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Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems

Volume I: Pre-Optimization Screening (Method and Demonstration)

FINAL REPORT

HYDRAULIC OPTIMIZATION DEMONSTRATION FOR GROUNDWATER PUMP-AND-TREAT SYSTEMS

VOLUME 1:
PRE-OPTIMIZATION SCREENING (METHOD AND DEMONSTRATION)

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PREFACE

This work was performed for the U.S. Environmental Protection Agency (U.S. EPA) under Dynamac Contract No. 68-C4-0031. The technical work was performed by HSI GeoTrans under Subcontract No. S-0K00-001. The final report is presented in two volumes:

- Volume 1: Pre-Optimization Screening (Method and Demonstration)
- Volume 2: Application of Hydraulic Optimization

Volume 1 provides a spreadsheet screening approach for comparing costs of alternative pump-and-treat designs. The purpose of the screening analysis is to quickly determine if significant cost savings might be achieved by modifying an existing or planned pump-and-treat system, and to prioritize subsequent design efforts. The method is demonstrated for three sites. Volume 1 is intended for a very broad audience.

Volume 2 describes the application of hydraulic optimization for improving pump-and-treat designs. Hydraulic optimization combines groundwater flow simulation with linear and/or mixed-integer programming, to determine the best well locations and well rates subject to site-specific constraints. The same three sites presented in Volume 1 are used to demonstrate the hydraulic optimization technology in Volume 2. Volume 2 is intended for a more technical audience than Volume 1.

The author extends thanks to stakeholders associated with the following three sites, for providing information used in this study:

- Chemical Facility, Kentucky
- Tooele Army Depot, Tooele, Utah
- Offutt Air Force Base, Bellevue, Nebraska

At the request of the facility, the name of the Kentucky site is not specified in this report.

Information was provided for each site at a specific point in time, with the understanding that new information, if subsequently gathered, would not be incorporated into this study. Updated information might include, for instance, revisions to plume definition, remediation cost estimates, or groundwater models.

The author also extends thanks to Kathy Yager of the U.S. EPA Technology Innovation Office (TIO) and Dave Burden of the U.S. EPA Subsurface Protection and Remediation Division (SPRD), for their support. Finally, the author extends thanks to the participants of the three Stakeholder Workshops for providing constructive comments during the course of the project.

EXECUTIVE SUMMARY

The screening analysis presented in this report can be used to quickly determine if significant cost savings may be achieved by altering key aspects of an existing or planned pump-and-treat system. The spreadsheet-based screening analysis allows quick and inexpensive cost comparison of competing alternatives at a site, in terms of Net Present Value (NPV). Site-specific values input to the spreadsheet can be based on very detailed engineering calculations and modeling results, or may be based on "ballpark estimates". The suggested approach includes a "checklist" of important site-specific factors to evaluate, and requires the formulation of potential system modifications. System modifications may be postulated with respect to the same goals as the present system, or with respect to modified goals.

The intended results are as follows:

- For alternatives that offer the potential of significant cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a high priority;

- For alternatives that offer little or no potential for cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a low priority.

The cost of a screening analysis at a site should be low relative to overall remediation costs (i.e., several thousand dollars for most sites).

The screening approach was demonstrated for three sites with existing pump-and-treat systems. The three sites can be summarized as follows:

Site	Existing Pumping Rate	Cost Per gpm	Potential Savings from System Modification	Additional Analysis Merited?
Kentucky	Moderate	High	> $6M	Yes
Tooele	High	Low	> $3M	Yes
Offutt	Low	Low	Little or None	No

Note: Potential savings represent millions of dollars, net present value (NPV), over 20 years

For Kentucky and Tooele, the screening analysis suggests that millions of dollars may be saved if additional analysis is performed to reduce the total pumping rate (the potential savings incorporate the additional Up-Front costs associated with additional analyses and system modification). Therefore, additional analyses at these sites (modeling, optimization, engineering) are worthwhile. The additional analyses would be performed to determine actual reductions in pumping rate that can be achieved, plus detailed design efforts (if appropriate) for a modified system. For Offutt, the screening analysis suggests that little or no savings is likely from a system modification, and additional analysis regarding system modification at that site should be a low priority.

This project was primarily focused on the reduction of pumping total pumping rate at pump-and-treat sites (of course, other forms of optimization, such as the application of alternate treatment technologies, may also provide significant benefits). Hydraulic optimization simulations were performed for each of the three sites, to more rigorously determine the extent to which pumping rates (and associated costs) might be reduced at each site. The results of the hydraulic optimization simulations are presented in Volume 2 of this report.

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1.0 INTRODUCTION

This report (Volume 1 of 2) presents a spreadsheet approach for comparing costs of alternative pump-and-treat designs. The work presented herein was commissioned by the U.S. EPA Subsurface Protection and Remediation Division (SPRD) and the U.S. EPA Technology Innovation Office (TIO).

1.1 PURPOSE OF PERFORMING A SCREENING ANALYSIS

The purpose of this screening analysis is to quickly determine if significant cost savings might be achieved by altering key aspects of an existing or planned pump-and-treat system, and to prioritize subsequent design efforts. Reasons for altering a pump-and-treat system design might include any or all of the following:

- potential to reduce the total cost;
- potential to speed cleanup;
- revised contaminant distribution; and
- revised regulations and/or regulatory climate.

Design aspects to be considered for alteration might include:

- total pumping rate;
- locations of wells;
- number of wells;
- projected cleanup time;
- treatment technology employed;
- remediation goal (cleanup versus containment); and
- the target containment zone.

Typically there are many remediation scenarios to consider (e.g., containment only, containment plus aggressive mass removal, containment of a smaller region, etc.), and many potential design options for each of those scenarios (e.g., well locations, well rates, treatment technology, etc.).

The screening analysis allows quick and inexpensive cost comparison of competing alternatives. Total costs (NPV) are estimated for each alternative, and compared to the total cost of a baseline system (typically the existing system). The intended results of the screening analysis are as follows:

- for alternatives that offer the potential of significant cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a high priority;

- for alternatives that offer little or no potential for cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a low priority.

The results of the screening analysis provide a basis for prioritizing subsequent design activities. For example:

- if the screening analysis indicates that system costs are driven by total pumping rate, then additional design effort may be focused on minimizing total pumping rate (e.g., hydraulic optimization to minimize pumping required for containment);

- if the screening analysis indicates that system costs are driven by cleanup time (and reduction in cleanup time is considered to be technically feasible), then additional design effort may be focused on reducing cleanup time (e.g., evaluating options with aggressive core zone pumping, and/or use of transport optimization);

- if the screening analysis indicates that system costs are driven by groundwater treatment and/or discharge costs, and alternate technologies are potentially feasible, then additional design effort may be focused on technology optimization (e.g., technology review, pilot testing, etc.).

The results of the screening analysis can also be used to prioritize specific scenarios to consider during a subsequent optimization analysis. For instance, the screening can compare estimated costs for scenarios with and without the addition of new wells. If the screening analysis suggests that significant cost reduction may be possible when no new wells are considered, but little cost reduction is likely when costs of new wells are included, then the subsequent mathematical optimization analysis might only be performed on the basis of existing well locations. On the other hand, if the screening analysis suggests that significant cost reduction might be possible even when the costs of new equipment are considered, then the mathematical optimization analysis might consider new well locations in addition to the existing well locations.

Advantages of this screening approach are:

- it is easy to understand and apply;

- it is based on *estimates* of cost factors (which can be as simple as "ballpark estimates"), and therefore can be applied very quickly and at little cost;

- it provides a simple and consistent framework for organizing cost data for pump-and-treat systems; and

- it instigates the consideration of alternatives to existing pump-and-treat designs.

The spreadsheet tool is free, and is intended to be available via download from an EPA web site. The cost of a screening analysis at a site should be low relative to overall remediation costs (i.e., several thousand dollars for most sites).

1.2 CASE STUDY EXAMPLES

Three sites with existing pump-and-treat systems were evaluated in this study:

- Chemical Facility, Kentucky (hereafter called "Kentucky");
- Tooele Army Depot, Tooele, Utah (hereafter called "Tooele"); and
- Offutt Air Force Base, Bellevue, Nebraska (hereafter called "Offutt").

A brief comparison of the three sites is provided below:

	Kentucky	Tooele	Offutt
Pumping rate, current system (gpm)	600	7500	200
Annual Operations & Maintenance (O&M)	$1,800,000(1)	$1,800,000	$122,000
Type of treatment	Steam Stripping	Air Stripping	POTW(2)
Discharge of treated water	River	Reinjection	N/A
Most significant annual cost	Steam	Electricity	Discharge Fee
Year system started	1992	1993	1996(3)
Cost of a new well	$20,000	$300,000	$40,000
Flow model exists?	Yes	Yes	Yes
Transport model exists?	No	Being Developed	Yes

(1) Does not include analytical costs.
(2) POTW stands for Publicly Owned Treatment Works.
(3) An interim system has operated since 1996, and a long-term system has been designed.

Three sites were included in this study to demonstrate differences in the application of the screening approach that result from site-specific factors.

1.3 STRUCTURE OF THIS REPORT

The report is structured as follows:

- Section 2: Overview of Spreadsheet Screening Approach
- Section 3: Important Site-Specific Factors
- Section 4: Case #1: Kentucky
- Section 5: Case #2: Tooele
- Section 6: Case #3: Offutt
- Section 7: Discussion and Conclusions
- Section 8: References

2.0 OVERVIEW OF SPREADSHEET SCREENING APPROACH

2.1 COMPONENTS OF THE SPREADSHEET

Table 2-1 provides a spreadsheet-based framework for evaluating major costs components of a pump-and-treat system. Major costs items included in Table 2-1 are:

- annual O&M costs;
- the time horizon for each annual O&M item;
- costs of performing analyses associated with system improvement;
- costs of potential system modifications; and
- the discount rate (to calculate the NPV of future costs)

The table is further divided into two categories of costs:

- Up-Front costs
- Annual Costs

"Up-Front Costs" are input in present-day dollars. "Annual Costs" are also input in present-day dollars, and a time horizon is specified in the column "# Years". The total amount of present-day dollars resulting from annual values is calculated in the column "Total of Annual Costs", based on the time horizon and the discount rate (the PV function available in Microsoft Excel was utilized, with the option to calculate payments at the beginning of each year). In simple terms, the discount rate accounts for the fact that money (if not spent today) can be invested at a rate greater than inflation, such that future dollars have less value than present-day dollars (see Appendix A). The last column,"Total Costs", combines the "Up-Front Costs" with the "Total of Annual Costs". This column represents the NPV of all costs (i.e., expressed in present-day dollars).

The current value of a future costs is determined with the following relationship:

$$V_j = \frac{v}{(1+D)^{j}}$$

where:

v = annual cost per year, in present-day dollars
V_j = value of annual cost incurred during the *j*th year, in present-day dollars
D = discount rate (a percentage)
j = number of years (yrs) from present time

The actual discount rate (D) is a function of inflation, investment rates, and other opportunity costs associated with present and future value of money. A full explanation of the discount rate is beyond the scope of this document. The reader is referred to Damodaran (1994) or Ross et. al. (1995) for a detailed explanation. Complications can include formulating discount rate with or without inflation, change in discount rate over time, change in annual costs over time, and others. For the simplified analyses discussed herein, a discount rate between 3 and 8 percent will generally apply.

This screening spreadsheet is quite general with respect to range of application. Values input into the spreadsheet can be based on very detailed engineering calculations and modeling results, or may be based on "ballpark estimates". The spreadsheet can also be customized for specific sites. For instance, additional rows can be added if a more detailed cost breakdown is desired.

It is important to remember that the cost calculations in Table 2-1 are highly dependant on the cost estimates, time horizon, and discount rate. Those values are subject to uncertainty. Cost calculations can be performed with different combinations of parameter values, to provide an evaluation of the sensitivity of the results to those uncertainties.

2.2 SCREENING STEPS

To determine the potential benefits of system modifications, the following steps are suggested:

(1) compile and/or estimate cost components for a Baseline Scenario, and calculate Total Cost for that scenario (the Baseline Scenario might be the current system, or might be the current system design for a system not yet installed);

(2) review site-specific factors (evaluate which cost components are most significant, and which cost components could be potentially reduced by a system modification);

(3) formulate alternate scenarios that have the potential to reduce costs;

(4) for each alternate scenario, estimate cost factors and calculate Total Cost;

(5) compare the Total Cost of each scenario to that of the Baseline Scenario;

(6) determine which scenarios (if any) merit further analysis (e.g., detailed design of well locations and well rates, detailed evaluation of alternate treatment technologies, etc.).

A recommended approach for performing steps 1 through 3 is to arrange a phone call or meeting with a team of individuals familiar with the site (e.g., site manager, site operator, regulator, site consultant, groundwater modeler), to quickly compile cost data and identify potential scenarios for system modification. For systems originally designed on the basis of trial-and-error groundwater flow modeling, an estimated reduction in pumping rate of 10 to 40 percent may be anticipated if mathematical optimization techniques are to be applied (Dr. Richard Peralta, personal communication, June 1999).

