical benzene plume shapes. This result provides information about exposed populations, but does not reflect differences in benzene plumes and contamination scenarios based on geological setting.

Note that most data needed for this approach are publicly available from the U.S. Census (e.g., census block group data, including use of private wells) or from available literature (e.g., plume sizes). We also believe that data on the location of public wells is likely to be available from states in a publicly available format that are available for collection without requiring an ICR. However, if states do not have well location data readily available, then an ICR might be necessary to collect data from more than nine states. This approach would likely require more effort than the simple approach outlined above in order to develop the GIS model; however, the level of effort required would depend on the availability of data.

---

[24] Since studies frequently use benzene concentration data for the purpose of defining groundwater plumes (e.g., 10 ppb for both the Texas and the California study) with concentrations increasing towards the source of contamination, we could use available information on typical concentration gradients to estimate the likelihood of specific contaminant concentrations occurring within the plumes.

4.1.3 *Spatial Analysis With Pathway Modeling for Reduction in Cancer Risk*

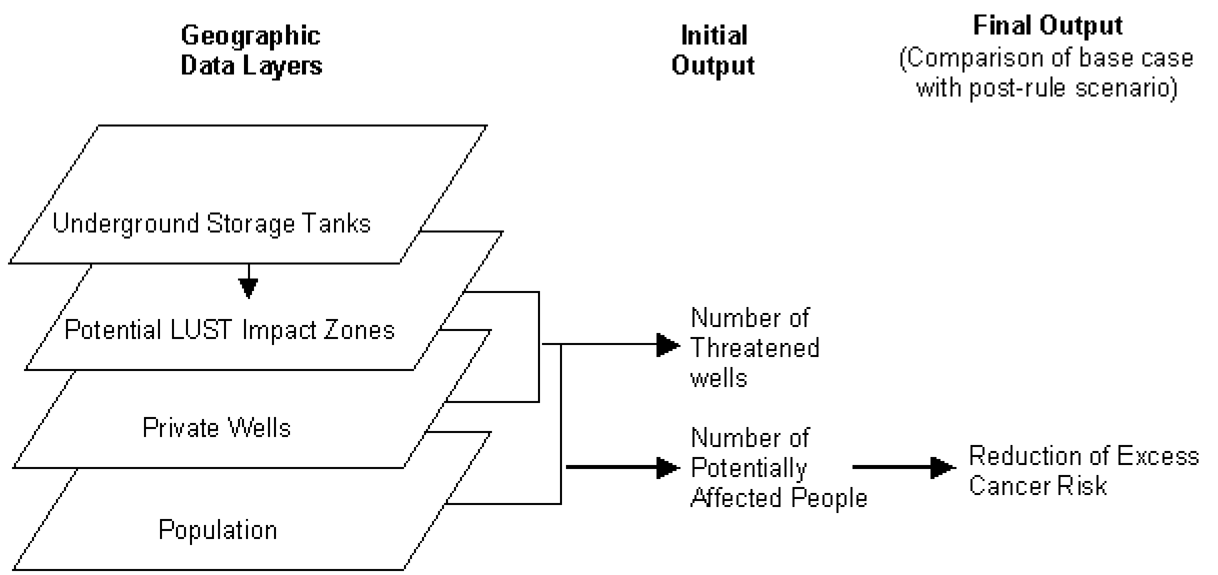
The spatial analysis with pathway modeling is similar to the spatial analysis but requires additional pathway modeling steps. This method addresses key uncertainties associated with the spatial benefits estimate, including the extent of benzene plumes in various geographic settings, and the effect of cleanup activities on benzene plume size and contaminant concentrations. The cost of this approach would be significantly more than the simple and spatial approaches.

Approach: For the base case, we would first model the extent of benzene plumes using input parameters that reflect ranges of LUST incidents and local environmental conditions. To account for cleanups in the post-rule scenario, we would then also model the effect of cleanup activities on the size of benzene plumes and contaminant concentrations. Similar to the spatial analysis described above, we would then use the GIS model to identify the number of affected wells in both scenarios by superimposing benzene plumes on all LUSTs. Finally, using census data on the number of potentially affected individuals, we would estimate population risk and MEI risks in both scenarios.

For the prospective analysis, we propose to provide two benefits estimates, one that assumes future compliance with the UST cleanup program similar to compliance behavior encountered in the past and one that assumes full compliance. The method for projecting would involve analytical steps identical to the ones identified in the spatial analysis (see above).

Exhibit 4-5

USE OF GEOGRAPHIC DATA IN THE SPATIAL ANALYSIS TO ESTIMATE REDUCTION IN CANCER RISK



Data Sources: In addition to data required for the spatial analysis, the analysis with pathway modeling would require geographic information on environmental conditions and the size of releases, as well as soil-groundwater and groundwater transport models (see Exhibit 4-6). Most geographic information on environmental conditions is likely to be available from U.S. Geological Survey or from EPA. Release size (i.e., source mass) data are most likely available from states or can be estimated using values from the literature. If data collection from more than nine states is necessary and source mass data are not in a form readily available to the public, then an ICR may be required to collect these data. This approach would require additional effort related to assembling the data and programing the model.

Exhibit 4-6

DATA SOURCES FOR THE SPATIAL ANALYSIS WITH PATHWAY MODELING (REDUCTION IN CANCER RISK)

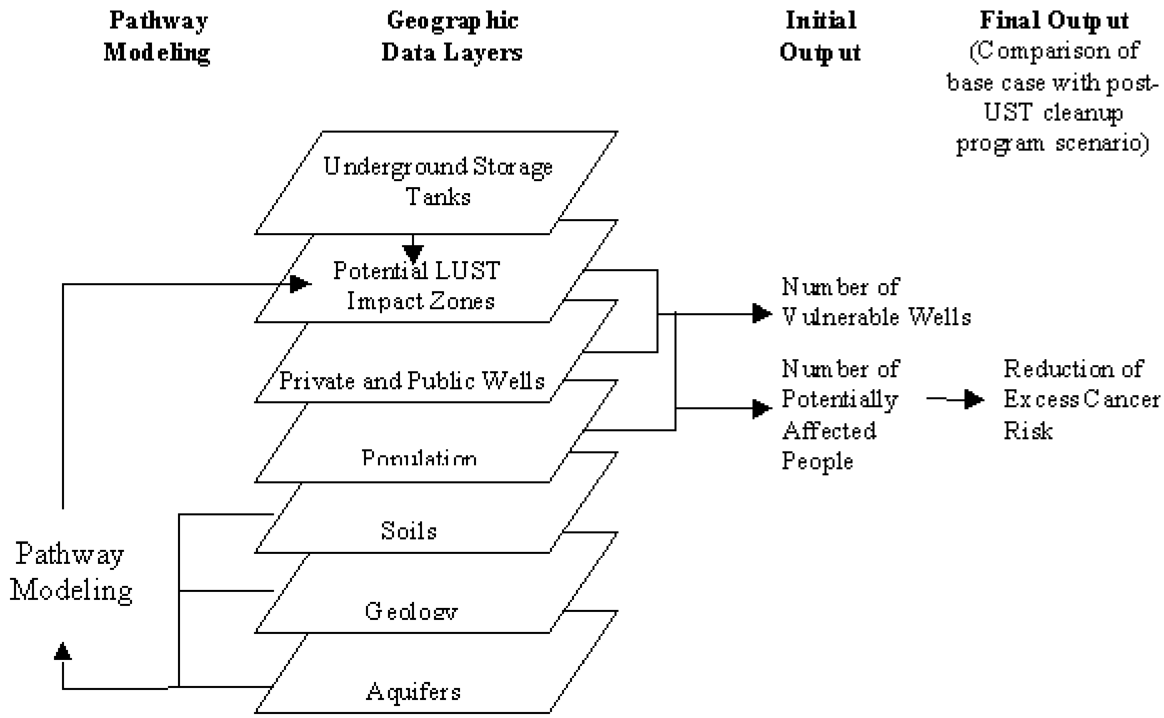
Data Type	Potential Sources
Digital Maps of Local Environmental Conditions	Digital maps available from USGS include soil maps from the *Soil Survey Geographic Database* and geological maps (*Surficial Geology of the Conterminous United States*).[25] Some state and local agencies also maintain digital maps of environmental conditions.
Source Mass	Some states collect information on the size of releases from LUSTs in databases or case files.
Pathway Models	A variety of fate and transport models are available to model the soil-groundwater pathway (see: *RBCA Fate And Transport Models: Compendium And Selection Guidance;* ASTM, 1999). These models differ in terms of sensitivity to specific input parameters and the availability of default settings. In choosing an appropriate model, availability of site-specific environmental information may influence the decision. For example, models sensitive to soil characteristics may only be useful in cases where information on soil properties is available. Additional desirable characteristics of models include the ability of the model to account for the effect of cleanup activities and for biodegradation of benzene. Some models also include Monte Carlo capability to characterize uncertainty in the analysis.

Exhibit 4-7 is a schematic representation of data layers for the spatial analysis with pathway modeling. To summarize, we would first identify environmental conditions in the study areas using digital maps of soil and geological conditions and would then use this information as input into the pathway models. From pathway modeling efforts, we would obtain information on plume sizes and concentration in the absence and in the presence of cleanup activities, which we would superimpose

[25] The USGS digital maps on soil conditions do not yet cover the entire U.S.

Exhibit 4-7

USE OF GEOGRAPHIC DATA IN THE SPATIAL ANALYSIS WITH PATHWAY MODELING (REDUCTION IN CANCER RISK)



on LUSTs in the GIS to estimate the number of threatened wells in both scenarios. The risk analysis would be based on benzene concentration and exposure duration data derived from the modeling efforts.