The next section of this report (Section 3) discusses site-specific factors that should be considered in developing alternate scenarios and estimating cost factors for those scenarios. The spreadsheet screening approach is then demonstrated for three existing sites (Sections 4, 5, and 6).

3.0 IMPORTANT SITE-SPECIFIC FACTORS

Site-specific factors that impact management decisions for pump-and-treat designs include:

- potential savings in annual O&M;
- the projected remediation timeframe;
- the target containment zone;
- the remediation goal (containment versus cleanup);
- the status of groundwater modeling;
- the costs of additional design and system modification;
- the historical system performance;
- political/social issues; and
- uncertainties.

These factors can be thought of as a "checklist" when conducting a screening analysis. Each of these site-specific factors is discussed below.

3.1 POTENTIAL SAVINGS IN ANNUAL O&M

Major components of annual O&M expenses for pump-and-treat systems typically include:

- electric (for operating well pumps, blowers, transfer pumps, etc.);
- material (carbon, chemicals for pretreatment, etc.);
- well/pump maintenance;
- water discharge fees, such as to a Publicly Owned Treatment Works (POTW);
- labor (monitoring, cleaning, reporting, system operation, etc.); and
- analytical.

Estimating reductions in annual O&M that might result from a system modification (e.g., reduced pumping rate and/or reduced number of wells) can be quite complicated and site specific. At some sites electricity associated with pumping water is the most significant cost. At some sites, the materials (e.g., granular activated carbon or chemical additions) are the most significant cost. At other sites, discharge costs such as to POTW are most significant. At some sites the analytical costs may be the greatest component of annual O&M, but the analytical costs may not be sensitive to modifications in system design.

To utilize the screening spreadsheets, revised O&M costs must be estimated for alternate scenarios. These estimates are site-specific. For instance, at some sites a specific reduction in total pumping rate will yield annual savings of $10K or less, while at other sites the same reduction in total pumping will yield annual savings of $1M or more. The cost estimates used in the spreadsheet analysis may be based on historical site data, or may be "ballpark estimates".

3.2 ANTICIPATED REMEDIATION TIMEFRAME

System modification will generally result in greater benefits for projects with long remediation periods, due to the cumulative nature of O&M cost savings with time. The cumulative savings due to a reduction in annual O&M are far greater if the remediation timeframe is 20 yrs rather than 3 yrs. If cleanup is currently anticipated to last only a few months or years, system modifications are unlikely to yield significant net benefits (unless existing O&M costs are extremely high).

Unfortunately, remediation timeframe is a very difficult design parameter to estimate. This is because the site-specific factors affecting cleanup time are difficult to accurately characterize (due to presence of NAPLs or other continuing sources, heterogeneities in the subsurface, dispersivity, etc.). Cleanup time has historically been underestimated at many sites, even when sophisticated modeling techniques are employed.

In some cases it is appropriate to define the remediation timeframe as "a very long time". For instance, this may be the case if NAPLs are known to provide a continuing source of dissolved groundwater contamination, or if contaminants strongly sorb onto solids. In such cases, the screening analysis should utilize a time horizon of approximately 20 or 30 yrs (the same value should be used for all scenarios). This is because the NPV of costs associated with expenditures beyond 20 or 30 yrs become less significant, due to the time value of money. Also, assumptions regarding applicable technologies and/or regulatory requirements beyond 20 or 30 yrs are subject to very significant uncertainty.

In cases where cleanup is considered feasible within 20 or 30 yrs, the screening analysis should utilize the best available estimates. These estimates may be based on transport modeling, or may be simple "ballpark estimates". Observed concentration trends are sometimes utilized to predict cleanup times, but often these trends are non-linear and become asymptotic at low (yet unacceptable) contaminant levels (Cohen et al., 1997). Some reasons for these phenomena are: (1) continuing (and sometimes undefined) source areas; (2) time-limited desorption of contaminants; and (3) slow diffusion of contaminants from low permeability areas.

If one alternative is considered likely to reduce cleanup time (relative to competing alternatives), that should be reflected in the screening analysis by reducing the "# Years" for that scenario. The sensitivity of screening results to different estimates of remediation timeframe can be easily assessed by assigning different values within the spreadsheet.

3.3 TARGET CONTAINMENT ZONE

A design component of most pump-and-treat systems is to prevent the movement of contaminants beyond a prescribed boundary, even if the primary remediation objective is cleanup. The volume of water to be contained (the "target containment zone") may be defined by a property boundary, or by water quality criteria such as the 5 part per billion (ppb) trichloroethene (TCE) contour. To evaluate if a specific design is feasible, the target containment zone must be defined. Note that the target containment zone may vary with depth if contaminant distribution varies with depth.

For some existing pump-and-treat systems, the target containment zone has not been formally defined. For other systems, modifications to the target containment zone may be appropriate. If the plume has expanded, or cleanup levels have become more strict, the target containment zone may need to be increased in size. Alternatively, if the plume has contracted, or cleanup levels have been relaxed, the target containment zone can be reduced in size.

In some cases, several alternatives for the target containment zone can be considered during the screening analysis. For instance, one target containment zone may represent a current regulatory limit (e.g., 5-ppb TCE contour) while an alternative target containment zone may represent a potential risk-based limit (e.g., 20-ppb TCE contour). Potential cost reductions associated with the smaller target containment zone can be quantified with the screening spreadsheets. If the results indicate that potential savings associated with a smaller target containment zone are significant, then those alternatives may merit further consideration (within the context of potential regulatory requirements intended to protect human health and the environment).

3.4 CONTAINMENT VERSUS CLEANUP

Existing pump-and-treat systems fall into one of three categories:

- **containment:** The main goal is to prevent further spreading of contaminants;

- **cleanup:** The main goal is reduction of contaminant concentrations below specific cleanup levels (frequently in conjunction with containment or removal of contaminant source areas); or

- **hybrid:** The main goal is containment, but cleanup may be possible and accelerated mass removal is considered a benefit.

A "containment" goal is appropriate when there is a continuing source of groundwater contamination that will prevent aquifer cleanup within any reasonable time frame, or when the contaminants cannot effectively be removed from the aquifer. An example would be the presence of Dense Non-Aqueous Phase Liquids (DNAPLs) below the water table, which are difficult to remove and provide a long-term source of dissolved contamination. Containment may also be appropriate if the cost of cleanup is prohibitively high relative to the cost of containment. Containment systems often consist of pumping that is predominantly located at the downgradient portion (i.e., the "toe") of the target containment zone. Sometimes reinjection wells are included downgradient of the pumping wells (to add hydraulic control), or far upgradient of the pumping wells so that hydraulic control from the pumping wells is not compromised.

A "cleanup" goal is appropriate when the source of groundwater contamination has been removed or contained, and when contaminants can effectively be removed from the aquifer. Cleanup systems generally consist of extraction wells located throughout the contaminated region, especially in highly contaminated areas to maximize contaminant mass removal. Sometimes injection wells are added upgradient of highly contaminated areas, to increase gradients towards the extraction wells and flush contaminants through the aquifer.

A "hybrid" goal is appropriate when containment is of primary importance, but additional mass removal is desired. In addition to pumping near the toe of the plume (for containment), one or more extraction wells are placed in more highly contaminated areas, to remove additional mass. The concept is that cleanup may be possible at the site, and therefore accelerated mass removal may provide a net benefit.

Unfortunately, cleanup of aquifers to regulatory levels is often difficult to achieve for a variety of reasons, with "tailing" and "rebound" phenomena frequently observed (Cohen et al., 1997; NRC, 1994). At many sites where cleanup is the goal, the estimated time frame required for cleanup is subject to significant uncertainty. Historically, estimates of cleanup time have been overly optimistic.

The goal for a site (containment versus cleanup) significantly impacts the formulation of remedial alternatives. If the goal is containment, minimizing total pumping required for containment will typically minimize the remediation cost. If the goal is cleanup, there is a complex cost tradeoff associated with aggressive pumping (annual O&M costs are higher, but there is a potential for reduced remediation timeframe).

For sites where a cleanup goal or hybrid goal has been employed, the screening spreadsheets can be used to estimate potential savings from a switch to "containment-only". In this way, the potential benefits of accelerated cleanup (from mid-plume and/or source area wells) can be evaluated against the additional cost they require to operate.

3.5 STATUS OF GROUNDWATER MODELING

A primary component of many pump-and-treat designs is an "adequate" groundwater simulation model. If a system modification will require additional groundwater modeling and/or optimization modeling to implement (e.g., for detailed design), then estimated costs for those modeling efforts should be included as "Up-Front" costs in the screening process. The costs of groundwater modeling and mathematical optimization are site-specific, and are not easily generalized. They could range from $10K or less to $100K or more.

Models represent simplifications of the aquifer system. They are based on imperfect input data, and are subject to significant uncertainty. An "adequate" model, as defined here, is a site-specific simulator that is accepted as a valid tool for evaluating aquifer responses as they relate to pump-and-treat alternatives. The acceptance of the model is ideally based on a comparison of simulated versus observed conditions under both pumping and non-pumping conditions (or multiple pumping conditions). Observed conditions might include water levels, horizontal and/or vertical gradients (magnitude and direction), gains or losses to streams, and contaminant distributions.

Two general classes of groundwater models are: (1) groundwater flow models; and (2) groundwater transport models. For hydraulic optimization, a groundwater flow model is utilized for predictions of water levels, drawdowns, gradients, and velocities, and also can be used as a basis for particle tracking to illustrate groundwater flowpaths and capture zones. For transport optimization (which incorporates contaminant concentrations and/or cleanup times) a solute transport model is required. Transport models are generally more complicated than flow models, and require more input (initial plume distribution, dispersion coefficients, sorption parameters, etc.). In addition, the predicted concentrations from a groundwater transport model are subject to greater uncertainty than predictions of water levels from a groundwater flow model.

If a site has not been previously modeled, the cost and time required to construct an "adequate" groundwater model for conducting mathematical optimization must be considered. If modeling has previously been performed, an evaluation should be made regarding the adequacy of the model for making predictions. Issues that must be considered include: (1) is the type of model appropriate for the desired analysis (i.e., a flow model is not appropriate if prediction of concentrations is required)? (2) is the model accepted as a tool for comparing alternatives? (3) have aquifer stresses changed substantially since the model was constructed (such as new pumping wells)? (4) is the model grid spacing sufficiently small to analyze well capture zones? (5) are model boundaries sufficiently far from pumping wells? (6) is model layering appropriate for the desired analysis? and (7) have model results been evaluated with respect to observations during actual pumping conditions? If it is anticipated that revisions to the existing model are required, the costs and time required for the revisions should be included.

3.6 COSTS OF ADDITIONAL DESIGN AND SYSTEM MODIFICATION

When contemplating modifications to a pump-and-treat system, the costs of additional design and/or system modifications should be considered. In addition to groundwater and/or optimization modeling (discussed above), these may include: (1) engineering design; (2) regulatory negotiation; (3) field implementation (i.e., installing new wells, piping, controls, pilot testing, and/or additional site characterization); and (4) increased monitoring to assess the effects of system changes. For the screening analysis, these costs should be estimated and included as “Up-Front Costs”.

3.7 HISTORICAL SYSTEM PERFORMANCE

Historical performance of a pump-and-treat system can provide information that is pertinent for a screening analysis. For instance: (1) O&M costs can be estimated with greater certainty on the basis of historical data; (2) historical pumping rates and water levels can be used to evaluate if an existing groundwater model reasonably predicts aquifer responses; (3) historical data may indicate problems that tend to increase overall system costs (such as well clogging); and (4) observed reductions in contaminant mass due to historical system performance may suggest the potential for large-scale strategy changes (such as a reduction in the size of the target containment zone).

3.8 POLITICAL/SOCIAL ISSUES

It is important to consider a variety of political and/or social issues when formulating alternative remediation scenarios. Some of these include:

- risks associated with system failure;
- likelihood of regulatory acceptance for a system modification;
- public perception and/or public relations;
- availability of funds for “Up-Front Costs”; and
- resistance to change (at many levels).

In some cases, alternatives that might reduce costs are nevertheless infeasible for one or more of these reasons, and should probably be eliminated before the screening analysis is performed. Similarly, some alternatives may be qualitatively preferable to others for one or more of these reasons, and those “intangible” aspects should be considered when evaluating the results of the screening analysis (rather than only comparing costs of competing alternatives).

3.9 UNCERTAINTIES

As previously discussed, the screening approach is based on many estimates (cost factors, remediation timeframe, discount rate, etc.). Cost calculations with different combinations of these parameters should be performed to evaluate the impacts of those uncertainties on screening results.

4.0 CASE #1: KENTUCKY

4.1 SITE BACKGROUND

4.1.1 Site Location and Hydrogeology

The facility is located in, Kentucky, along the southern bank of a river (see Figure 4-1). There are in excess of 200 monitoring points and/or piezometers at the site. The aquifer of concern is the uppermost aquifer, called the Alluvial Aquifer. It is comprised of unconsolidated sand, gravel, and clay. The Alluvial Aquifer has a saturated thickness of nearly 100 feet in the southern portion of the site, and a saturated thickness of approximately 30 to 50 feet on the floodplain adjacent to the river. The decrease in saturated thickness is due to a general rise in bedrock elevation (the base of the aquifer) and a decrease in surface elevation near the floodplain. The hydraulic conductivity of the Alluvial Aquifer ranges from approximately 4 to 75 ft/d.

Groundwater generally flows towards the river, where it is discharged (see Figure 4-2). However, a groundwater divide has historically been observed between the site and other nearby wellfields (locations of wellfields are illustrated on Figure 4-1). The groundwater divide is presumably caused by pumping at the nearby wellfields.

4.1.2 Plume Definition

Groundwater monitoring indicates site-wide groundwater contamination. Two of the most common contaminants, 1,2-dichloroethane (EDC) and benzene, are used as indicator parameters because they are found at high concentrations relative to other parameters, and are associated with identifiable site operations. Shallow plumes of EDC and benzene are presented in Figures 4-3 and 4-4, respectively. Concentrations are very high, and the presence of residual NAPL contamination in the soil column is likely (SVE systems have recently been installed to help remediate suspected source areas in the soil column).

4.1.3 Existing Remediation System

A pump-and-treat system has been operating since 1992. Pumping well locations are illustrated on Figures 4-3 and 4-4. There are three groups of wells:

- BW wells: River Barrier Wells
- SW wells: Source Wells
- OW wells: Off-site Wells

The primary goal is containment at the BW wells, to prevent discharge of contaminated groundwater to the river. The purpose of the SW wells is to accelerate mass removal. The purpose of the OW wells is to prevent off-site migration of contaminants towards other wellfields. A summary of pumping rates is as follows:

	Number of Wells	Design Rate (gpm)	Typical Rate (gpm)
BW wells: *Original Design* *Current System*	 18 23	 549 N/A	 N/A 420-580
SW wells	8	171	80-160
OW wells	8	132	25-100
Total System: *Original Design* *Current System*	 34 39	 852 N/A	 N/A 500-800

Five BW wells were added after the initial system was implemented, to enhance capture where monitored water levels indicated the potential for gaps. The operating extraction rates are modified as the river level rises and falls (when the river level falls, aquifer water levels also fall, and transmissivity at some wells is significantly reduced). The eight OW wells controlling off-site plume migration have largely remediated that problem, and will likely be phased out in the near future.

Contaminants are removed by steam stripping. The steam is purchased from operations at the site. Treated water is discharged to the river. Site managers have indicated their desire for accelerated mass removal, if it is not too costly. They do not favor significant reductions in pumping (and associated annual costs) if that will result in longer cleanup times.

4.1.4 Groundwater Flow Model

An existing 2-dimensional, steady-state MODFLOW (McDonald and Harbaugh, 1988) model is a simple representation of the system. There are 48 rows and 82 columns. Grid spacing near the river is 100 ft. The model has historically been used as a design tool, to simulate drawdowns and capture zones (via particle tracking) resulting from specified pumping rates.

4.2 SCREENING ANALYSIS

4.2.1 Step 1: Organize Costs of Existing System (Baseline Scenario)

The current system has an annual O&M cost of approximately $1.8M/yr, excluding analytical costs. Costs are summarized in Table 4-1, in the format of the screening spreadsheet. For this analysis, a remediation timeframe horizon of 20 yrs is specified , to represent “a very long time”. The total cost (NPV) of the current system, for a 20-year time horizon, is estimated to be $23.55M (Table 4-1).

4.2.2 Step 2: Review Site-Specific Factors

Potential Reductions in Annual O&M. The steam cost ($1.2M/yr) is the most significant annual cost. According to the site managers, the steam cost is essentially proportional to the pumping rate, such that reductions in pumping rate would likely yield significant savings. Electrical cost ($200K/yr) and materials cost associated with pH adjustment ($100K/yr) could also be reduced by a reduction in pumping rate. Maintenance cost (50K/yr) and O&M labor cost ($250K/yr) would not be significantly reduced by a reduction in pumping rate. Because steam is the most significant cost, a review of potential alternate treatment technologies might also be worthwhile.

Remediation Timeframe. Due to the likelihood of residual NAPL in the soil column, and the high levels of contaminants in groundwater, it is likely that any alternatives to the current system considered will have a remediation timeframe of more than 20 yrs. Therefore, using a consistent timeframe that represents "a very long time" (e.g., 20 yrs) is appropriate.

Target Containment Zone. The priority of this system is to prevent discharge of contaminated water to the River. A secondary target containment zone has historically been associated with off-site migration of contaminants towards other wellfields, but a formal containment zone for that area has not been reported, and the OW wells associated with that containment zone are planned to be phased out based on observed concentration reductions.

Containment Versus Cleanup. The current system is a hybrid system, where containment is the primary goal, but additional wells have been installed for accelerated mass removal (the SW wells). Site managers have indicated their desire for accelerated mass removal, if it is not too costly. Therefore, it may be appropriate to compare the current system to a "containment only" system, so that the additional costs for accelerated mass removal can be quantified. In addition, the current SW wells may not be ideally located with respect to maximum contaminant concentrations (based on updated plume maps), and consideration of additional SW wells may be appropriate if accelerated mass removal continues to be a goal.

Status of Groundwater Modeling. The current groundwater model is a simplified representation of the hydrogeologic system. It is a useful tool for approximating drawdowns and capture zones. However, the following are noted: (1) model grid spacing of 100 ft in the vicinity of the river permits only 1 or 2 cells between some wells and the river, and a finer grid spacing would be better; (2) transient impacts associated with changes in river level are not currently simulated by this steady-state model; (3) historical pumping and water level data may provide an opportunity to verify predictions of the groundwater model; and (4) the two-dimensionality of the model limits any ability to evaluate three-dimension aspects of groundwater flow at the site.

Costs of Additional Analysis and System Modification. Because a reduction in pumping rate might significantly reduce annual O&M costs, additional groundwater modeling and/or optimization modeling may be considered to determine improved pumping rates. If the system is to be modified, costs associated with engineering design and the regulatory process can also be anticipated. If new wells are to be considered, the approximate cost (including associated piping) of new wells must be considered. Ballpark estimates for these costs are:

additional flow modeling:	$ 25,000
hydraulic optimization:	$ 15,000
additional engineering design:	$ 40,000
regulatory process:	$ 25,000
additional wells:	$ 20,000 per well

Historical System Performance. Based on concentration trends, the OW wells will likely be phased out in the near future. Also, historical data suggest that when water level falls, production at some wells is reduced (due to reduced aquifer transmissivity), and this is not accounted for by the groundwater flow model.

Political/Social Issues. None identified.

Uncertainties. Components of annual O&M costs are based on historical performance, so there is little uncertainty in those values. There is also little uncertainty that the remediation timeframe for most (if not all) scenarios will be 20 yrs or more. There are uncertainties (as always) in the discount rate and any predictions made by the groundwater flow model.

4.2.3 Step 3: Formulate Alternative Scenarios

Two alternate scenarios were considered for this demonstration. In each scenario, it is assumed that a reduction in pumping rate of 33 percent can be achieved in a modified system (from approximately 600 gpm to 400 gpm). A 33 percent reduction in flow rate could be accomplished in one or more of the following ways:

- a reduction in rates at the BW wells required to maintain containment (via optimization);
- a reduction in pumping at the OW wells; and/or
- a reduction in pumping at the SW wells;

In Scenario 1, no new wells are assumed. In Scenario 2, the addition of up to 5 new wells are assumed (i.e., possibly to improve the efficiency of containment, or possibly to improve the efficiency of mass removal in highly contaminated areas).

For the purposes of this screening analysis, a potential reduction in pumping rate of 33 percent is a reasonable goal. Of course, additional screening calculations could be performed with alternate values for percent reduction, to assess the sensitivity of screening conclusions to the assumed reduction in total pumping rate.

4.2.4 Step 4: Estimate Cost Components and Calculate Total Cost for Each Scenario

A spreadsheet analysis for each scenario is presented in Tables 4-2 and 4-3, respectively. The following Up-Front costs are estimated for each alternate scenario:

$ 25K:	improve the groundwater flow model
$ 15K:	perform hydraulic optimization modeling
$ 40K:	engineering design associated with a system modification
$ 25K:	regulatory process associated with a system modification

For Scenario 2, an additional Up-Front cost is associated with the addition of new wells:

$100K:	up to 5 new wells at $20K/well

The following reductions in annual O&M costs are estimated to result from a 33 percent reduction in pumping rate, if it can be achieved:

steam:	33 percent reduction
electric:	20 percent reduction
materials:	33 percent reduction
maintenance:	0 percent reduction
O&M labor:	0 percent reduction

These estimates of cost reductions are based on the fact that steam cost is directly proportional to the volume of water treated, that electricity cost is a function of pumping rates at the wells, and materials cost (associated with a pH adjustment) is directly proportional to the volume of water treated.

A 20-year time horizon is used for all scenarios.

4.2.5 Step 5: Compare Total Cost of Each Alternate Scenario to Baseline Scenario

Preliminary cost estimates for each alternate scenario are compared to the baseline scenario:

	Up-Front Costs ($)	Sum of Annual Costs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$23,553,578	$23,553,578
Scenario #1	$105,000	$17,364,221	$17,469,221
Scenario #2	$205,000	$17,364,221	$17,569,221

4.2.6 Step 6: Is Additional Analysis Merited?

The screening analysis suggests that significant savings might be achieved by modifying the pump-and-treat system at the Kentucky facility, and therefore additional analysis is merited. The majority of potential cost savings would be derived from a reduction in steam costs that would be associated with a potentially reduced pumping rate. The assumed pumping rate reduction of 33 percent may or may not be achievable. However, the screening analysis suggest that performing additional analyses (e.g. modeling, mathematical optimization, engineering design) in an attempt to reduce the pumping rate has the potential to yield savings of millions of dollars (NPV) over a 20 year period, and therefore is worthwhile. Similarly, if pumping rates can be reduced by switching to a “containment-only” system, net savings of millions of dollars might results, and consideration of that alternative is also suggested.

The screening results for Scenario 2 indicate that the Up-Front cost associated with five additional wells is small, relative to potential savings afforded by a significant reduction in pumping rates. This suggests that additional well locations should be considered if it is thought that those wells may lead to an overall reduction in total pumping. Similarly, it indicates that if pumping rates required for containment (e.g., at the BW wells) can be substantially reduced, the long-term savings will more than offset the cost of installing additional wells in the most highly contaminated areas, for the purpose of increased mass removal.

The cost factors used in the spreadsheet screening method are all estimates. However, an uncertainty analysis can be performed to assess the sensitivity of screening results to different cost estimates. For this site, modifying the discount rate or time horizon will not change the overall conclusions. Increasing the Up-Front cost estimates (modeling, engineering, etc.) by a factor of two or five will not change the overall conclusions. Similarly, a different assumption for achievable reduction in pumping that might result from additional analysis and/or a switch to a containment only system (e.g., 20 percent rather than 33 percent) will also not change the overall conclusions. Therefore, these uncertainties do not change the conclusion that additional analysis regarding system modification is merited at this site.

5.0 CASE #2: TOOELE

5.1 SITE BACKGROUND

5.1.1 Site Location and Hydrogeology

The facility is located in Tooele Valley in Utah, several miles south of the Great Salt Lake. (see Figure 5-1). The aquifer of concern generally consists of alluvial deposits. However, there is an uplifted bedrock block at the site where groundwater is forced to flow from the alluvial deposits into fractured and weathered rock (bedrock), and then back into alluvial deposits.

The unconsolidated alluvial deposits are coarse grained, consisting of poorly sorted clayey and silty sand, gravel, and cobbles eroded from surrounding mountain ranges. There are several fine-grained layers assumed to be areally extensive but discontinuous, and these fine-grained layers cause vertical head differences between adjacent water-bearing zones. Bedrock that underlies these alluvial deposits is as deep as 400 to 700 feet. However, in the vicinity of the uplifted bedrock block, depth to bedrock is shallower, and in some locations the bedrock is exposed at the surface.

Depth to groundwater ranges from 150 to 300 ft. The hydraulic conductivity of the alluvium varies from approximately 0.13 to 700 ft/day, with a representative value of approximately 200 ft/day. In the bedrock, hydraulic conductivity ranges from approximately 0.25 ft/day in quartzite with clay-filled fractures to approximately 270 ft/day in orthoquartzite with open, interconnected fractures.

Groundwater generally flows to the north or northwest, towards the Great Salt Lake (see Figure 5-2). Recharge is mostly derived from upgradient areas (south of the facility), with little recharge from precipitation. Gradients are very shallow where the water table is within in the alluvial deposits. There are steep gradients where groundwater enters and exits the bedrock block, and modest gradients within the bedrock block. There is more than 100 ft of head difference across the uplifted bedrock block. This suggests that the uplifted bedrock area provides significant resistance to groundwater flow. North (i.e., downgradient) of the uplifted bedrock block, the vertical gradient is generally upward.