4.1.4 *Evaluation of Proposed Methods And Addressing Uncertainties*

Exhibit 4-8 summarizes major characteristics and uncertainties of the three methods for estimating reduction in cancer risk.[26] The simple benefits analysis provides a rough estimate assuming immediate and total cleanup of all contaminated sites. In addition to data needed for the simple benefits analysis, the spatial analysis would require digital data on the location of USTs as well as digital census block group data. The major advantage of this method is that it would provide a high end estimate of reduced cancer risk in addition to the low end estimate derived from state data. This high end estimate would account for completely prevented well contamination incidents

[26] For a summary on data needs for all methods please refer to Chapter 8.

as well as potential under-reporting of well contamination incidents in state data. While the data requirements for spatial analysis are substantial and the costs higher than for either the simple or augmented simple approaches, it is possible to use data obtained for this analysis to analyze other attributes.

The spatial analysis would use stabilized benzene plumes to define potential impact zones of USTs. Because we would derive these data from empirical studies in limited geographic locations, there is uncertainty associated with transferring these data to different geographic locations. These empirical benzene plume sizes also reflect plumes in a variety of cleanup stages under the program. The effect cleanup activities may have had on the mix of plume sizes encountered in the environment is uncertain and using empirical information on benzene plume sizes may underestimate the extent of benzene plumes in the base case.[27] While there is some uncertainty associated with the spatial method, using this information on benzene plume sizes for the analysis would significantly reduce the amount of effort required to estimate benefits since any study which considers local geological conditions is likely to involve pathway modeling.

The spatial analysis with pathway modeling addresses uncertainties associated with the spatial analysis by modeling benzene plumes under local environmental conditions and accounting for the effect of cleanup activities on benzene concentrations. It would, however, require the most extensive data collection and analysis and, therefore, be the most costly.

Exhibit 4-8

COMPARISON OF METHODS (REDUCTION IN CANCER RISK) CHARACTERISTICS AND UNCERTAINTIES

Characteristics / Uncertainties	Simple Benefits Analysis	Spatial Analysis	Spatial Analysis With Pathway Modeling
Results	The method provides a rough estimate of reduction in population risk and the number of MEIs.	The method provides low and high end estimates of reduction in population risk and the number of MEIs.	The method provides low and high end estimates of reduction in cancer risk and MEI based on extensive modeling.

27 The spatial analysis (with and without pathway modeling) might overestimate the number of contaminated wells; in some cases wells may not be contaminated despite spatial proximity to plumes if they derive water from different geological layers.

Exhibit 4-8

COMPARISON OF METHODS (REDUCTION IN CANCER RISK) CHARACTERISTICS AND UNCERTAINTIES

Characteristics / Uncertainties	Simple Benefits Analysis	Spatial Analysis	Spatial Analysis With Pathway Modeling
Frequency of LUST incidents	The frequency of LUST incidents is uncertain. 1988 RIA Data: requires assumptions about the mix of substandard and upgraded tanks. State Data: may provide mix of substandard and upgraded tanks	The frequency of LUST incidents is less uncertain. In both analyses, estimates would be based on the number of detected LUSTs in state data. The frequency of the incidents would also reflect UST technical standards and changes in approaches to cleanup activities over time (e.g., RBDM).	
Number of Contaminated Wells in the Base Case	1988 RIA Data: frequency of LUSTs that lead to well contamination is uncertain. State Data: may include information about frequency of well contamination.	The high end estimate may overestimate the number of well contamination incidents in cases where wells are not affected despite spatial proximity (e.g., because wells retrieve water from unaffected geological layers or because incidents would not have affected the groundwater in absence of cleanup activities).[28]	Like the spatial analysis, the method may overestimate the number of well contamination incidents in cases where wells are not affected despite spatial proximity (e.g., because wells retrieve water from unaffected geological layers). The method would address uncertainty about minor incidents unlikely to affect the groundwater since it considers the sources mass and models the soil-groundwater pathway.
Effect of Cleanup Activities	1988 RIA Data: The method assumes immediate and total cleanup of contamination and does not account for past compliance rates or preventative cleanups. State Data: The method accounts for compliance rates because it is based on cleanup activities actually undertaken in the states.	The method accounts for compliance rates because it is based on cleanup activities actually undertaken in the states. It also accounts for preventative cleanups.	The method would further characterize the effect of cleanup activities by modeling benzene plumes with and without cleanup activities.

[28] To the extent that information on source mass and/or minor incidents (e.g., surface spills) is available from the states, we would use this information to identify leaks that are unlikely to reach the groundwater in the absence of cleanup activities.

Exhibit 4-8 COMPARISON OF METHODS (REDUCTION IN CANCER RISK) CHARACTERISTICS AND UNCERTAINTIES			
Characteristics / Uncertainties	**Simple Benefits Analysis**	**Spatial Analysis**	**Spatial Analysis With Pathway Modeling**
Groundwater Plumes And Benzene Concentrations	The method would not require assumptions about groundwater plumes and benzene concentrations beyond those made in the 1988 RIA.	Uncertainty is associated with assuming stabilized benzene plumes and with transferring empirical data from different geographic regions.	The method does not require assuming stabilized plumes or transferring empirical information on plume sizes between different geographic regions. It would also provide modeled benzene concentrations under local environmental conditions.
Future Benefits	The method assumes that all LUSTs have been detected and all tanks have been upgraded. It does not account for benefits associated with existing but not yet detected and/or cleaned up LUSTs.	The spatial analyses would account for detected and not yet cleaned up LUSTs, not yet detected LUSTs, and not yet upgraded tanks. Uncertainty is, however, associated with the number of not yet detected LUSTs, the future mix of upgraded and substandard tanks, and associated failure rates.	

Addressing Uncertainties: We could address uncertainties associated with the three methods by conducting sensitivity analyses for key assumptions. For each of the methods we believe the following sensitivity analyses might be helpful:

- **Simple Benefits Analysis:** A sensitivity analysis could compare various mixes of substandard and upgraded tanks by assuming that averaged over the time period of the analysis 20 to 80 percent of the tanks were substandard tanks.[29] As shown on Exhibit 4-8, state data may be used to augment the simple benefits analysis (see also Exhibit 4-2 and related discussion on Data Sources for the simple benefits analysis). Sensitivity analyses addressing associated uncertainties would depend on the quality of state data.

- **Spatial Analysis:** In addition to the sensitivity analyses described above, a sensitivity analysis comparing ranges of benzene plumes sizes and concentration of contaminants (see Appendix A).

[29] This estimate is derived from EPA's *Blue Ribbon Panel on Oxygenates in Gasoline (Executive Summary and Recommendations*. Final, July 27, 1999).

- **Spatial Analysis With Pathway Modeling:** Sensitivity tests for the spatial analysis with pathway modeling would focus on a Monte Carlo analysis of key impacts.[30]

4.2 ECOLOGICAL BENEFITS

The UST cleanup program can have ecological benefits in cases where cleanup activities reduce the exposure of wildlife to contaminants. Wildlife may be especially threatened by LUST incidents if contaminated groundwater reaches surface waters such as rivers and lakes.[31] In surface waters, some petroleum compounds may be ingested by animals such as fish and birds, and may bioaccumulate, leading to toxic effects.[32] These toxic effects include increased mortality or lower reproductive rates. Potential ecological benefits of the UST cleanup program include avoided habitat destruction and reduced pressure on biological communities, endangered species, and species valuable for recreational purposes. These ecological benefits may differ widely among geographic regions depending on the number and type of surface waters present. For example, benefits may be considerably higher in areas with many rivers and lakes, such as the Northeast, than in dryer areas where surface waters tend to be less prevalent and more seasonal.

Petroleum compounds are complex mixtures of hundreds of chemicals, each having its own physical and toxicological characteristics. These compounds may be classified in terms of ecological risks according to the following chemical-specific properties: (1) persistence, (2) bioaccumulation, and (3) toxicity. Chemical persistence in the environment is a combination of biotic and abiotic degradation processes that varies greatly with chemical structures and environmental conditions (e.g., temperature). Chemicals with a high potential for bioaccumulation

---

[30] Monte Carlo analyses are frequently used to describe uncertainties associated with modeling efforts and involve comparing model outputs using a range of input data for environmental conditions.

[31] Ecological risks may also be associated with the contamination of soil with petroleum compounds. These risks include those associated with the contamination of agricultural products as well as those associated with the accumulation of contaminants along terrestrial food chains. In our proposed methods, however, we do not account for risks associated with the contamination of terrestrial sites due to the typically limited amount of agricultural or vegetated areas in the vicinity of regulated USTs.

[32] This transfer of contaminants along the food chain may also lead to human health effects through the consumption of contaminated animals (e.g., fish). If preliminary estimates of the number of surface waters affected by LUSTs indicate that this pathway may contribute significantly to human health impacts and if we can identify data sufficient to conduct the analysis we would evaluate associated human health effects.

and/or magnification are likely to pose greater risks to ecological receptors at a variety of trophic levels. According to a review of existing information on bioaccumulation, petroleum compounds can exhibit relatively high bioaccumulation potentials. Toxicity of the various petroleum compounds varies with the type of the compound as well as with affected species. Information on species-specific toxicity values is available for a number of aquatic and bird species.[33]

According to EPA's *Guidelines for Preparing Economic Analysis*, economic benefits derived from improvements in ecological conditions and associated service flows can include (1) market benefits, (2) non-market benefits, (3) indirect benefits, and (4) non-use benefits. Below in Exhibit 4-9 we summarize ecological benefits potentially associated with the UST cleanup program according to the various categories identified in the guidelines.[34]

Exhibit 4-9

POTENTIAL ECOLOGICAL BENEFITS OF THE UST CLEANUP PROGRAM

Benefit Type	Description	Examples of Benefits Potentially Associated With the UST Cleanup Program [35]
Market Benefits	Provision of products that can be bought and sold on a competitive market	Commercial fisheries benefits.
Non-Market Benefits	Consumptive uses	Recreational fishing benefits.
	Non-consumptive uses	Improvement in non-consumptive recreational opportunities (e.g., wildlife viewing).
Indirect Benefits	Support of off-site ecological resources or maintenance of biological and biochemical processes	Avoided habitat destruction and conservation of green space via brownfields redevelopment. Reduced pressure on endangered species and biodiversity.
Non-Use Benefits	Value associated with ecological resources without using or intending to use it, passive use values associated with the knowledge the resources exists in an improved state, bequest values for future generations, and altruistic values for others' enjoyment of the resource.	Non-use values associated with improved groundwater and surface water conditions.