5.1.2 Plume Definition

The specific plume evaluated in this study originates from an industrial area in the southeastern corner of the facility, where former operations (since 1942) included handling, use, and storage of TCE and other organic chemicals. Groundwater monitoring indicates that the primary contaminant is TCE, although other organic contaminants have been detected. TCE concentrations in the shallow (model layer 1) and deep (model layer 2) portions of the aquifer are presented on Figure 5-2. Concentrations are significantly lower in the deeper portions of the aquifer than in shallow portions of the aquifer. Also, the extents of the shallow and deep plumes do not directly align, indicating a complex pattern of contaminant sources and groundwater flow. Continuing sources of dissolved contamination are believed to exist.

5.1.3 Existing Remediation System

A pump-and-treat system has been operating since 1993. The system consists of 16 extraction wells and 13 injection wells (see Figure 5-3 for well locations). An air-stripping plant, located in the center of the plume, is capable of treating 8000 gpm of water. It consists of two blowers operated in parallel, each capable of treating 4000 gpm. Sodium hexametaphosphate is added to the water prior to treatment, to prevent fouling of the air stripping equipment and the injection wells. Treated water is discharged via gravity to the injection wells.

Based on the well locations and previous plume delineations, the original design was for cleanup. At the time the system was installed, the source area was assumed to be north of the industrial area (near a former industrial waste lagoon). Subsequently, it was determined that the source area extended far to the south (in the industrial area). As a result, the current system essentially functions as a containment system (there are no extraction wells in the area of greatest contaminant concentration).

Historically, the target containment zone has been defined by the 5-ppb TCE contour. Given the current well locations, anticipated cleanup time is "a very long time". However, a revised (i.e., smaller) target containment zone is now being considered, based on risks to potential receptors. A revised target containment zone might correspond to the 20-ppb or 50-ppb TCE contour.

5.1.4 Groundwater Flow Model

A three-dimensional, steady-state MODFLOW model was originally constructed in 1993 (subsequent to the design of the original system), and has been recalibrated on several occasions (to both non-pumping and pumping conditions). The current model has 3 layers, 165 rows, and 99 columns. Cell size is 200 ft by 200 ft. Model layers were developed to account for different well screen intervals, as follows:

Layer 1:	0 to 150 ft below water table
Layer 2:	150 to 300 ft below water table
Layer 3:	300 to 600 ft below water table

Boundaries include general head conditions up- and down-gradient, no flow at the sides and the bottom. The model has historically been used as a design tool, to simulate drawdowns and capture zones (via particle tracking) that result from specified pumping and injection rates.

5.2 SCREENING ANALYSIS

5.2.1 Step 1: Organize Costs of Existing System (Baseline Scenario)

The current system has an annual O&M cost of approximately $1.8M/yr. Costs are summarized in Table 5-1, in the format of the screening spreadsheet. For this analysis, a remediation timeframe horizon of 20 yrs is specified , to represent "a very long time". The total cost (NPV) of the current system, for a 20-year time horizon, is estimated to be $23.68M (Table 5-1).

5.2.2 Step 2: Review Site-Specific Factors

Potential Reductions in Annual O&M.   The most significant cost is the electric cost, which is approximately $1.0M/yr. According to the site managers, the electric cost is driven by the cost of extracting water and delivering it to the treatment plant. A reduction in pumping rate would therefore reduce electrical costs. Also, if pumping rate is reduced below 4000 gpm, an additional savings in electricity could result by shutting down one of the two blowers. Sodium hexametaphosphate cost ($200K/yr) is directly proportional to pumping rate. Maintenance cost (30K/yr) and O&M labor cost ($500K/yr) may or may not be significantly reduced by a reduction in pumping rate. Analytical costs

($80K/yr) would not likely be impacted by a reduction in pumping rate.

Remediation Timeframe. It is likely that any system limited to the existing well network will have a remediation timeframe of more than 20 yrs. This is because there is a continuing source of dissolved groundwater contamination, and the current wells do not provide source control. Therefore, using a timeframe that represents "a very long time" (e.g., 20 yrs) for scenarios limited to the existing wells is appropriate. However, for scenarios with the addition of new wells near the source area, use of a 20-year time horizon may be conservative. This is because containment of the source area could eventually allow most or all of the existing wells to be shut off (i.e., O&M costs associated with some wells might be incurred for significantly less than 20 yrs).

Target Containment Zone. Historically, the target containment zone has been defined by the 5 ppb TCE contour. However, a smaller target containment zone (based on risk to potential receptors) is being considered. A revised target containment zone might correspond to the 20 ppb or 50 ppb TCE contour, rather than the 5 ppb TCE contour. The target containment zone varies with depth. The target containment zone in the deeper portion of the aquifer is significantly smaller than in the shallow aquifer.

Containment versus Cleanup. Based on the well design, the original goal was cleanup, assuming a source area north of the industrial area. Subsequently, it was determined that the source area extends south to the industrial area, and therefore the current system functions essentially as a containment system (there are no extraction wells in the area of greatest contaminant concentration). Presumably, cleanup is still a long-term goal at this site, since concentrations are relatively low.

Status of Groundwater Modeling. The current groundwater model is a useful tool for approximating drawdowns and capture zones. However, the following are noted: (1) near the source area, simulated flow directions are not consistent with the shape of the observed plume; and (2) the bedrock block is a very complex feature, and accurate simulation of that feature is very difficult.

Costs of Additional Analysis and System Modification. Because a reduction in pumping rate would significantly reduce annual O&M costs, additional groundwater modeling and/or optimization modeling may be considered to optimize pumping rates. Because cleanup is possible at this site if the source area is contained, solute transport modeling and/or transport optimization may also be considered. If the system is to be modified, costs associated with engineering design and the regulatory process can also be anticipated. If new wells are to be considered, the approximate cost should be included. Ballpark estimates for these costs are:

additional flow modeling:	$ 10,000
transport modeling:	$ 30,000
optimization (hydraulic or transport):	$ 25,000
additional engineering design:	$ 40,000
regulatory process:	$ 45,000
additional wells:	$300,000 per well.

Historical System Performance. The toe of the plume has contracted since the system was installed, and well E-12 has been shut off as a result. This is likely the result of mass removal provided by wells upgradient of E-12, which extract a very significant amount of water.

Political/Social Issues. There a no receptors immediately downgradient of the plume, so risks associated with failure of a containment system are lower than at many other sites.

Uncertainties. Components of annual O&M costs are based on historical performance, so there is little uncertainty in those values. There are uncertainties (as always) in the discount rate and any predictions made by the groundwater flow model.

5.2.3 Step 3: Formulate Alternative Scenarios

Two alternate scenarios were considered for this demonstration. In each scenario, it is assumed that a reduction in pumping rate of 33 percent can be achieved in a modified system (from approximately 7500 gpm to 5000 gpm). This could be accomplished by:

- optimizing rates to achieve more efficient containment of the 5-ppb plume; and/or
- reducing the size of the target containment zone (if independently demonstrated to maintain protection of human health and the environment).

In Scenario 1, no new wells are assumed. In Scenario 2, the addition of up to 5 new wells are assumed (i.e., possibly to improve the efficiency of containment, or possibly to improve the efficiency of mass removal in highly contaminated areas).

For the purposes of this screening analysis, a potential reduction in pumping rate of 33 percent is a reasonable goal. Of course, additional screening calculations could be performed with alternate values for percent reduction, to assess the sensitivity of screening conclusions to the assumed reduction in total pumping rate.

5.2.4 Step 4: Estimate Costs Components and Calculate Total Cost for Each Scenario

A spreadsheet analysis for each scenario is presented in Tables 5-2 and 5-3, respectively. The following Up-Front costs are estimated for each alternate scenario:

$ 10K:	improve the groundwater flow model
$ 30K:	perform transport modeling
$ 25K:	perform optimization modeling (hydraulic or transport)
$ 40K:	engineering design associated with a system modification
$ 40K:	regulatory process associated with a system modification

For Scenario 2, an additional Up-Front cost is associated with the addition of new wells:

$1.5M:	up to 5 new wells at $300K/well

The following reductions in annual O&M costs are estimated to result from a 33 percent reduction in pumping rate, if it can be achieved:

electric:	20 percent reduction
materials:	33 percent reduction
maintenance:	0 percent reduction
O&M labor:	0 percent reduction
analytical	0 percent reduction

These estimates of cost reduction are based on the fact that electricity cost is a function of pumping rates at the wells, and materials cost (associated with addition of sodium hexametaphosphate to prevent clogging) is directly proportional to the volume of water treated.

A 20 year time horizon is used for each scenario. As previously discussed, this may be conservative if additional well are added in the source area, because the addition of source control may allow some existing wells to be turned off in less than 20 yrs.

5.2.5 Step 5: Compare Total Cost of Each Alternate Scenario to Baseline Scenario

Preliminary cost estimates for each alternate scenario are compared to the baseline scenario:

	Up-Front Costs ($)	Sum of Annual Costs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$23,684,431	$23,684,431
Scenario #1	$145,000	$20,195,007	$20,340,007
Scenario #2	$1,645,000	$20,195,007	$21,840,007

5.2.6 Step 6: Is Additional Analysis Merited?

The screening analysis for Scenario 1 suggests that significant savings might be achieved by modifying the pump-and-treat system at Tooele, and therefore additional analysis is merited. The majority of potential cost savings would be derived from a reduction in electrical costs that would be associated with a reduced pumping rate. The assumed pumping rate reduction of 33 percent may or may not be achievable. However, the screening analysis suggest that performing additional analyses (e.g. modeling, mathematical optimization, engineering design) to reduce the pumping rate has the potential to yield savings of millions of dollars (NPV) over a 20 year period, and therefore is worthwhile.

The screening results for Scenario 2 indicates that additional well locations, even at a cost of $300K/well, should be considered if it is thought that those wells may lead to an overall reduction in total pumping. This is because nearly $2M of potential savings are indicated, even when the costs of up to five new wells are included.

The cost factors used in the spreadsheet screening method are all estimates. However, an uncertainty analysis can be performed to assess the sensitivity of screening results to different cost estimates. For this site, modifying the discount rate will not change the overall conclusions. Similarly, reducing the timeframe for all scenarios (e.g., from 20 to 10 yrs) will not change the overall conclusions, although the potential savings indicated for Scenario 2 will be reduced (because the high cost of adding new wells will be offset by fewer years of savings in annual O&M). Increasing the Up-Front cost estimates (modeling, engineering, etc.) by a factor of two or five will not change the overall conclusions. A different assumption for achievable reduction in pumping (i.e., less than 33 percent) might change the overall conclusions. However, given the extremely high rate of pumping at this site, and the potential for reducing the size of the target containment zone, it may be possible to reduce pumping rates by *more than* 33 percent. Therefore, these uncertainties do not change the conclusion that additional analysis regarding system modification is merited at this site.

6.0 CASE #3: OFFUTT

6.1 SITE BACKGROUND

6.1.1 Site Location and Hydrogeology

The facility is located in Sarpy County, Nebraska, next to the City of Bellevue (see Figure 6-1). The specific plume evaluated in this study is in the Southern Plume within the Hardfill 2 (HF2) Composite Site at Offutt. The principal aquifer at the site consists of unconsolidated sediments resting on bedrock. The aquifer system is heterogeneous and complex. Groundwater flows easterly and southeasterly (see Figure 6-2). Depth to groundwater is generally 5 to 20 ft. The hydraulic conductivity of the alluvium varies significantly with location and depth, due the complex stratigraphy.

6.1.2 Plume Definition

Groundwater monitoring indicates that the primary contaminants are chlorinated aliphatic hydrocarbons (CAH's) including TCE, 1,2-dichloroethene (1,2-DCE), and vinyl chloride. Releases (initially as TCE) formed localized vadose zone and dissolved groundwater plumes. Subsequent groundwater transport from these multiple sources has resulted in groundwater contamination in shallow and deeper portions of the Alluvial Aquifer.

The extent of the Southern Plume is illustrated on Figure 6-3. The core zones are defined as follows:

- shallow zone: upper 20 ft of saturated zone
- shallow-intermediate zone: from 930 ft MSL to 20 ft below water table
- intermediate zone: 910 ft MSL to 930 ft MSL
- deep zone: below 910 ft MSL

The Southern Plume is approximately 2400 ft long, and extends just beyond the southern site boundary.

6.1.3 Existing Remediation System

An interim remediation system is in place, and consists of three wells (see Figure 6-3), pumping a total of 150 gpm:

- one "Toe Well" that is located within the southern plume, at 50 gpm; and
- two wells downgradient of the plume (the "LF wells"), at 100 gpm combined.

The extracted water is discharged to a POTW.

The two LF wells are associated with a landfill located downgradient from the Southern Plume boundary. The LF wells are considered part of the interim system, because they provide a degree of ultimate containment for the plume. However, allowing the plume to spread towards the LF wells is considered to be a negative long-term result.

To prevent further spreading of the Southern Plume, a long term pump-and-treat system has been designed, with the addition of a "Core Well" within the southern plume (see Figure 6-3). The design of the long-term system calls for 200 gpm total, as follows:

- one Toe well that is located within the southern plume, at 50 gpm;
- one Core well that is located within the southern plume, at 50 gpm; and
- two wells downgradient of the plume (the "LF wells"), at 100 gpm combined.

The intent is for the Toe well and Core well to prevent the Southern Plume from spreading beyond it's present extent (rather than allowing the plume to flow towards the LF wells), and also to more effectively contain the source areas (because the core well is located immediately downgradient from the source areas). Under this scenario, the LF wells are not actually providing containment or cleanup for the Southern Plume (in fact, pumping at the LF wells negatively impacts containment of the Southern Plume). The original purpose of the LF wells is not related to remediation of the Southern Plume, and it is hoped that pumping at the LF wells may be reduced (or even terminated) in the future.

6.1.4 Groundwater Flow Model

A three-dimensional, steady-state MODFLOW model was originally constructed in 1996. In addition, a solute transport model was created with the MT3D code (Zheng, 1990). The groundwater models were used to simulate various groundwater extraction scenarios. The current model has 6 layers, 77 rows, and 140 columns. Cell size varies from 25 by 25 ft to 200 x 200 ft. Layer 4 represents an alluvial sand layer, and that layer has historically been evaluated with particle tracking to determine if containment is achieved under a specific pumping scenario.

The solute transport model indicates the following:

- under the interim system, pumping will be required for more than 20 yrs to maintain containment (due to the continuing source), and concentrations near the site boundary will be reduced to MCL levels within 10 to 20 yrs;

- under the long-term design, pumping will be required at the Core well for more than 20 yrs to maintain containment (due to the continuing source), but cleanup of the area downgradient of the core well will be achieved in less than 10 yrs.

In each case, some component of pumping is anticipated for "a very long time", due to continuing sources.

6.2 SCREENING ANALYSIS

6.2.1 Step 1: Organize Costs of Existing System (Baseline Scenario)

For this analysis, the baseline system is the currently designed system. That system has an annual O&M cost of approximately $122,000. Costs are summarized in Table 6-1, in the format of the screening spreadsheet. For this analysis, a remediation timeframe of 20 yrs is used, to represent "a very long time". However, based on the previous solute transport model results for the baseline system, it is assumed that the Toe well may be shut off in 10 yrs, so a 10-year time horizon is specified for discharge fees associated with the Toe Well. The total cost (NPV) of the current system, for a 20-year time horizon, is estimated to be $1.58M (Table 6-1).

6.2.2 Step 2: Review Site-Specific Factors

Potential Reductions in Annual O&M. The most significant cost for this system is associated with discharge of pumped water to the POTW, which costs approximately $400 per gpm per year. Reducing the pumping will reduce the discharge fees proportionately. With the exception of discharge costs, no other cost component would be substantially reduced by reducing the pumping rate.

Remediation Timeframe. It is anticipated that pumping will be required for "a very long time" to maintain containment of the source area. It is expected that pumping at the Core well will effectively contain the source area, allowing the Toe well to be turned off within 10 yrs.

Target Containment Zone. The primary goal is to prevent additional spreading of the Southern Plume. An additional goal of the long-term system is containment of the source areas, which will promote cleanup of the plume downgradient of the Core Well.

Containment versus Cleanup. Full cleanup is not currently anticipated. This is primarily a containment system. However, the addition of a Core well in the long-term design promotes cleanup of the plume downgradient of the Core Well, by effectively containing the source areas.

Status of Groundwater Modeling. The current groundwater flow model is a useful tool for approximating drawdowns and capture zones. A transport model has already been developed and applied.

Costs of Additional Analysis and System Modification. If optimization modeling is to be performed in an attempt to reduce total pumping, costs associated with optimization must be considered. If a system without the Core well is considered (i.e., containment of the Southern Plume by pumping only near the toe of the plume), the "Up-Front" cost of the Core well can be removed (approximately $40K). If new wells are to be considered, the approximate cost is estimated at $40K/well.

Historical System Performance. A full system (including the core well) has not yet been implemented.

Political/Social Issues. None identified.

Uncertainties. Components of annual O&M costs are straightforward, and there is little uncertainty in those values. There are uncertainties (as always) in the discount rate and any predictions made by the groundwater flow model. The cleanup time predictions made with the solute transport code are subject to significant uncertainty.

6.2.3 Step 3: Formulate Alternative Scenarios

Five alternate scenarios were considered for this demonstration:

Scenario 1: Reduce Toe well pumping by 33% while maintaining containment at the plume toe, and design rates of 50 gpm at the Core well and 100 gpm combined at the LF wells;

Scenario 2: Same as Scenario 1, but consider addition of up to 2 new wells near the toe of the plume;

Scenario 3:	No core well, increase pumping at the Toe well from 50 gpm to 75 gpm to maintain containment at the Plume toe, and design rate of 100 gpm combined at the LF wells;
Scenario 4:	Same as Scenario 3, but consider up to 2 additional wells near the toe of the plume;
Scenario 5:	Same as baseline scenario, but cut pumping at the LF wells by half.

6.2.4 Step 4: Estimate Costs Components and Calculate Total Cost for Each Scenario

A spreadsheet analysis for each scenario is presented in Tables 6-2 through 6-6. Estimated Up-Front costs, and estimated changes in annual O&M costs, are presented below for each scenario.

Scenario 1: reduce pumping at toe by 33 percent, no additional wells

Up Front Costs:

$ 15K:	additional transport modeling
$ 15K:	perform optimization modeling (hydraulic or transport)
$ 47K:	fixed construction for all scenarios (transition from interim system)
$ 20K:	regulatory process associated with a system modification
$ 40K:	new core well

O&M Costs:

discharge fee:	33 percent reduction for toe well, over 10 yrs

Scenario 2: reduce pumping at toe by 33 percent, 2 new toe wells

Same as scenario 1, but add $80K in Up-Front costs (2 additional new wells at $40K/well)

Scenario 3: do not install core well (save 50 gpm), increase toe well from 50 to 75 gpm, no new toe wells

Up Front Costs:

$ 15K:	additional transport modeling
$ 15K:	perform optimization modeling (hydraulic or transport)
$ 47K:	fixed construction for all scenarios (transition from interim system)
$ 20K:	regulatory process associated with a system modification

O&M Costs:

discharge fee:	50 percent increase for toe well (50 -> 75 gpm), over 20 yrs
discharge fee:	33 percent reduction for other wells (150 -> 100 gpm), over 20 yrs

Based on the transport modeling previously performed, the remediation timeframe associated with the toe well is increased from 10 yrs to 20 yrs for this scenario, because there is no longer a core well to provide effective containment of the source area.

Scenario 4: do not install core well (save 50 gpm), increase toe well from 50 to 75 gpm, 2 new toe wells

Same as scenario 3, but add $80K in Up-Front costs (2 additional new wells at $40K/well)

Scenario 5: cut pumping at LF wells from 100 to 50 gpm

Up Front Costs:

$ 15K:	additional transport modeling
$ 47K:	fixed construction for all scenarios (transition from interim system)
$ 20K:	regulatory process associated with a system modification
$ 40K:	new core well

O&M Costs:

discharge fee: 33 percent reduction for non-toe wells (150 -> 100 gpm), over 20 yrs

6.2.5 Step 5: Compare Total Cost of Each Scenario to Baseline Scenario

Preliminary cost estimates for each alternate scenario are compared to the baseline scenario:

	Up-Front Costs ($)	Sum of Annual Costs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$87,000	$1,496,859	$1,583,859
Scenario #1	$137,000	$1,442,804	$1,579,804
Scenario #2	$217,000	$1,442,804	$1,659,804
Scenario #3	$97,000	$1,465,556	$1,562,556
Scenario #4	$177,000	$1,465,556	$1,642,556
Scenario #5	$122,000	$1,235,153	$1,357,153

6.2.6 Step 6: Is Additional Analysis Merited?

The screening analysis suggests that little savings are likely to be achieved by modifying the pump-and-treat system at Offutt. The most promising modification (Scenario 5) is based on a reduction of pumping at the downgradient LF wells, which are not specifically managed with respect to the Southern Plume. Scenarios 1 through 4, which pertain to management of the wells within the Southern Plume, offer less promise for cost reduction.

The reason that this system offers little promise for cost reduction is that there is a low total pumping rate, and a relatively low treatment cost. Therefore, little total savings can be generated by reducing the pumping rate (even by as much as 33 percent). The Up-Front costs associated with modifying the system will not be justified by the minimal annual savings that might result. Therefore, additional analysis at this site (with respect to system modification) is a low priority.

7.0 DISCUSSION AND CONCLUSIONS

The screening analysis presented in this report can be used to quickly determine if significant cost savings may be achieved by altering key aspects of an existing or planned pump-and-treat system. The spreadsheet-based screening analysis allows quick and inexpensive cost comparison of competing alternatives at a site, in terms of Net Present Value (NPV). Site-specific values input into the spreadsheet can be based on very detailed engineering calculations and modeling results, or may be based on "ballpark estimates". The suggested approach includes a "checklist" of important site-specific factors to evaluate, and requires the formulation of potential system modifications. System modifications may be postulated with respect to the same goals as the present system, or with respect to modified goals.

The intended results are as follows:

- For alternatives that offer the potential of significant cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a high priority;

- For alternatives that offer little or no potential for cost reduction, more detailed design effort (e.g., flow or transport modeling, optimization modeling, technology evaluation, etc.) is a low priority.

The cost of a screening analysis at a site should be low relative to overall remediation costs (i.e., several thousand dollars for most sites).

The spreadsheet screening approach was demonstrated for three sites with existing pump-and-treat systems. The three sites can be summarized as follows:

Site	Existing Pumping Rate	Cost Per gpm	Potential Savings from System Modification	Additional Analysis Merited?
Kentucky	Moderate	High	> $6M	Yes
Tooele	High	Low	> $3M	Yes
Offutt	Low	Low	Little or None	No

Note: Potential savings represent millions of dollars, net present value (NPV), over 20 years

For Kentucky and Tooele, the screening analysis suggests that millions of dollars may be saved if additional analysis is performed to reduce the total pumping rate (the potential savings incorporate the additional Up-Front costs associated with additional analyses and system modification). Therefore, additional analyses at these sites (modeling, optimization, engineering) are worthwhile. The additional analyses would be performed to determine actual reductions in pumping rate that can be achieved, plus detailed design efforts (if appropriate) for a modified system. For Offutt, the screening analysis suggests that little or no savings is likely from a system modification, and additional analysis regarding system modification at that site should be a low priority.

This project was primarily focused on the reduction of pumping total pumping rate at pump-and-treat sites (of course, other forms of optimization, such as the application of alternate treatment technologies, may also provide significant benefits). Hydraulic optimization simulations were performed for each of the three sites, to more rigorously determine the extent to which pumping rates (and associated costs) might be reduced at each site. The results of the hydraulic optimization simulations are presented in Volume 2 of this report.

8.0 REFERENCES AND DOCUMENTS PROVIDED BY SITES

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FIGURES

H012009A.DWG

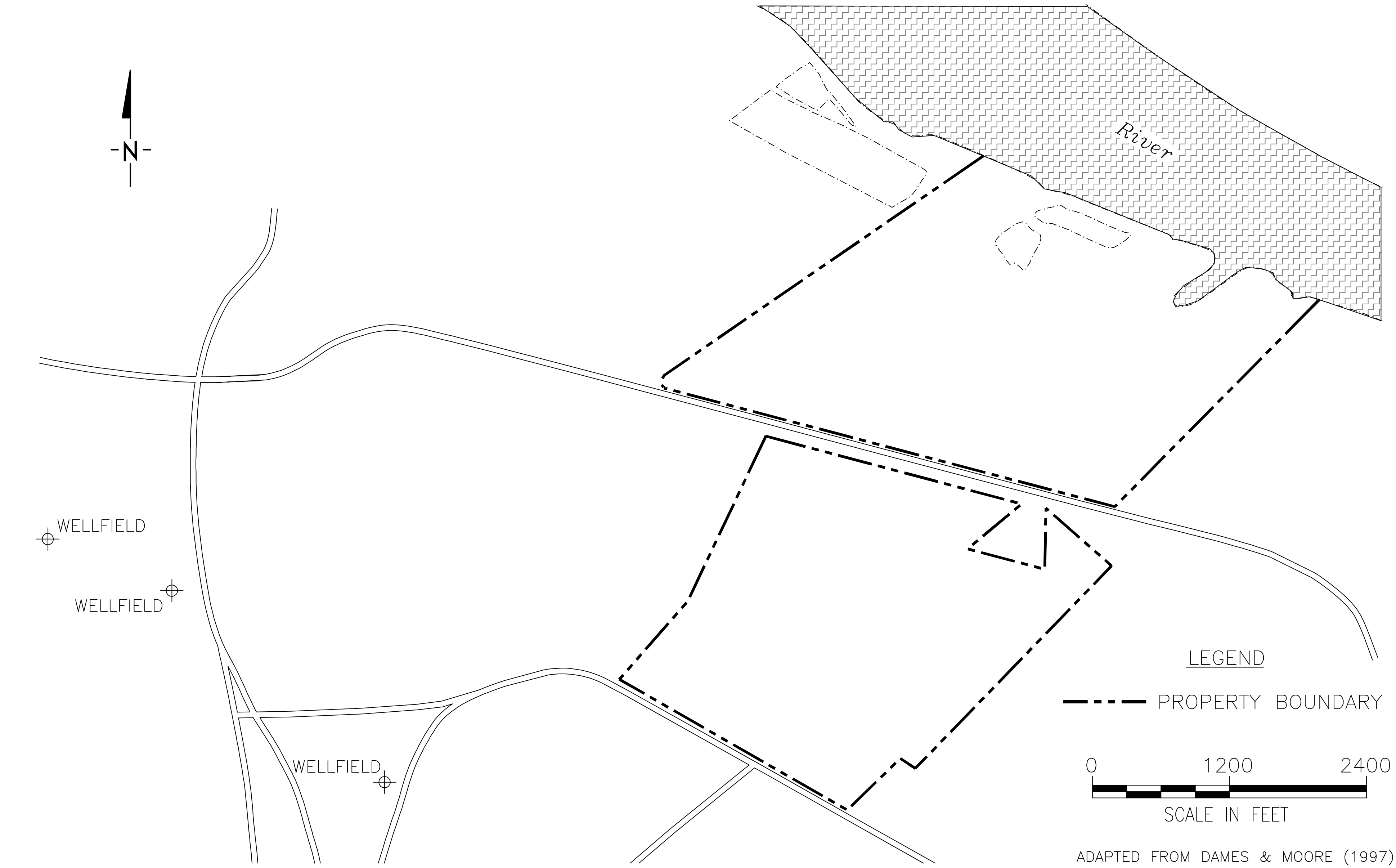

Figure 4-1. Site location map, Kentucky.