---

[33] Foster Wheeler Environmental Corporation, 1997. *Final Technical Memorandum: Preliminary Selection of Candidate Petroleum Hydrocarbons as Surrogates for Ecological Risk Revaluation of TPH*. Brownfields/TPH Project. Phase 2, Task 4, Subtask 4.2.1.

[34] EPA, 1999. *Guidelines for Preparing Economic Analysis.* Review Draft. June 1999.

[35] We note that some of the potential benefits listed in Exhibit 4-9 are likely to be marginal due to potentially limited impacts of LUSTs on surface waters.

Below we describe our proposed methods for estimating ecological benefits from reduced surface water contamination. We then describe our methods for estimating total use and non-use values associated with clean groundwater resources. Additional ecological benefits may also be associated with the promotion of brownfields development in cases where valuable greenspace is protected at the urban fringe. We discuss methods for characterizing these effects in Chapter 6 (i.e., distributional impacts).

4.2.1 *Ecological Benefits from Reduced Surface Water Contamination*

We propose three methods for estimating reduction in surface water contamination which parallel our methods for measuring reduction in health risk (i.e., simple, spatial, and spatial with pathway modeling). All these methods would provide estimates of the number of surface water contamination incidents avoided by cleanup activities. While the simple analysis would not provide a quantitative estimate of associated ecological risk, we would augment the analysis with qualitative descriptions of associated ecological benefits. The spatial analysis could be extended to estimate ecological risk depending on the availability of empirical data on contaminant concentrations in surface waters.[36] The spatial analysis with pathway modeling would provide sufficient information on the concentration of contaminants in surface water to estimate the ecological risk associated with these contamination incidents.

Similar to our methods for estimating reduction in health risk, we would base the simple benefits analysis on reported surface water contamination incidents and assumptions about the effect cleanup activities on reducing the number of incidents. Our spatial analysis of ecological benefits would provide a new estimate of the number of surface water contamination incidents that is based on the proximity of USTs to surface waters.[37] Finally, the spatial analysis with pathway modeling would model soil-groundwater and groundwater pathways to estimate the extent of benzene plumes under local environmental conditions and the effect of cleanup activities on the extent of benzene plumes. In addition to these estimates of plume sizes, we can also use modeling to characterize the groundwater-surface water interface.

---

[36] At this point in our methodology development, we have not identified sufficient empirical information on the concentration of LUST contaminants in surface water and their duration to allow estimation of surface water concentrations.

[37] The spatial analysis would assume that surface waters are threatened, if they are located in the vicinity of USTs. Similar to our spatial analysis of cancer risk, vicinity would be defined by the size of groundwater benzene plumes.

4.2.1.1 Simple Benefits Analysis of Ecological Benefits

The endpoint of the simple analysis would be the number of surface water bodies contaminated in the base case and in the post-rule scenario. Information on the frequency of LUST surface water contamination is available from either the 1988 RIA or from state data. In addition to this quantitative description, we would add a qualitative discussion of resources and ecological service flows affected by LUST surface water contamination.

Approach: To establish the post-rule scenario, we would first estimate the total number of LUST incidents (see method for human health benefits) and calculate the total number of associated surface water contamination incidents using 1988 RIA information on the frequency of LUSTs that affect surface waters. We would then assume immediate and total cleanup of incidents in the post-rule scenario and no reduction in contamination in the base case scenario.

For the prospective analysis, we would use our estimate of the number of future tank failures identified in the health risk analysis to establish a scenario that assumes full compliance with the UST cleanup program.

Data Sources: The method relies on 1988 RIA data on the frequency of surface water contamination for both substandard and upgraded tanks. We would also use 1988 RIA estimates of the number of LUSTs and failure rates of upgraded and substandard tanks to estimate the total number of LUSTs (see simple analysis of reduced cancer risk). To the extent that empirical data on surface water contamination incidents are available from the states, it would be possible to use this information to augment the analysis, as we proposed for simple benefits analysis of reduced cancer risk.[38] Empirical data on surface water contamination may, however, introduce uncertainties about the representativeness of these data and potential under-reporting of the number of incidents.

4.2.1.2 Spatial Benefits Analysis of Ecological Benefits

Our spatial analysis of ecological benefits would provide estimates of the number of surface water bodies contaminated in the base case and the post-rule scenario based on the geographic proximity of LUSTs to surface waters and information on completed cleanup activities. A major advantage of this method is that it accounts for potential under-compliance with the UST cleanup program and provides more defensible low and high end estimates of the number of contaminated surface water bodies in both scenarios. Depending on the availability of data on the concentration of contaminants in surface waters following LUST incidents, it may be possible to estimate

---

[38] To the extent that empirical data on LUST-induced contaminant concentration in surface waters and duration of exposure are available, it also may be possible to provide quantitative estimates of reduction in ecological risks.

reduction in ecological risk associated with cleanup activities.[39] If we cannot identify data sufficient to conduct the ecological risk assessment, we would add a qualitative discussion of resources and service flows potentially affected by surface water contamination. Depending on data availability, we may also be able to identify the sizes of affected water bodies to provide an indication of the magnitude of impacts. Analytic steps for this analysis are similar to those proposed for the spatial analysis of reduction in health risk. We describe these steps below.

Approach: For the base case scenario we first would identify all surface waters threatened by LUSTs in the absence of cleanup activities. For this purpose, we would create county GIS maps with information on the location of surface waters and superimpose a stabilized benzene plume over each UST. We would then scale the estimate to the number of LUSTs and the shape of benzene plumes. This estimate would provide a high end estimate of the number of contaminated surface water bodies in the absence of cleanup activities. To obtain a low end estimate, we would use state data on the number of actually recorded surface water incidents.

For the post-rule scenario we propose to establish low and high end estimates of incidents avoided or remediated through cleanup activities:

- For the high end estimate, we would use our high end estimate of surface water contamination incidents in the base case from the GIS. We would then assume that all soil and soil/groundwater cleanups completely prevented surface water contamination incidents and associated ecological risks.

- For the low end estimate, we propose to use state data on the number of surface water cleanups to estimate the number of remediated sites.

Then, using empirical information on the concentration of LUST contaminants and duration of contamination in surface waters, we would estimate risk to wildlife in the base case and the post-rule scenario.[40] We would then repeat the analysis for a number of counties representing a variety of environmental conditions (e.g., densities of surface water bodies) and cleanup programs and extrapolate to the national level using the number of nation-wide LUSTs (see spatial analysis of reduction in health risk).

For the prospective benefits analysis, we would provide a scenario assuming future compliance rates similar to those encountered in the past by projecting retrospective benefits into

---

[39] While data on actual groundwater-to-surface water discharge zones would be helpful in identifying surface waters likely to be affected, we have not identified any readily available sources of these data; we therefore estimate surface water contamination using reported incidence data.

[40] As stated earlier, this step depends on the availability of empirical information about contaminant concentrations and their persistence in the environment.

the future. In addition, we would estimate benefits derived from full compliance with the UST cleanup program, assuming complete reduction of risk in the post-rule scenario as in the spatial analysis of health risk.

Data Sources: The spatial analysis would require digital maps of USTs for selected counties, information on the number of detected LUSTs, and information on the number and types of cleanup activities undertaken in these counties. The potential sources for these data types are the same as those identified in the spatial analysis for cancer risk. We would also require digital maps of the location of surface waters within the counties selected for the analyses. These maps are generally available from state or local governmental agencies. Information on the toxicity of benzene to wildlife is available in the scientific literature.

4.2.1.3 Spatial Analysis With Pathway Modeling of Ecological Benefits

The spatial analysis with pathway modeling would address major uncertainties associated with the spatial benefits estimate, including the extent of benzene plumes under various environmental conditions, the effect of cleanup activities, and the percentage of plumes reaching surface waters. Since modeling efforts would provide information on the concentration of contaminants in surface waters, the endpoint of this analysis would be reduction in ecological risk associated with cleanup activities. While we could build on modeling results from the reduction in cancer risk analysis, we would need additional modeling to characterize the groundwater to surface water pathway.

Approach: First, we would establish the base case scenario using modeled benzene plumes from the human health benefits analysis to identify the number of threatened surface water bodies. This is done by superimposing ranges of modeled plumes on LUSTs in the GIS and identifying all surface waters within the area of these plumes. We would then repeat this analysis for the post-rule scenario using benzene plumes modeled in the presence of cleanup activities. Finally, we would model the groundwater to surface water pathway to determine the range of benzene concentrations in affected surface waters and the number of plumes actually reaching surface waters. Our calculation of ecological risks in both scenarios would be based on these modeling results and literature values on toxicity thresholds. To estimate nationwide retrospective benefits, we would repeat this analysis in a variety of counties and extrapolate using estimates of the number of nationwide LUSTs.

For the prospective analysis, we would provide two benefits estimates, one that assumes future compliance with the UST cleanup program similar to compliance behavior encountered in the past and one that assumes full compliance. The method for projecting benefits would involve analytical steps identical to the ones identified in the spatial analysis of reduction in cancer risk.

Data Sources: For pathway modeling purposes, we would require a variety of additional geographic data layers with information on local environmental conditions such as soils, geology, and groundwater characteristics and information on source mass. Most of these data layers are available from government sources (e.g., from the U.S. Geological Survey or the U.S. Department of Agriculture's Natural Resource Conservation Service), though the availability of highly detailed local hydrogeological data may vary.