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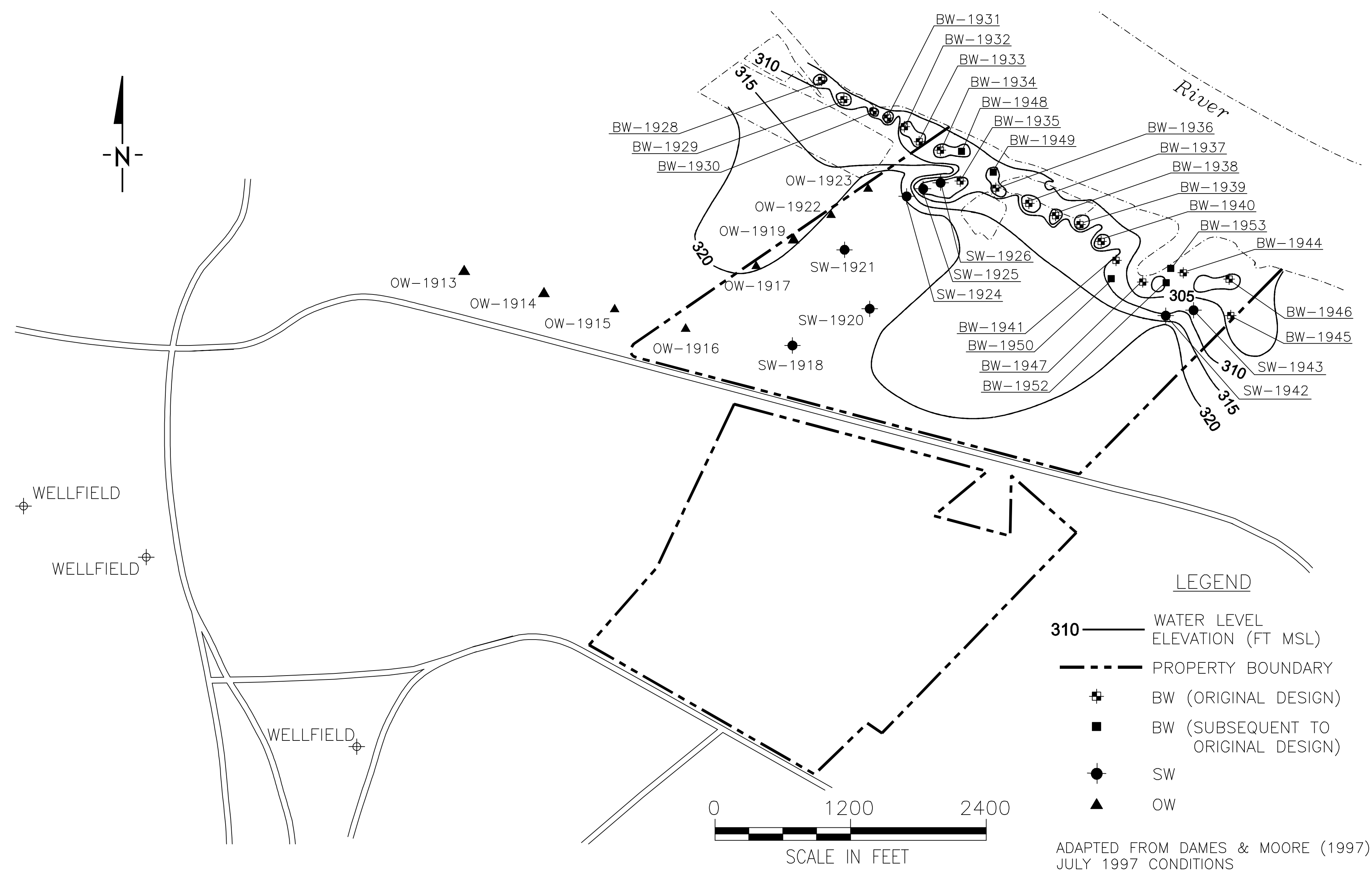
H012010A.DWG



NOTE: REMEDIATION WELLS ARE ILLUSTRATED ON THIS FIGURE. ALL WATER LEVEL DATA POINTS NOT SHOWN.

Figure 4–2. Groundwater elevation contours, Kentucky.

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H012011A.DWG

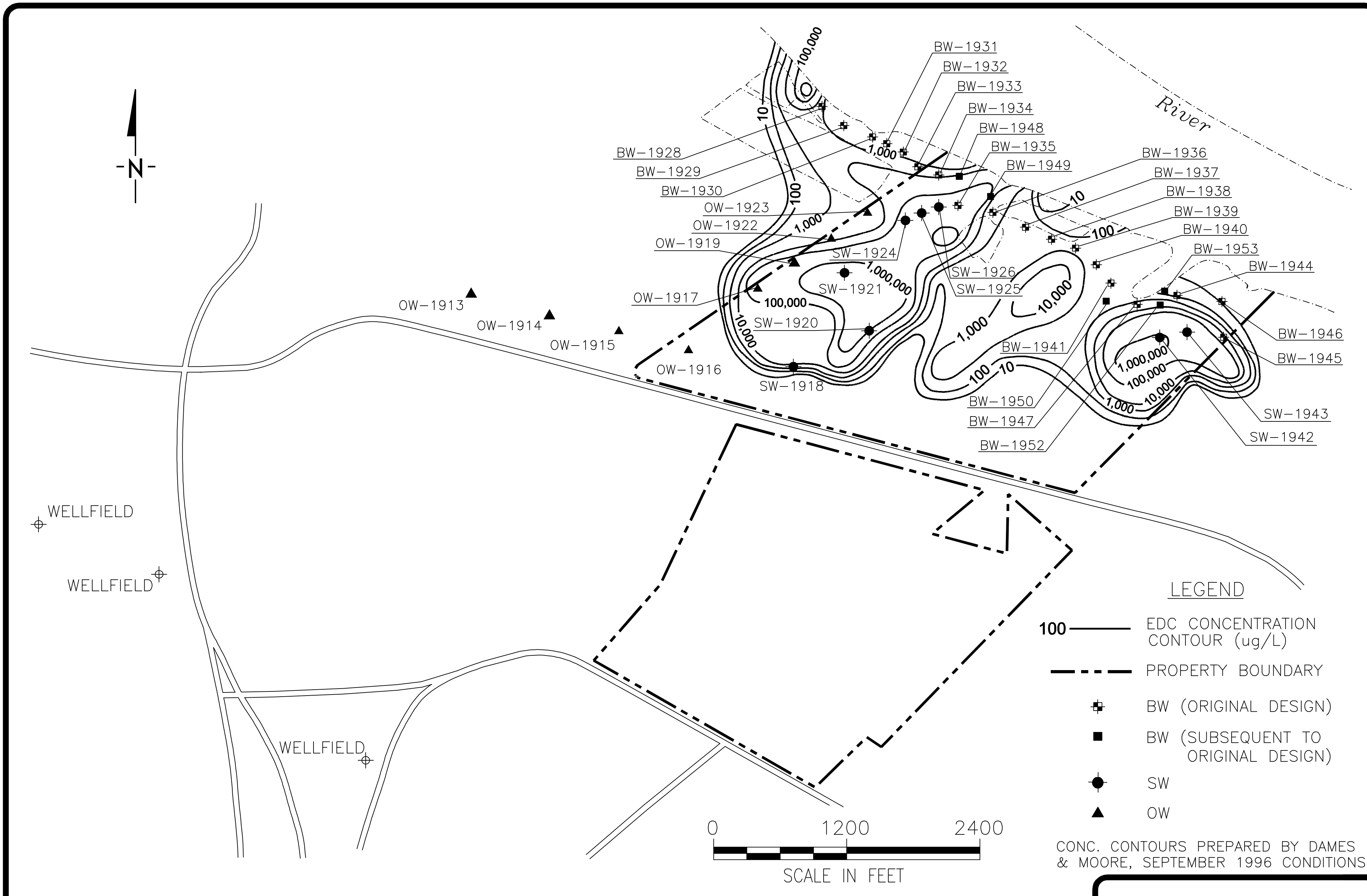

Figure 4-3. EDC concentrations and current remediation wells, Kentucky.

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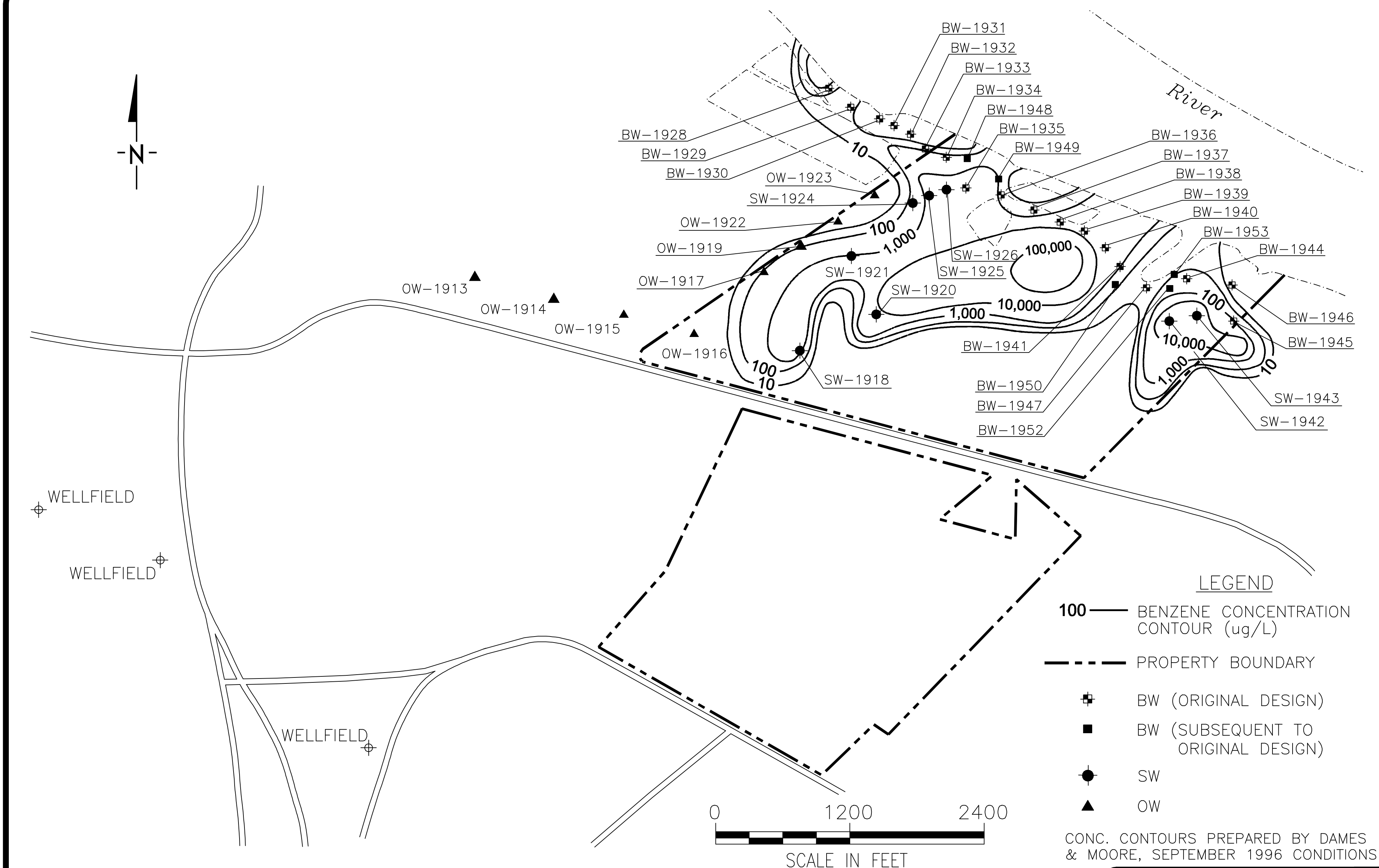

Figure 4-4. Benzene concentrations and current remediation wells, Kentucky.

HSI GEOTRANS
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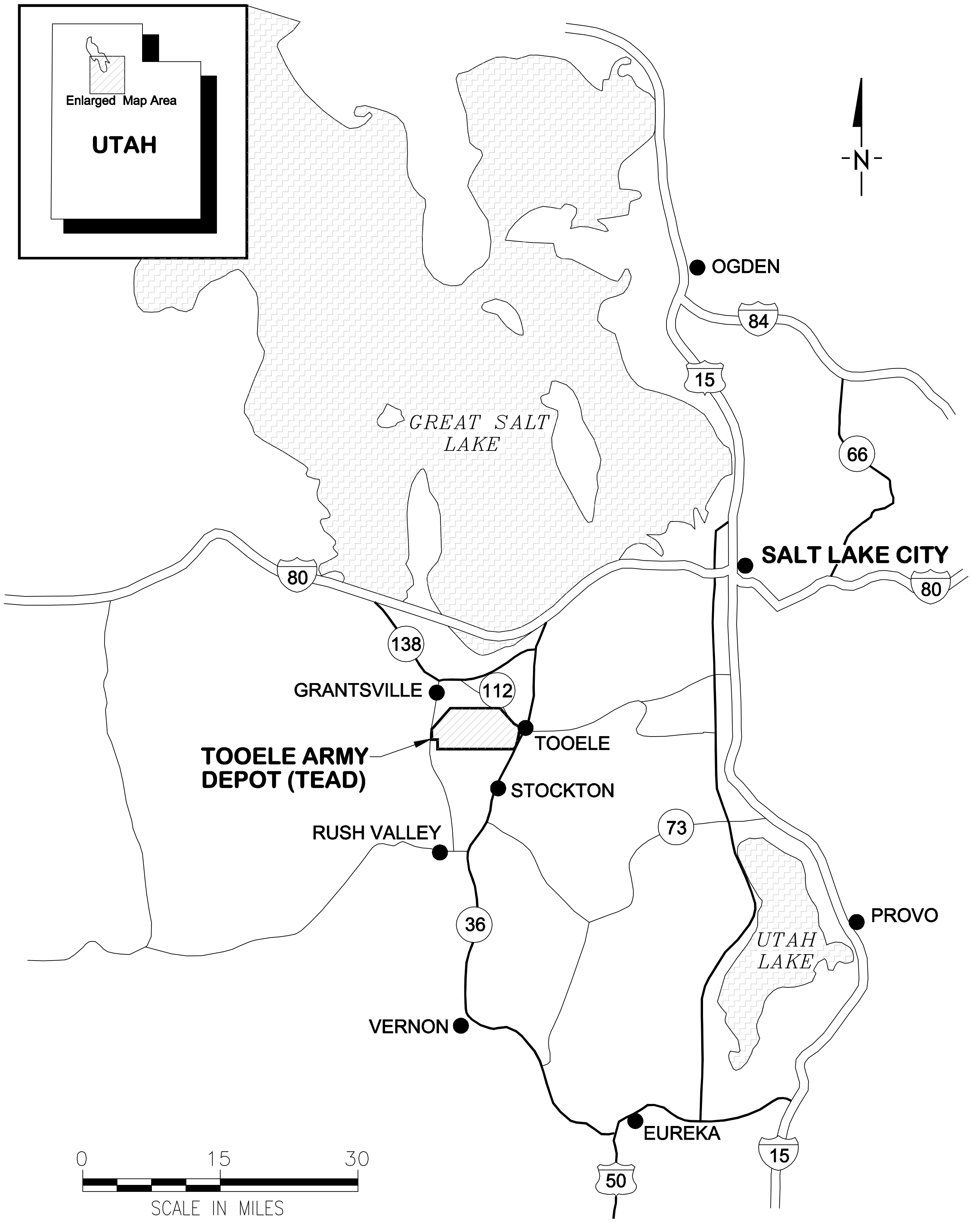

H012002A.DWG

Figure 5-1. Site location map, Tooele.

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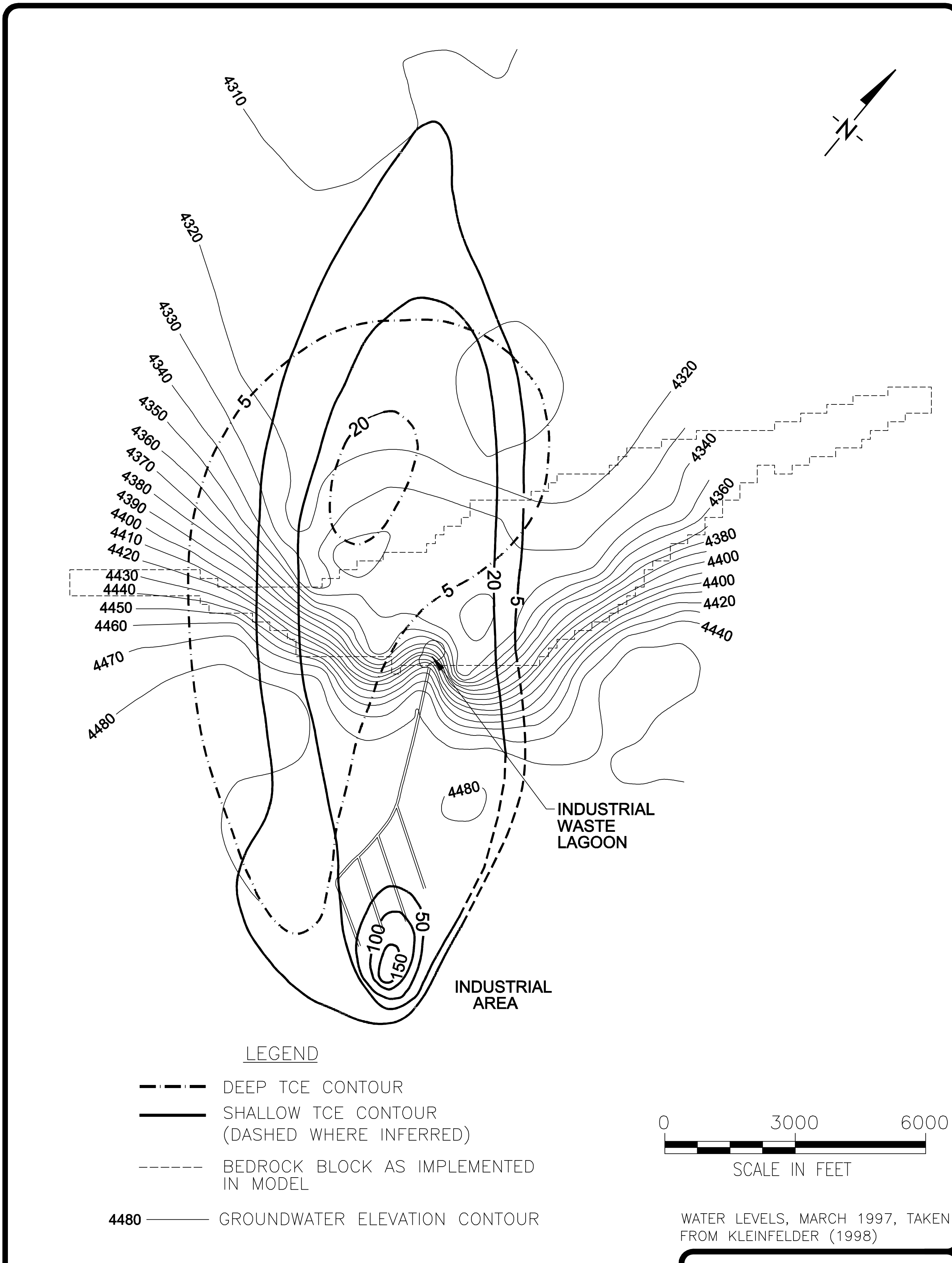

H012003A.DWG

Figure 5-2. Groundwater elevation contours, Tooele.

HSI GEOTRANS
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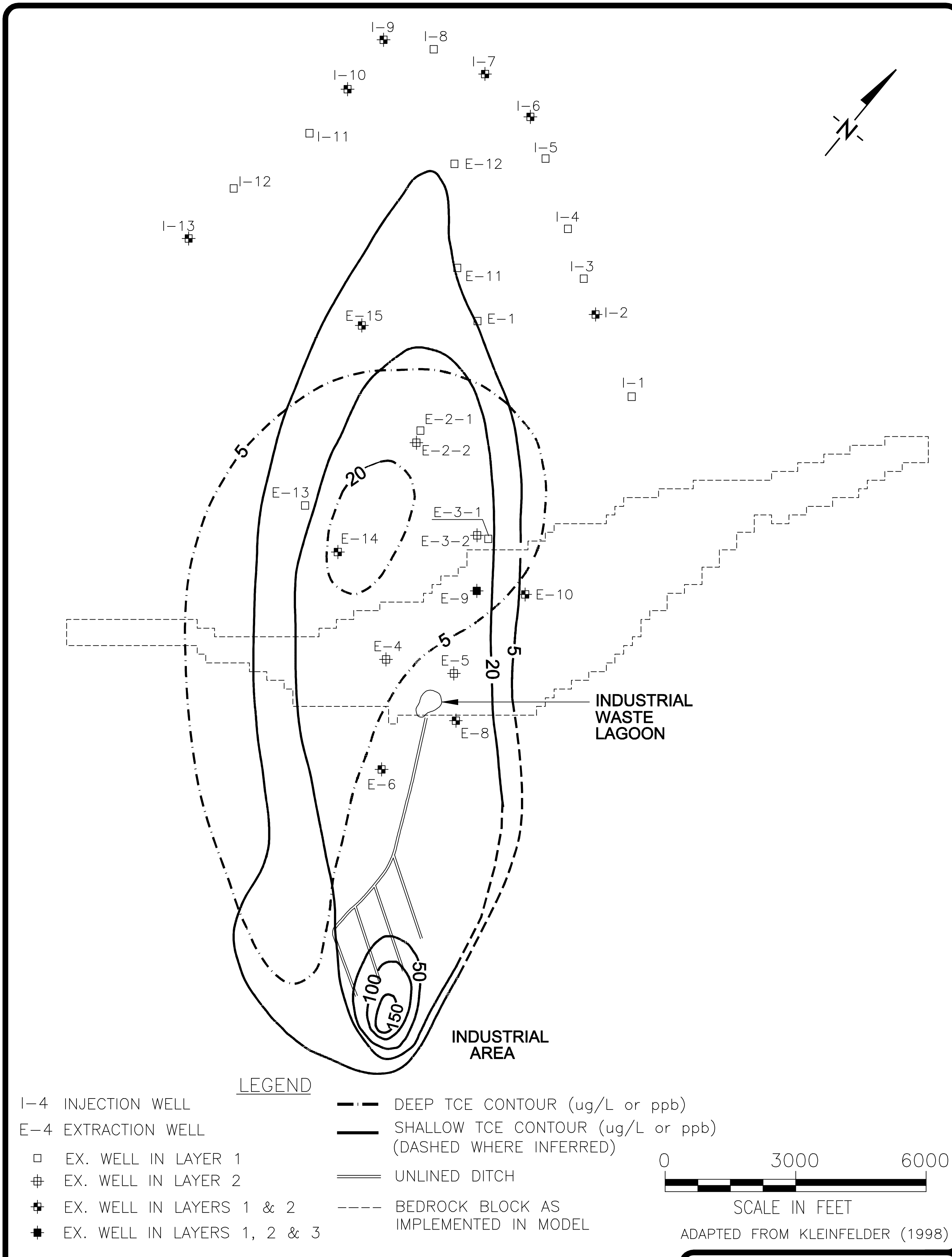

H012004A.DWG

Figure 5-3. TCE concentrations and current remediation wells, Tooele.