4.2.1.4 Evaluation of Proposed Methods And Addressing Uncertainties

We summarize characteristics of the three proposed methods for estimating ecological benefits from reduced surface water contamination in Exhibit 4-10. The simple benefits analysis would be easy to implement, require only existing information, and would provide a rough estimate of the number of contaminated surface water bodies in the base case. The method, however, is not sensitive to the actual number of cleanup activities and does not account for surface water contamination incidents that were not completely avoided by cleanups. In addition, this approach makes assumptions about the mix of upgraded and substandard tanks and uses the 1988 RIA estimates on the frequency of surface water contamination, which are based on a very small and potentially biased sample of geographic locations. While it is possible to address some of these uncertainties by using state data on completed cleanups, this augmented simple benefits analysis would not account for completely avoided surface water incidents and would be sensitive to a potential under-reporting of surface water contamination incidents in state data.

The spatial analysis would require additional resources, but would provide more defensible low and high end estimates of the number of contaminated surface waters; furthermore, this analysis could potentially be extended to estimate reduction in ecological risk. If available data are insufficient to conduct an ecological risk assessment, we would add a qualitative discussion of resources and service flows potentially affected by surface water contamination. Major issues associated with the spatial analysis of ecological benefits are similar to those for the spatial analysis of human health benefits: uncertainty associated with the use of stabilized benzene groundwater plumes; uncertainty associated with the effect of cleanup activities on plumes; and potential overestimation of the number of contaminated surface waters in both scenarios in cases where groundwater plumes do not reach surface waters despite spatial proximity. Collection of data from more than nine states might also require an ICR.

The spatial analysis with pathway modeling would address uncertainties associated with plume sizes and the percentage of groundwater plumes not reaching surface waters despite spatial proximity. It would also provide estimates of the concentration of contaminants in surface waters. Its implementation would, however, require substantial information and resources.

Addressing Uncertainty: We could address uncertainties associated with all methods by testing their sensitivity to key assumptions. We describe potential sensitivity analyses in our discussion of human health risks (see Section 4.1 above).

Exhibit 4-10 COMPARISON OF METHODS (ECOLOGICAL BENEFITS FROM REDUCED SURFACE WATER CONTAMINATION) CHARACTERISTICS AND UNCERTAINTIES			
Characteristics and Uncertainties	**Simple Benefits Analysis**	**Spatial Analysis**	**Spatial Analysis With Pathway Modeling**
Results	1988 RIA Data: the method provides a general estimate that accounts for surface water contamination incidents limited in duration due to cleanup activities. The method does address reduction in ecological risk. State Data: may include better accounting of surface water contamination incidents addressed.	The spatial analysis provides low and high end estimates of the number of surface water contamination incidents avoided through cleanup activities or limited in duration. It may be possible to estimate reduction in ecological risk provided that sufficient empirical information on contaminant concentrations can be identified.	Pathway modeling yields detailed information on the number of reduced surface water contamination incidents and associated reduction in ecological risk.
Number of Contaminated Surface Waters	1988 RIA Data: these data are based on a small and potentially biased set of geographic locations. State Data: if available from multiple states, data may be representative.	The method would provide high and low end estimates of the number of affected surface waters. The high end estimate may overestimate damages in cases where groundwater plumes do not reach surface water despite spatial proximity.	Modeling of the groundwater to surface water pathway would add additional information on the number of groundwater plumes actually reaching surface water.
Effect of Cleanup Activities	The method may underestimate the effect of cleanup activities because it does not account for benefits associated with preventative cleanups.	It provides low and high end estimates of the benefits associated with cleanup activities, including preventative cleanups.	The method would further address uncertainty by modeling the effect of cleanup activities on groundwater plumes.

4.2.2 *Total Groundwater Use and Non-use Values*

This attribute is a comprehensive monetary estimate for an entire set of effects from the UST cleanup program that includes values associated with the current use of groundwater as well as non-use values. Groundwater use values are derived from the consumption of groundwater (e.g., as drinking water sources) and non-use values are derived from the existence of clean groundwater in absence of current use. These non-use values include the option to use groundwater for future purposes (i.e., option value) and values associated with the existence of clean groundwater in absence of any planned future use (i.e., existence value).

Total groundwater use and non-use values are derived from contingent valuation (CV) studies, which provide estimates of the combined effects of policies leading to clean groundwater. CV estimates are elicited directly from individuals (via interviews or questionnaires) in the form of maximum willingness to pay (WTP) or minimum willingness to accept (WTA) compensation for hypothetical changes in groundwater quality. Because estimates derived from CV studies reflect both use and non-use values of groundwater, they can be useful as a high-end indicator of the benefits expected from the sum of values developed with the attribute-by-attribute approach.[41]

However, there is not yet a suitable method available for separately evaluating use and non-use values for groundwater based on existing CV surveys. For this reason, we structured this attribute to measure combined use and non-use values, rather than separate groundwater use, option, and existence values associated with clean groundwater.

Approach: In order to estimate total groundwater use and non-use benefits for the UST cleanup program, we would use benefits estimates from existing CV studies to assess values associated with the cleanup of LUSTs. This "benefits transfer" approach would involve describing all effects potentially associated with groundwater contaminated by LUSTs (including severity and extent of health effects and costs associated with contaminated water) and identifying comparable studies (i.e., studies looking at a similar effects). Subsequently, we would identify the range of WTP or WTA monetary estimates provided by these studies and transfer benefits to the UST cleanup program based on the median U.S. income.

Data Sources: We have identified a variety of potentially applicable studies. Edwards estimated the value of reducing the probability of nitrate contamination on Cape Cod in Massachusetts; McClelland et al. estimated the national benefits of avoiding groundwater contamination from landfills; and Powell et al. studied people's WTP for groundwater protection in 12 communities in the Northeast.[42] Edwards estimated groundwater values to range from $0 to $1,623 per household annually. Most estimates from other CV studies fall within that range.

---

[41] Values derived from the attribute-by-attribute approach and potentially captured by CV estimates are the reduction in human health risk, avoided costs of providing alternative water supplies, ecological benefits, and sustainability benefits. We discuss potential double counting of these benefits in Section 8.

[42] Edwards, S.F., 1988 'Option Prices For Groundwater Protection.' *J. Environ. Econ. and Management* 15:465-487; McClelland, G.H. et al., 1993 *Methods for Measuring Non-Use Values: A Contingent Valuation Study of Groundwater Cleanup*. Final Report, U.S.EPA, Office of Policy. Powell, J.R., D.J. Allee, and C. McClintok, 1994 'Groundwater Protection Benefits and Local Community Planning: Impact of Contingent Valuation Information.' *Amer. J. of Agricultural. Economics* 76:1068-1075.

Evaluation: The proposed method would provide monetary estimates of the upper bound on total values associated with use and non-use values of clean groundwater. The method, however, is associated with some significant uncertainties including transferring WTP estimates from existing studies to the UST cleanup program scenario, and from limited geographic regions to the entire U.S.

Addressing Uncertainty: We could address uncertainties associated with this method by transferring ranges of literature values from appropriate studies to the UST cleanup program scenario and identifying corresponding total values.

4.3 AVOIDED COSTS

LUST-induced damages may be associated with a variety of costs to public and private entities, including costs incurred for the provision of alternative water supplies as a consequence of the contamination of drinking water sources and costs associated with LUST damages to buildings.[43] In this section we first present our proposed methods for estimating avoided costs related to the contamination of drinking water sources. We then discuss methods that could be used to estimate reduction in costs incurred due to vapor damages to buildings and to fires and explosions.

4.3.1 *Provision of Alternative Water Supplies*

Groundwater contamination can generate a variety of costs to public or private entities associated with the provision of alternative water supplies and other actions taken to avoid exposure to contaminants. Private entities such as households or firms typically incur costs associated with the contamination of private wells. These costs may result from one or more of the following: purchasing durable goods (e.g., point-of-use treatment systems) and nondurable goods (bottled water), switching to nearby surface water or public water supplies, drilling a new well spatially isolated from the plume, changing daily routines (e.g., reducing frequency and duration of shower), and the amount of time required for averting actions (e.g., time to purchase water).

Costs associated with the contamination of public drinking water sources more frequently involve groundwater cleanup or water treatment. In addition to costs, municipal expenditures associated with the contamination of public drinking water sources may also include costs associated

[43] Where avoided costs are associated with government-mandated costs under alternative programs (e.g., the Safe Drinking Water Act), they represent a specific program benefit. Where avoided costs result from voluntary averting behaviors, they represent a low-end "proxy" for the value of avoiding risk. In developing our methods, we did not distinguish between the different roles of avoided cost analysis; however, any implementation of an avoided cost analysis should include careful consideration of its role in the overall assessment and of implications for double-counting.

with additional monitoring, public notification, risk communication, locating alternative water sources, and increases in the level of anxiety of fear within the community.

We propose three methods for measuring costs averted by the UST cleanup program - a simple benefits analysis based on data from the 1988 RIA, a spatial analysis which provides new estimates of the number of contaminated wells, and a spatial analysis with pathway modeling. All of our methods would require (1) identifying literature on expenses associated with private and public well contamination incidents, (2) identifying the number of affected households in the base case, (3) estimating reductions in well contamination incidents in the post-rule scenario, and (4) applying literature values to the number of reduced well contamination incidents.

Below we describe the simple and the spatial approaches for characterizing benefits. We do not specifically address analytic steps for the pathway modeling approach, which would be very similar to those described in the section on reduction in cancer risk.

4.3.1.1 Simple Benefits Analysis (Provision of Alternative Water Supplies)

This method uses data on the number of contaminated wells from the simple benefits analysis of reduction in health risk (i.e., based on RIA estimates). Like all our simple benefits analyses based on 1988 RIA data, this analysis could be augmented by using empirical data from the states (see simple benefits method for reduction in cancer risk).

Approach: For the base case scenario, we would first identify the number of contaminated private and public wells in the absence of cleanup activities, using data from the simple benefits analysis of health risk. Then, we would apply a range of estimates of associated costs to private users and municipalities derived from the literature to calculate annual costs. Subsequently, we would assume that well contamination incidents have been evenly distributed over the time frame of the retrospective analysis (i.e., all wells would have been contaminated an average of six years after the implementation the cleanup program) to calculate total expenses.[44]

For the post-rule scenario, we would assume that cleanup is initiated at all contaminated wells immediately after detection of the contamination, and that avoided costs accrued only over the duration of cleanup activities. We would then extrapolate benefits to the national level using nationwide estimates of the number of well contamination incidents. For the prospective analysis,

[44] This analysis assumes that well contamination incidents are evenly distributed over the time frame of the retrospective analysis (i.e, 12 years). Consequently, incidents occurred an average of six years ago and contamination continues to exist indefinitely absent cleanup. To define the time frame for the averted costs analysis we suggest calculating averted costs over a time period of 20 years. Beyond this point, discounting reduces incremental changes to less significant levels.

we would provide one scenario assuming full compliance with the UST cleanup program and UST technical standards.

Data Sources: We have identified a number of studies providing cost estimates that we could use for this analysis. EPA's Office of Water has developed cost estimates for a range of technologies for effectively removing contaminants from drinking water and/or for replacing contaminated supplies with alternative water sources. In addition, OUST's 1988 RIA includes estimates of costs associated with supplying users of private wells with an alternative water supply and replacing public wells.[45]

Averting behavior costs (e.g,. purchasing bottled water) can be assessed from a variety of studies of the costs associated with contamination incidents For example, Abdalla, et al. (1992) researched the effects of a drinking water contamination incident in Perkasie, Pennsylvania, where trichloroethylene was detected in a well at levels exceeding EPA standards.[46] The authors used a mail survey to gather information about averting expenditures and behavior in response to the contamination. Based on the responses to the questionnaire, the authors estimate the total cost of these averting actions for the community ($6,300 to $131,300 over 88 weeks). The study found that only 43 percent of the respondents were aware of the contamination of their water despite mandatory notification of the contamination. Of these, only 44 percent undertook specific actions to avert exposure to contaminants.[47]

Another study on expenditures by private well users associated with well contamination found that 76 percent of the 1012 households had made some adjustments to the presence of contaminants (Abdalla, 1990).[48] The author estimates that over a six month period, each household spent $71 for bottled water, and $174 for hauling (transportation cost plus loss of leisure time), plus additional expenses associated with a variety of other averting actions.

---

[45] The study bases cost estimates for private well users on data from 38 Superfund sites. The report estimates costs of $10,500 per contaminated well over a 30 year period of time. These costs are associated with connecting households to public water supplies and using bottled water before connection. Municipal expenses associated with the contamination of public water supplies identified in the 1988 RIA amount to $210,000 for replacing a public water supply.

[46] Abdalla, C.W., B.A. Roach, D.J. Epp., 1992 'Valuing Environmental Quality Changes Using Averting Expenditures: An Application to Groundwater Contamination' *Land Economics* 68(2): 163-169.

[47] In the case of LUST contamination, the percentage of households taking averting actions may be substantially higher due to the unpleasant odor of hydrocarbon contaminants.

[48] Abdalla, C. W., 1990 "Measuring the Economic Losses from Groundwater Contamination: An Investigation of Household Avoidance Costs." *Water Resources Bulletin* 26(3):451-463.

In addition to literature estimates, we would need information on the number of contaminated wells from the simple benefits analysis of health risk and the average duration of groundwater cleanup activities. Information on the duration of groundwater cleanups is available from state data. For example, Washington state provides cleanup start and end dates on the Internet. Note, however, that if collection of state data requires specific searches, then an ICR might be needed.

4.3.1.2 Spatial Benefits Analysis (Provision of Alternative Water Supplies)

We would base the spatial analysis on the number of contaminated wells identified in the spatial analysis of health risk. The major advantage of this method is that it considers benefits associated with preventative cleanups and provides more certain estimates of the number of households affected by contaminated wells.

Approach: As a first step, we would establish a base case using information on the number of contaminated wells and affected households from the spatial analysis of health risk. We then would apply cost data from the literature to estimate annual costs per well contamination incident.

To calculate total costs in the base case scenario, we would need to estimate the duration of well contamination incidents over the time frame of the retrospective analysis. In our base case we would assume that avoided costs begin at the point of leak detection and continue indefinitely in the absence of cleanups. To estimate this, we would use state data on date of leak detection to calculate an average time between leak detection and the present time. For the post-rule scenario we would then identify the actual duration of contamination from the point of detection to completion of cleanup, as well as the number of well contamination incidents completely avoided by cleanups.

To calculate benefits derived from completely avoided incidents, we would multiply the number of avoided well contamination incidents by the total costs per incident identified in the beginning of the analysis. Then, to estimate benefits derived from incidents that may not have been completely avoided, we would calculate total costs incurred between the detection of leaks and the completion of groundwater cleanup efforts, assuming no avoided costs prior to leak detection. We would then extrapolate to the national level and to prospective benefits using estimates of the nationwide number of LUSTs.

Data Sources: The analysis would require information on the number of contaminated wells and the number of groundwater cleanup activities from the spatial analysis of health risk. Additional information on the time of leak detection, and initiation and completion of groundwater cleanup efforts would be available from state data. Similar to the simple analysis, this data may be publicly available from states; if data collection requires customized searches then an ICR may be necessary.

4.3.1.3 Evaluation of Proposed Methods and Addressing Uncertainties

The simple analysis provides a quick estimate of avoided costs related to alternative water supply. Similar to all our simple benefits analyses, the method assumes immediate and total cleanup of all contaminated wells and therefore does not account for costs associated with wells that may not have been cleaned up in the post-rule scenario. To address this uncertainty it would be possible to use state data on the number of completed cleanups, though this would increase the level of resources needed for the approach. Additional uncertainty is associated with the duration of contamination and the number of households taking risk averting actions.

The spatial analysis would result in more defensible low and high end estimates of avoided cost. However, uncertainty is associated with the use of stabilized benzene plumes for estimating the number of contaminated wells. Additional uncertainty is associated with potential risk averting actions prior to the detection of the leaks (e.g., due to unpleasant odors) and the number of households taking risk averting actions. The spatial analysis would require collection of state data and would thus be more resource intensive than the RIA-based simple analysis.

We could characterize uncertainty associated with the proposed methods through the following sensitivity analyses:

- The simple analysis could be tested for its sensitivity to the points in time when well contamination incidents are assumed to be detected. For example, we could compare total avoided costs derived from the core analysis (i.e., assuming an average duration of six years) to costs that would accrue over four and eight years periods of time.

- The spatial analysis of avoided costs could be tested for its sensitivity to groundwater plume sizes to characterize resulting ranges in avoided costs. To estimate uncertainty associated with the number of households taking averting actions, the method could be tested by applying a range of available literature estimates of the percentage of households taking actions.

- Both the simple and spatial analyses could be adjusted using state data to reflect situations in which averting costs represent permanent expenditures (e.g., a house is connected to a municipal water system) and no costs are avoided by cleanup activities.

4.3.2 *Reduction in Fire and Explosion Incidents and Vapor Damages*

The UST cleanup program may reduce the number of fires and explosions due to LUSTs. Fire and explosion incidents typically occur when contaminants seep into basements or enter buildings through underground utility lines (e.g., telephone conduits).[49] Due to the number of environmental conditions necessary to complete this pathway, fire and explosion incidents tend to be rare compared to well contamination incidents. However, in cases where incidents occur, property damages and health risks to people located in or near affected buildings may be substantial.

---

[49] Since vapors can enter underground utility conduits, reduced damages to utility lines could constitute an additional benefit of the program. At the current stage of our methodology development, however, we have not identified data that would be sufficient to conduct the analysis.

Another benefit of the program may be reduction in unpleasant or dangerous petroleum vapors in buildings, which also result from contact of contaminated groundwater with building foundations. Costs associated with these damages may result from the evacuation of buildings and the provision of alternative buildings.[50]

To estimate benefits associated with fire and explosion incidents and vapor damages avoided through cleanup activities, we propose a simple benefits analysis using baseline information on incidents from the 1988 RIA and state data on post-UST cleanup program frequencies. In addition, we propose a more complex benefits analysis focusing on information on pre- and post- UST cleanup program frequencies of incidents from the states and selected case studies. The endpoint of both analyses for reduction in fire and explosion risk would be the costs avoided for replacing or evacuating affected buildings. The endpoint for the analyses of reduction in vapor damages would be avoided costs associated with the relocation of individuals for some period of time.

4.3.2.1 Simple Benefits Analysis of Fire/Explosion and Vapor Damage Incidents

The simple benefits analysis of reduced fire and explosion incidents would estimate the number of incidents in the base case using 1988 RIA estimates on the frequency of LUST incidents causing fires and explosions prior to the UST cleanup program. To establish the post-rule scenario, we would then use recent empirical data on the frequency of incidents. To augment the quantitative analysis, we would also provide a qualitative discussion on potential impacts of fires and explosions.

The simple benefits analysis of reduced vapor damages would employ very similar analytic steps to estimate the number of buildings affected in both scenarios as well as total costs associated with the vapor damages. We would base these estimates on available information on the frequency of LUSTs leading to vapor damages prior to and after the implementation of the cleanup program and available information on associated costs from a sample of field cases. As is the case with our method for estimating reduction in fire and explosion incidents, we would also add a qualitative discussion on the types of impacts associated with vapor damages.

Approach: For the base case scenario we first would estimate the total number of LUSTs that existed between the implementation of the cleanup program and the present time. We would

---

[50] We note that vapor damages may also affect human health in cases where individuals decide not to relocate despite vapor damage, or if human health effects exist at contamination levels below the odor threshold. At the current stage of our methodology development, however, we have not identified information on the percentage of people relocating as a consequence of vapor damages or information on odor threshold associated with vapors from petroleum compounds. To the extent that this information is available from some states, it may be possible to provide estimates of reduction in human health risk associated with reduced inhalation of vapors.

then apply the frequency of fire and explosion incidents (and vapor damages) prior to the UST cleanup program to the number of LUSTs to identify the total number of incidents in the absence of the cleanup program. Then using information on the number of incidents recorded after implementation of the cleanup program, we would estimate the number of incidents in the post-rule scenario and calculate associated costs using state data.

For the post-rule scenario, we would provide a benefits estimate assuming compliance rates similar to the ones encountered in the past. For this purpose, we would apply the frequencies of base case and post-rule incidents to the total number of future LUST sites. The full compliance prospective analysis would assume no damages in the post-rule scenario.

Data Sources: Pre-cleanup program frequencies of LUSTs that lead to fire and explosion incidents as well as LUSTs that lead to vapor damages are available from the 1988 RIA.[51] The 1988 RIA also provides estimates of the average cost per building associated with vapor damages based on a limited sample of field cases. The study, however, does not provide information on cost estimates for fire and explosion incidents. Therefore it would be necessary to estimate replacement costs based on limited number of field incidents.

Post-cleanup program frequencies of LUST fire and explosion incidents as well as vapor damages are available from state or local agencies. We would obtain data from a number of areas representing a variety of environmental conditions and a range of building construction types.

4.3.2.2 More Complex Benefits Analysis of Fire/Explosion and Vapor Damage Incidents

Approach: The more complex benefits analyses of fire/explosion and vapor damage incidents would be similar to the simple analysis but would involve obtaining additional data on pre-UST cleanup program frequencies of incidents from the states to address uncertainties associated with the 1988 RIA data. In addition, we would provide case studies based on information from the states to obtain more detailed information on post-UST cleanup program frequencies of vapor damages and fires and explosions and associated accidents and costs. To the extent that states make these data readily available to the public this approach would not require an ICR; if data collection

[51] 1988 RIA estimates are based on the *Analysis of the National Database of UST Incidents* (U.S.EPA, 1986). The sample size for fire and explosion incidents is a documented 141 out of a total of 10,000 release incidents. The frequency of vapor damages is based on an analysis of 72 UST plumes of known size that found that 26 percent of plumes over 10,000 square meters in size (or 5 of 19 sample plumes) were associated with vapor damages. The RIA calculated the frequency of vapor damages associated with plumes of different sizes by assuming a linear relationship between probability of vapor damage and the minimum distance traveled by a plume of a given size.

requires significant state effort then collection of data from more than nine states may require an ICR.

4.3.2.3 Evaluation of Proposed Methods and Addressing Uncertainties

Exhibit 4-11 compares proposed methods for measuring benefits associated with reduction in fire and explosion incidents and vapor damages. The simple analysis would be associated with uncertainty about the use of 1988 RIA data on pre-UST cleanup program frequencies of incidents. This uncertainty is derived from potential over- or underestimation of the number of incidents in the base case scenario. Overestimation of the number of incidents may be caused by a potential over-representation of LUSTs causing fire and explosion incidents (or vapor damages) in historical data sets.[52] Underestimation would be caused by potential failures to identify LUSTs as the cause for fire and explosion incidents or vapor damages in the past.

The more complex analysis would address some of the uncertainty associated with the simple analysis by providing additional information on the number of pre-UST program incidents from the states.[53] In addition, the analysis would provide information on the number of people affected by accidents and the percentage of people relocating as a consequence of vapor damages. However, this approach would require some additional effort to retrieve data from the states.

Exhibit 4-11

COMPARISON OF METHODS (REDUCTION IN FIRE AND EXPLOSION INCIDENTS AND REDUCTION IN VAPOR DAMAGES

	Simple Benefits Analysis	More Complex Analysis
Results	1988 RIA Data: the method would provide a estimate of the number of incidents avoided in the post-rule scenario and cost estimates for reduced vapor damages and fires and explosions. It is not sensitive to the number of people affected by the incidents.	State Data: The method would provide a more defensible estimate of the number of avoided incidents and associated costs. This method may also provide information on the percentage of people relocating in the case of vapor damages, the types of buildings affected, and the number of accidents due to fire and explosion.

[52] This bias would be caused by a higher discovery rate for LUSTs causing fire and explosion incidents or vapor damages than for LUSTs not causing these incidents.

[53] We note that the more complex benefits analysis would also be associated with uncertainty about the discovery rate of LUST-induced incidents but would be based on a larger set of data.

Base Case Frequency of Incidents	Uncertainty would be associated with applying 1988 RIA pre-rule vapor damage incident frequency data (based on a small sample) to post-rule scenario. Uncertainty would be associated reduction in incidents due to UST technical standards.	This method would provide more certain estimates of the number of incidents based on a larger sample of data. Uncertainty would be associated with reduction in incidents due to UST technical standards.

Addressing Uncertainties:

- **Simple Benefits Analysis:** We could characterize uncertainties associated with pre-UST cleanup program frequencies by conducting a sensitivity analysis using a range of frequencies of incidents. For example, we could assume 20 percent higher and 20 percent lower incidents rates.

- **More Complex Benefits Analysis:** Sensitivity tests would be similar to those proposed for the simple analysis.

4.4 PROPERTY VALUE ESTIMATES OF BENEFITS

There is a strong consensus in the environmental economics literature supporting the notion that residential and non-residential property can be negatively affected by proximity to environmental contamination. In addition, USTs are often cited as likely source of contamination that appraisers should look for. One study on the effect of LUST induced contamination on the value of contaminated properties adjacent to LUST sites found a 14 to 16 percent price reduction for those properties sold after contamination becomes known. For commercial properties adjacent to LUST sites, the authors found a significant reduction in transaction rates (33 percent lower) indicating delay in sales, and a reduction in sales price of approximately 28 to 42 percent.[54, 55]

Following remediation of the site, property values are expected to increase. However, properties may never regain their full unimpaired values due to a stigma associated with the contamination incident. One important component of the stigma, for example, would be fear or

---

[54] There is a wide range of property value effects associated with different environmental disamenities. This study (Simons, R.A. W.M. Bowen, and A. Sementell, 1997. *The Price and Liquidity Effects of UST Leaks From Gas Stations on Adjacent Contaminated Residential and Commercial Properties*. Unpublished report) is only one of many hedonic studies about environmental disamenities and one of only a few about USTs.

[55] Property value effects are an alternative measure of a range of benefits and are not additive with other benefits because property values theoretically reflect the value people place on multiple characteristics such as human health risk, ecological damage, and cost of alternative water supply.

uncertainty about a future recurrence and the degree to which properties are able to recover from this price effect.

We propose three methods for estimating property value benefits — a simple benefits estimate, a spatial analysis, and a spatial analysis with pathway modeling. All methods would include identifying properties with wells contaminated through LUST incidents, and estimating their property values prior to contamination and reduction in values following contamination. In our methods we would not account for property value losses that may be associated with on-site soil contamination and/or proximity to LUSTs in absence of well contamination, nor do we address changes in commercial property values. We limit our proposed analyses to residential properties with well contamination because these are the properties and effects best documented in the literature at this time. The hedonic literature is still developing, and decreases in property values are so often linked with multiple factors (i.e., due to reasons other than USTs). It is therefore important to base analysis of these impacts on established research in order to effectively isolate the impact of LUSTs.

Below we describe the simple and the spatial approaches for characterizing benefits. We do not specifically address additional analytic steps for pathway modeling, which would be very similar to those described in the section on reduction in cancer risk and would not have to be repeated for measuring property value benefits.

4.4.1 *Simple Benefits Analysis of Property Value Benefits*

We would base this method on the number of well contamination incidents identified in the simple benefits analysis of reduction in human health risk (i.e., based on the 1988 RIA data).

Approach: For the base case scenario, we would first identify the number of contaminated private wells in the absence of cleanup activities. Then, assuming that median U.S. housing values reflect uncontaminated properties, we would apply literature data on property value losses associated with contamination and calculate the total loss in the absence of cleanup activities. For the post-rule scenario, we propose to assume that all contaminated properties have been cleaned up and that cleanups fully restored property values. We would derive prospective benefits by calculating average benefits per LUST incident and applying this value to our estimate of future tank failures.

Data Sources: Data required for this analysis are the number of contaminated private wells, median U.S. property values, and literature estimates on property value losses due to contamination. As noted above literature estimates on property value loss are available for LUST sites.

4.4.2 *Spatial Benefits Analysis of Property Value Benefits*

The spatial analysis of property value benefits would employ estimates of the number of contaminated private and public wells derived from the spatial analysis of reduction in cancer risk.

This approach would provide information on a high end estimate of prevented and cleaned up incidents (see spatial analysis for reduction in cancer risk). In addition, in a GIS-based approach we could identify the values of potentially affected sites using census block group data, which would allow more accurate estimates of property value benefits associated with cleanup activities.

Approach: For the purpose of establishing the base case scenario, we would first identify the number of private and public wells contaminated in the absence of cleanup activities using data from the spatial analysis of reduction in cancer risk. Then, using digital maps of census data housing values, we would determine average values of potentially affected housing units. To estimate total loss in property values we would apply literature data on property value loss associated with contamination. For the post-rule scenario we would establish low and high end estimates of the effects of cleanup activities and estimate associated benefits.[56]

Finally, we would repeat the analysis for a set of counties and extrapolate to the national level using nationwide estimates of the number of LUSTs. The prospective analysis would provide two scenarios; one assuming future compliance rates similar to those encountered in the past, and one assuming full compliance and no loss in property value in the post-rule scenario (see reduction in cancer risk).

Data Sources: The spatial analysis would require estimates of the number of threatened private and public wells from the spatial analysis of health risk, literature data on the reduction of values of contaminated properties (see simple analysis), and a geographic data layer showing local property values. One data set containing this kind of information is the census block group data, which identifies ranges of property values within each block group.

4.4.3 *Evaluation of Proposed Methods and Addressing Uncertainties*

The simple benefits analysis would provide a quick, general estimate of the total property value benefits associated with cleanup activities, without requiring considerable data collection or resources. This analysis assumes no property value loss in the post-rule scenario and immediate and total cleanup of contaminated properties. While the simple benefits analysis could be augmented using state data to identify well contamination, it would still not account for benefits associated with

---

[56] The low end estimate would only account for cleanups of contaminated sites. For this purpose, we would identify the number of groundwater cleanups undertaken within the county and identify associated reduction in well contamination. The high end estimate would account for cleanups of contaminated sites as well as preventative cleanups. This step would involve identifying the number of wells threatened in the absence of cleanup activities using the GIS (see spatial analysis of reduction in cancer risk).

completely prevented incidents, and would require additional resources, potentially including an ICR (if state data are not readily available to the public).

The spatial analysis of property value benefits would provide more defensible low and high end estimates of property value benefits associated with the cleanup program. It would account for benefits associated with completely avoided well contamination incidents and would be sensitive to the value of properties in areas where USTs are predominately located. This approach would require limited additional resources for data collection and analysis, but all data needed for the approach are publicly available.

Both methods could be tested for their sensitivity to the percentage of actually known property contamination incidents. For the simple analysis, this could be done by assuming a range of undiscovered contamination incidents (e.g., 25 and 50 percent). For the spatial analysis, data on reported well contamination incidents could be used to provide a low end estimate of known well contamination incidents.[57]

4.5 LONG-TERM BENEFITS

In addition to the benefits of the program discussed above, cleanup activities under the UST cleanup program may lead to long-term benefits accruing beyond the 20 year period of time proposed as the time frame for the core analyses. For example, well contamination in the absence of cleanup could continue indefinitely into the future, requiring households to undertake risk averting actions for much longer periods of time.[58] Moreover, benefits may even have a tendency to increase over long periods of time due to a number of factors including the following:

Some aspects of long-term benefits (e.g., the number of cancer cases avoided) can be estimated through modeling. However, there is little consensus in the economics literature on assigning monetary values to the health effects and costs assumed (or avoided) by future generations.[59] Moreover, some benefits may occur far in the future, or may increase over long time horizons due to factors such as increased population density (which could increase exposure to

---

[57] We describe further sensitivity analysis common to all our spatial methods in the section on reduction in cancer risk.

[58] While some research has shown that certain contaminants (e.g., benzene) may stabilize and degrade significantly within a period of 20 years, other known contaminants (e.g., MTBE) may be more persistent and linger for many decades.

[59] EPA's *Guidelines for Economic Analysis* (Chapter 6) discusses the difficulties related to social discounting for inter-generational policies.

health risks). This chapter discusses four distinct aspects of potential long-term benefits. The first three methods address potential long-term impacts of OUST cleanup program:

- **Avoided long-term damages,** reflecting the continuation of health and ecological benefits into future generations.

- **Avoided increases in damages** due to changes in affected populations (e.g., future population growth that results in a higher number of people affected) and/or increases in costs of clean water and land.[60]
- **Avoided damage from unforeseen events or issues** such as environmental damages caused by petroleum substances associated with hazards that are poorly understood today, but are currently addressed by the UST cleanup requirements.[61]

While these long-term benefits represent regulatory impacts that are theoretically quantifiable (though perhaps not with currently available information), it is difficult to estimate their value because economic theory cannot predict the value that future generations will place on environmental goods. Increases (or decreases) in the value of environmental quality and resources would affect the value of all long-term benefits. We therefore address this third issue separately, and provide a separate method for characterizing potential changes in future generations' value of environmental quality. All of our methods focus on qualitative discussions, but we also identify quantitative analyses that may help illustrate the potential magnitude of benefits.

In addition to long-term benefits directly associated with cleanup activities, the UST cleanup program may also contribute to long-term changes in behavior regarding the management of both underground storage tanks and contaminated sites. Examples include behaviors directly mandated by regulation (e.g., financial assurance of ability to clean a site) and behaviors that appear to be indirectly related to specific programs (e.g., an increased demand on the part of property purchasers and banks for "clean" properties as a condition of sale). Although these changes in behavior may ultimately be associated with benefits, we discuss Behavioral Change in Chapter 7 as a Program Context Attribute because it is often impossible to determine either the net "value" or the causality associated with these changes, and also because they are often associated with specific regulatory initiatives.

One aspect to consider when characterizing potential long-term benefits is the degree to which natural processes such as biodegradation may lead to natural attenuation of contaminants over

---

[60] In addition to population growth, increases in costs of clean resources may also be associated with other factors such as decreased availability of potable water due to water scarcity.

[61] One recent example of such a substance is methyl tertiary-butyl ether (MTBE). We discuss MTBE in more detail below.

time, since natural attenuation might potentially off-set long-term damages. While the duration of hydrocarbon plumes in groundwater in the absence of cleanup activities is difficult to predict, there is evidence that natural attenuation is occurring. These natural processes can lead to the stabilization of contaminant concentrations in groundwater plumes and can cause the plumes to cease growing in size at some point in time. In addition, once the primary and the secondary sources are exhausted, contaminant concentrations can also decrease leading to a reduction in damages over time (Mace et al., 1997).[62]

As a result of the time frame for the analyses, long-term benefits are difficult to value and estimates are associated with significant uncertainties.[63] However, such potential benefits must be recognized in any comprehensive program evaluation. Below we present our proposed methods for characterizing long-term program benefits. While all of our methods focus on qualitative discussions, we also provide suggestions for the types of quantitative analyses that we could conduct to further illustrate benefits.

4.5.1 *Avoided damages Over a Long Period of Time*

For this attribute, we would focus on a qualitative discussion of how specific benefits associated with long-term duration of damages might accumulate (e.g., avoided costs, property value benefits) and factors potentially influencing benefits such as natural attenuation of contamination and changes in property values over time. In addition, we would project a quantitative estimate of retrospective and prospective benefits for a long-term horizon of more than 25 years (e.g., 50 or 100 years) and provide both discounted and undiscounted monetary values for these estimates.

This approach would provide a rough quantitative characterization of long-term benefits due to the inter-generational duration of damages, coupled with a qualitative discussion of the potential importance of these benefits. Because of the significant uncertainty associated with estimated plume duration in the absence of cleanup activities, as well as changes in property values or costs for providing alternative water supplies, the quantitative results of this analysis will be illustrative only.

---

[62] Duration of benzene groundwater plumes depends on a variety of factors, including source mass, the amount of hydrocarbons sorbed onto soils and aquifer surfaces, and the presence and types of cleanup activities. It is not currently possible to predict duration of plumes in absence of cleanup activities since important factors such as source mass are rarely known and there are only limited empirical data on the duration of plumes in absence of cleanup activities. To the extent that groundwater benzene plumes may continue to exist over time frames longer than 20 years, only long-term benefits analyses would capture associated benefits.

[63] In addition to uncertainties about plume behavior, uncertainties include projection of population data over long periods of time and future generations' valuation of environmental goods.

4.5.2 *Avoided Increases in Damages Related to Changes in Affected Populations*

For the purpose of characterizing long-term benefits associated with avoiding increases in future damages, we would provide a qualitative discussion of the factors that might drive these increases (e.g., population growth, scarcity of resources due to contamination, changes in the legal framework guiding resource utilization). We would then use the GIS model to conduct a quantitative sensitivity analysis of the spatial analysis for human health, adjusting population densities to illustrate the effect that higher population densities would have on the number of people potentially affected by contaminated groundwater.[64] These analyses would provide a rough estimate of the magnitude of benefits that might be associated with potential increases in LUST damages. In addition to factors of uncertainty discussed above, projections of future population densities and use of private or public wells would be uncertain; we would discuss the quantitative results of the analyses as illustrative examples in the context of a qualitative discussion.

4.5.3 *Benefits Associated with the Precautionary Principle: Protection Against Unforseen Events*

The OUST cleanup program may yield benefits associated with the reduction of currently unknown or underestimated risks. While these unforseen events are unknown when the rule is designed and implemented, EPA programs can provide some protection against associated risks due, for example, to an inherent risk averting character of many rules or to measures targeted at a range of substances. To the extent that the UST cleanup program will provide protection against substances whose risks are currently unknown, protection against these risks might constitute a long-term benefit of the program.

The "precautionary principle," which describes a preference of implementing protective policies or regulations in advance of conclusive scientific evidence that connects activities (or chemicals) to risk, has recently emerged in national and international policy-making.[65] While both

---

[64] This would be done by applying a reasonable range of future population densities to the GIS and assessing increases in the number of people potentially affected.

[65] There is a large body of theoretical literature discussing the development and implementation of versions of the precautionary principle. Treaties articulating the precautionary approach include the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, the 1992 Convention on Biological Diversity, the 1992 Treaty on European Union, and the 1992 Rio Declaration on Environment and Development, which states "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

the definition and practical implementation of a precautionary principle is still a matter of considerable debate, the essential wisdom of precaution is reflected in the notion that "an ounce of prevention is worth a pound of cure." While we do not attempt to resolve the issues surrounding the development and use of precautionary policies, this principle is consistent with the preventative objectives of the OUST cleanup program. It is possible that cleanup will reduce or prevent exposure to hazards that have not yet been identified or verified; the avoided exposure would ultimately be a measurable benefit of the program.

One example for such as substance with high relevance to the UST cleanup program is methyl tertiary-butyl ether (MTBE). MTBE is an oxygenate used as a gasoline additive to reduce emissions from motor vehicles. The compound recently has gained considerable attention as a substance potentially harmful to humans and the environment, and EPA has announced that it is seeking a phase-out of MTBE use under TSCA. While long-term impacts of MTBE releases are uncertain, there is considerable evidence that MTBE is extremely mobile in the environment and not subject to significant biodegradation. For these reasons, MTBE may accumulate in aquifers over time, potentially leading to the regional degradation of groundwater resources.[66]

At the time the UST remedial rule was promulgated, prevention of MTBE contamination was not considered a potential benefit of the rule. However, use of MTBE has resulted in growing detection rates of the chemical in drinking water in the past. It has been estimated that between five and ten percent of drinking water supplies in high oxygenate use areas show detectable amounts of MTBE. While only one percent of these drinking water supplies showed levels exceeding the current drinking water advisory for MTBE, lower levels of MTBE have raised consumer concerns about taste and odor and have caused water suppliers to stop using some water supplies and to incur costs of treatment and remediation.[67] In a few instances, detection of MTBE has caused the shutdown of large drinking water production wells. Santa Monica, California shut down seven of its eleven drinking water wells in 1996, losing more than half of its drinking water supply, due to MTBE contamination from LUSTs.

Though there is some indication that MTBE may be a human carcinogen, human health effects associated with MTBE are currently uncertain due to a lack of research in this area.[68] Human

---

[66] See: Happel, M., E. Beckenbach, and R.Halden, 1998. *Evaluation of MTBE Impacts to California Groundwater Resources*. Environmental Protection Department, Environmental Restoration Division.

[67] EPA, 1999. *The Blue Ribbon Panel on Oxygenates in Gasoline. Executive Summary and Recommendations*. Final, July 27.

[68] The current EPA drinking water health advisory for MTBE ranges from 20 to 40 µg/L and is based on taste an taste and odor threshold. See *Control of MTBE in Gasoline* . EPA420-F-00-010,

exposure data for MTBE are also too limited for a quantitative estimate of the full range and distribution of exposures to MTBE in the general population. However, experimental studies on animals indicate that MTBE is carcinogenic in rats and mice at multiple organ sites after inhalation or oral exposure. The mechanisms by which MTBE causes cancer in animals are not well understood at this time.[69]

4.5.3.1 Case Study of MTBE as an Indication of Possible Unforseen Benefits

We propose to use MTBE as an example of the benefits a program like UST can have with respect to unforseen events. The approach described here focuses on a qualitative description of potential of long-term impacts of MTBE groundwater contamination and other examples of historically unforseen risks. In addition, we would provide a quantitative estimate of reduction in the number of wells contaminated with MTBE over a long-term horizon of more than 25 years (e.g., fifty years) and an estimate of associated avoided costs. Similar to our other methods for estimating long-term benefits, this method would not provide monetizable benefits but would illustrate the types of benefits and their potential magnitudes.

Below we describe a spatial analysis for estimating the number of wells contaminated with MTBE in both the presence and the absence of cleanup activities. We also note that the spatial method could be combined with multi-pathway modeling to provide new estimates of the extent of MTBE plumes. Additional steps required for pathway modeling would be similar to those for estimating reductions in health risk.

Approach: To establish the base case, we would first estimate the number of past LUST sites involving tanks that contained MTBE. We would then identify the number of wells contaminated and the number of households affected by these incidents in 20 years, using the GIS model and estimates of the extent of MTBE plumes.[70] If new state or literature data are available

---

March 2000.

[69] See Belpoggi et al., 1997. 'Results of Long-Term Experimental Studies on the Carcinogenicity of Methyl Tertiary-Butyl Ether'. *Annals N.Y. Academy of Science*, 837, pp 77-95, December 26, 1997; Chun J. et al., 1992. 'Methyl Tertiary Ether: Vapor Inhalation Oncogenicity Study in Fisher 344 Rats'. *Bushy Run Research Center Report* No. 91N0013B, EPA/OPTS#42098, November 13, 1992; Burleigh-Flayer, H. et al., 1992. "Methyl Tertiary-Butyl Ether: Vapor Inhalation Oncogenicity Study in C-1 Mice," *Bushy Run Research Center Report* No. 91N0013A, EPA/OPTS#42098, October 15, 1992.

[70] Our rationale for estimating damages in 20 years is based on the availability of modeling data that project MTBE plume 20 years into the future. We may, however, adjust this number in the course of the implementation of the method.

we may be able to refine our estimates of the number and/or behavior or MTBE plumes.[71] To estimate reduction in well contamination in the post-rule scenario, we would establish estimates of the effect of cleanup activities identical to those established for the spatial analysis of reduction in health risk.

We would then estimate effects using the avoided costs method. To estimate total avoided costs we would assume no increase in the number of contaminated wells after 20 years but continuation of contamination over the time frame of the analysis. Finally, we would extrapolate to the national level by repeating this analysis in a set of counties and estimating the nationwide number of LUSTs containing MTBE.

Exhibit 4-12 summarizes data and potential sources that would be required in addition to digital maps on LUST locations, well location, number of households, and information on the number and types of cleanup activities (see spatial analysis of reduction in cancer risk).

---

[71] A recent analysis published in *Environmental Science and Technology* uses a similar approach to estimate the potential impact of MTBE on public wells; the analysis does not address private wells (and therefore has a different scope than our approach), but the estimate of LUST density relative to public drinking water sources may be useful in the analysis we outline. Specifically, we could define impact radii based on the California study or other available estimates of MTBE plume sizes. We could then use the density estimate to calculate the number of wells within the impact radii of LUSTs. See Johnson *et al.*, "MTBE: To What Extent Will Past Releases Contaminate Community Water Supply Wells?" *Environmental Science and Technology,* Vol. 34, No. 9, May 1, 2000, pp. 210A-217A.

Exhibit 4-12 DATA SOURCES FOR THE SPATIAL ANALYSIS (INTERGENERATIONAL EQUITY)	
Data Type	**Potential Data Sources**
Number of Tanks Containing MTBE	Information on MTBE is generally at the state level. Some national sources (e.g., petroleum associations) and recent articles may have data on MTBE use multiple states. Alternatively, we could assume that after 1990 all tanks in areas that did not meet the federal ambient air standard for carbon monoxide contained MTBE.[72] In addition, EPA is preparing to issue a proposed rule under the Toxic Substances Control Act section 6 to address the potential methods of better regulating MTBE. This rule may contain data which could be use to estimate the number of tanks containing MTBE.
Extent of MTBE Plumes	MTBE plumes are highly mobile in the environment and may not form stabilized plumes even long after the primary source has been removed. To derive our estimates of the extent of MTBE plumes after 20 years, we use modeling results from a study that modeled the extent of MTBE plumes using various source concentrations and a Monte Carlo Analysis (Happel, A., B. Dooher, and E. Beckenbach, 1999).
Effect of Cleanup Activities On Reducing MTBE	MTBE plumes can be substantially larger than benzene plumes due to MTBE's mobility in groundwater. As a result, cleanups targeting benzene may miss MTBE in the environment (though cleanups that remove the source and remediate the area would likely remove some quantity of MTBE from the environment and/or prevent its release). Our analysis would assume that cleanups in states with maximum contaminant levels (MCLs) for MTBE would reduce MTBE contamination.

The proposed analysis would provide a first cut at the types of long-term benefits potentially associated with the UST cleanup program. It is easy and quick to perform, provided GIS data layers are obtained for the purpose of measuring other attributes like the reduction in human health risk. Since MTBE plumes are generally regarded to be larger than BTEX plumes, our proposed method is likely to account for potential similar unforseen events associated with BTEX compounds.

Significant uncertainties associated with this method would include (1) projecting the extent of MTBE plumes, the location of wells, the number of affected people, and costs of providing alternative water supplies 20 years into the future, (2) efficiency of cleanup activities in reducing MTBE contamination, and (3) future MCLs for MTBE. In addition, measures undertaken under the UST cleanup program are likely to prevent only part of MTBE groundwater contamination because

---

[72] The number of tanks containing MTBE is uncertain due to regional variations in the adoption of MTBE as a gasoline additive. MTBE use in gasoline began in the late 1970s with the phase out of lead. During the 1980s, oxygenates came to wider use as part of some state programs to control carbon monoxide pollution. In 1990, the use of oxygenated gasoline was mandated under the Clean Air Act Amendments (CAAA) in areas that did not meet the Federal ambient air standard for carbon monoxide.

cleanup activities may not be targeted specifically at reducing MTBE contamination, and due to existing MTBE sources other than LUSTs, including airborne sources.[73]

Sensitivity tests of this analysis would be similar to those for the spatial analysis of reduced human health risk. A test for sensitivity to MTBE plume sizes would involve applying a range of MTBE plumes using estimates from existing modeling efforts (see Exhibit 4-10).

4.5.4 *Benefits from Long-term Changes in the Valuation of Environmental Quality*

Our proposed method for characterizing the effects of changes in risk aversion and valuation of environmental quality by future generations would focus on qualitative discussion of past trends and potential implications future continuation of these trends might have. Specifically, our discussion would include an assessment of historic decreases in acceptable risk over time and concurrent increases in the valuation of environmental goods. We would then provide a discussion of how this trend might change in the future and potential implications on future non-use values associated with clean resources might be. In addition, we would provide a discussion of potential changes in WTP for resource utilization (i.e., use values) that could, for example, be associated with changes in recreational behavior (e.g., increases in the amount of time for recreational activities available to individuals).

This analysis would provide a qualitative overview of implications that future generations' changes in values and risk acceptance might have on benefits associated with the program. Significant uncertainties include unexpected future changes in trends related to risk aversion and valuation of environmental amenities.

---

[73] Deposition of airborne MTBE may lead to the creation of an MTBE background level in some aquifers that would not be addressed through the UST cleanup program. In addition, cleanup measures under the UST cleanup program are likely to address only part of the LUST-induced contamination with MTBE since many states do not specifically target MTBE in their cleanup efforts.