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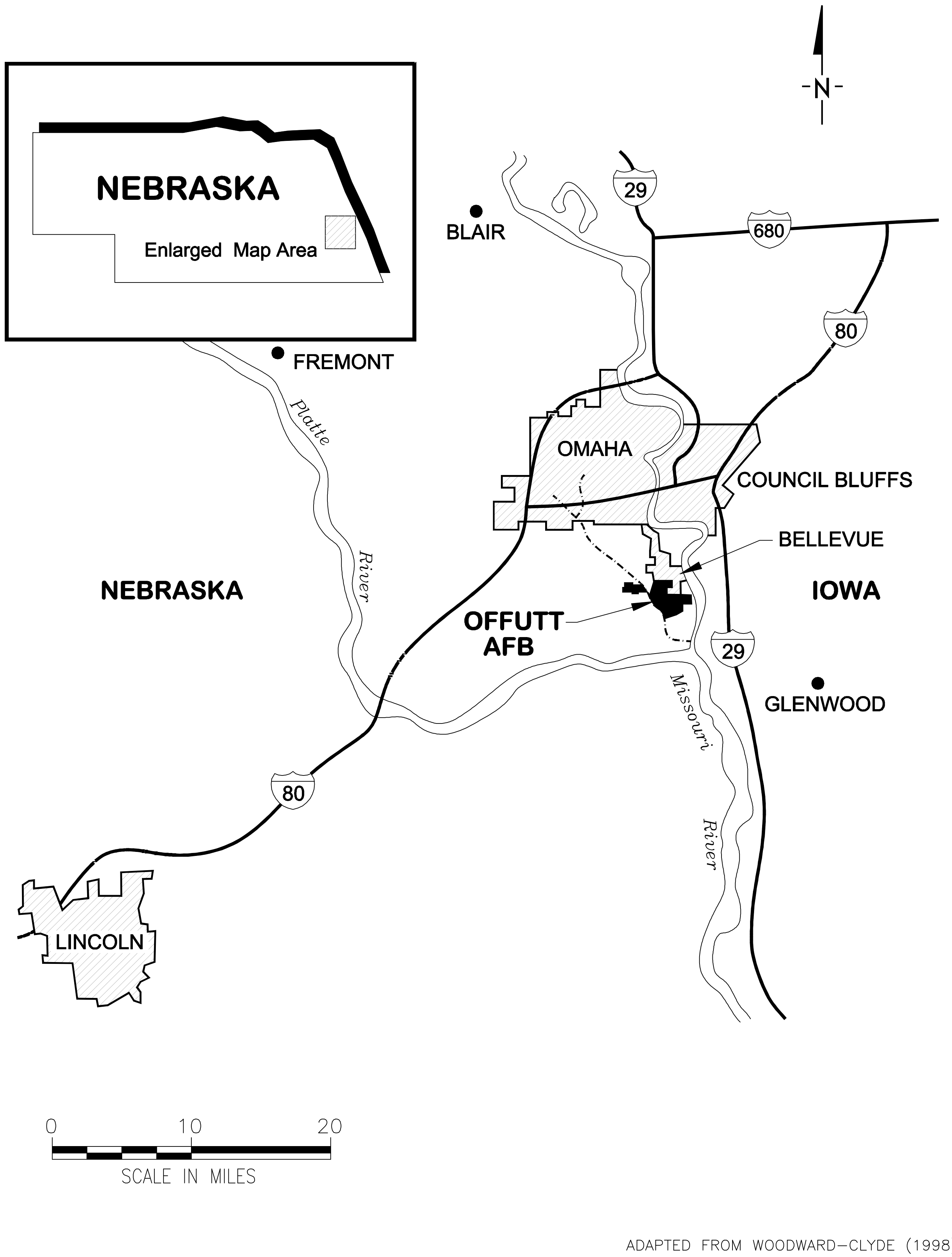

H012013A.DWG

Figure 6-1. Site location map, Offutt.

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H012014A.DWG

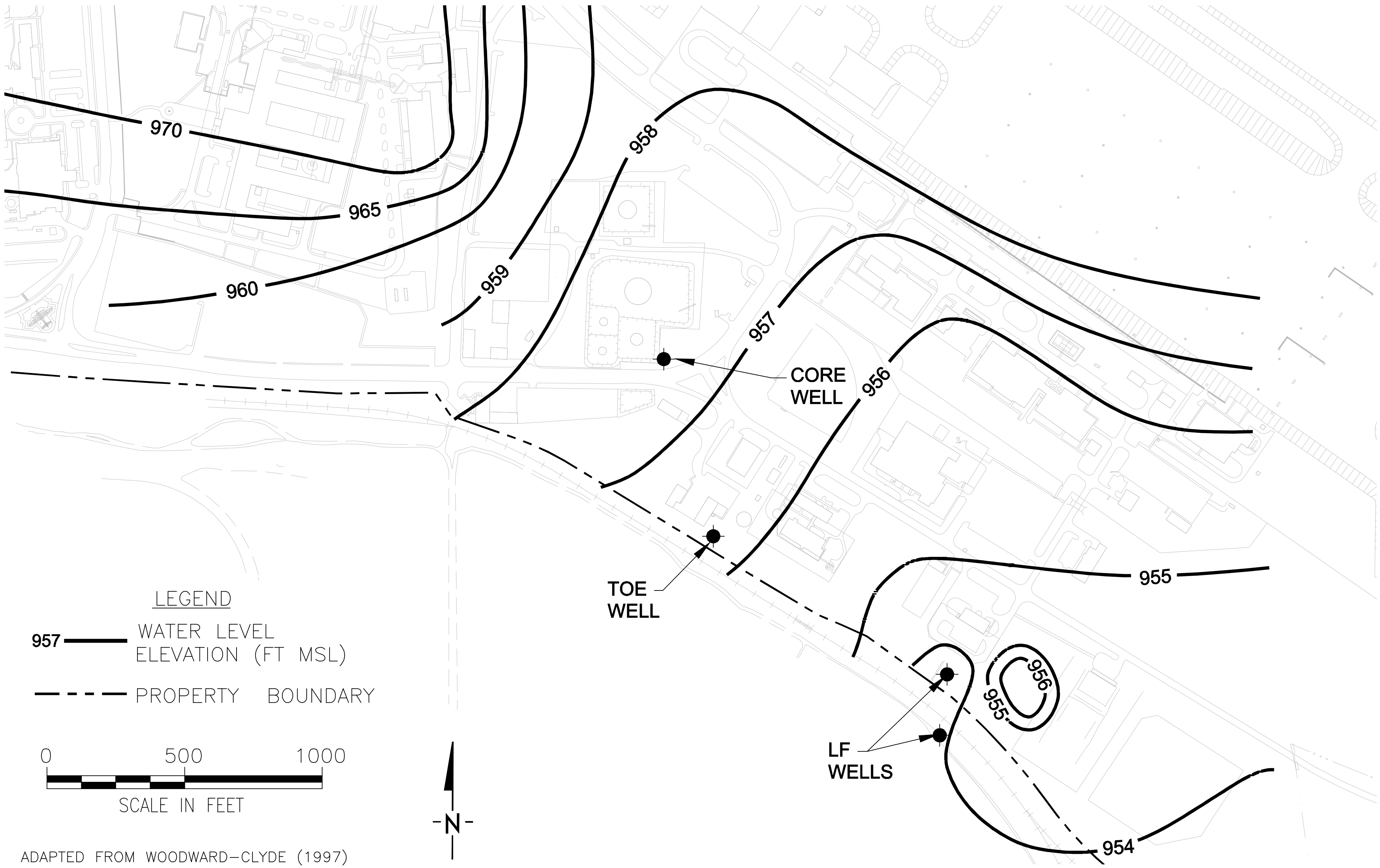

Figure 6-2. Groundwater elevation contours, Offutt.

HSI GEOTRANS
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H012015A.DWG

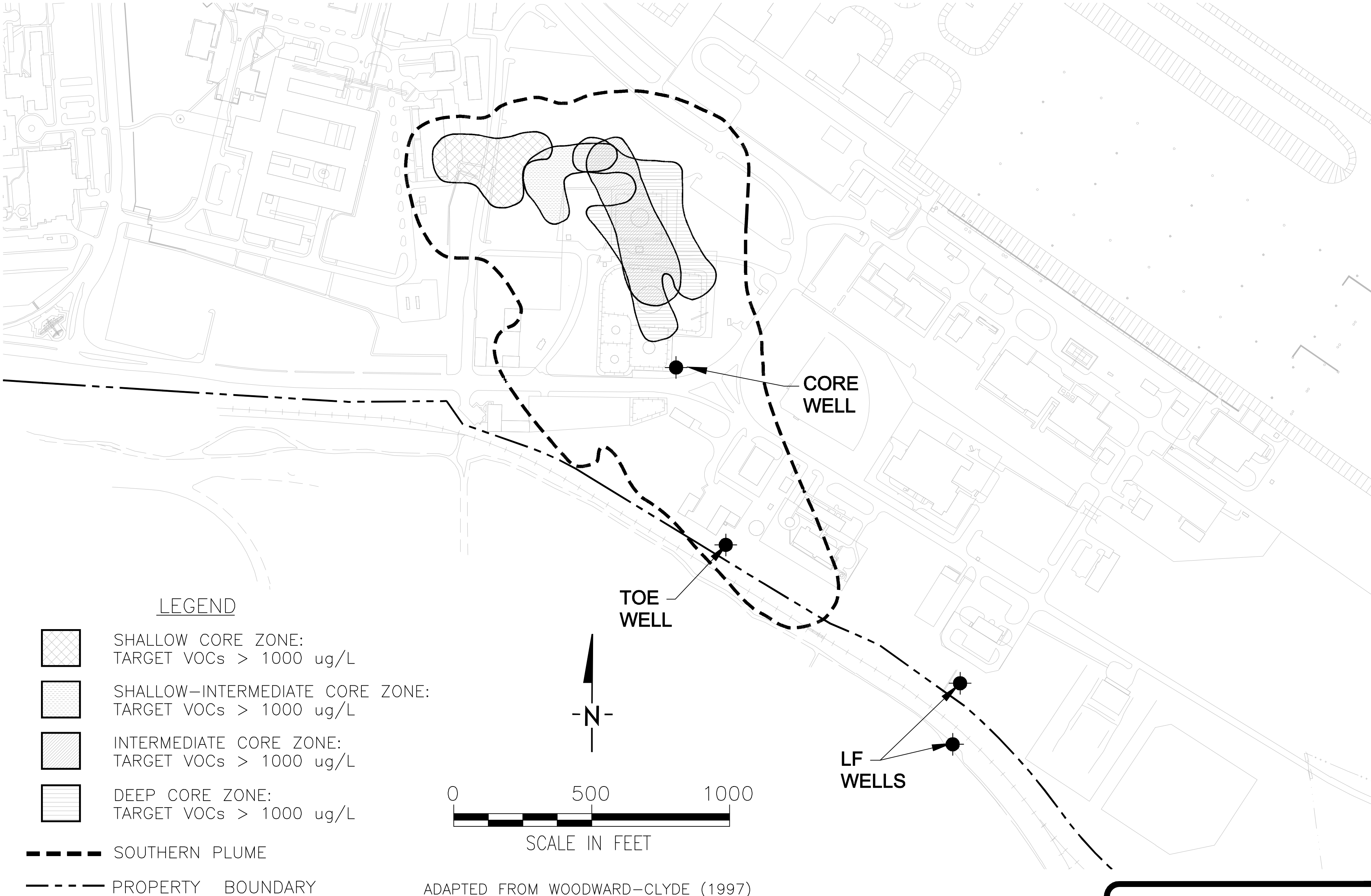

Figure 6–3. Southern plume and current remediation wells, Offutt.

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TABLES

Table 2-1. Format of the screening spreadsheet.

Screening Analysis

Site: **Acme**
Scenario: **Sample**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$160,000	20	$2,093,651	$2,093,651
-Materials (pH adjustment)	$0	$67,000	20	$876,716	$876,716
-Maintenance	$0	$50,000	20	$654,266	$654,266
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$250,000	20	$3,271,330	$3,271,330
-Analytical	$0	$0	20	$0	$0
-Steam	$0	$800,000	20	$10,468,257	$10,468,257
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$25,000	$0		$0	$25,000
-Transport Modeling	$0	$0		$0	$0
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$40,000	$0		$0	$40,000
-Regulatory Process	$25,000	$0		$0	$25,000
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$105,000**	**$1,327,000**		**$17,364,221**	**$17,469,221**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
None

Table 4-1. Current system, Kentucky.

Screening Analysis

Site: **Kentucky**
Scenario: **Current System**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$200,000	20	$2,617,064	$2,617,064
-Materials (pH adjustment)	$0	$100,000	20	$1,308,532	$1,308,532
-Maintenance	$0	$50,000	20	$654,266	$654,266
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$250,000	20	$3,271,330	$3,271,330
-Analytical	$0	$0	20	$0	$0
-Steam	$0	$1,200,000	20	$15,702,385	$15,702,385
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$0	$0		$0	$0
-Optimization	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$0	$0		$0	$0
-Regulatory Process	$0	$0		$0	$0
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$0**	**$1,800,000**		**$23,553,578**	**$23,553,578**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Analytical costs not included.

Table 4-2. Scenario 1, Kentucky: cut pumping by 33 percent, no new wells.

Screening Analysis

Site: **Kentucky**
Scenario: **1) Cut rate by 33%, no new wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$160,000	20	$2,093,651	$2,093,651
-Materials (pH adjustment)	$0	$67,000	20	$876,716	$876,716
-Maintenance	$0	$50,000	20	$654,266	$654,266
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$250,000	20	$3,271,330	$3,271,330
-Analytical	$0	$0	20	$0	$0
-Steam	$0	$800,000	20	$10,468,257	$10,468,257
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$25,000	$0		$0	$25,000
-Transport Modeling	$0	$0		$0	$0
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$40,000	$0		$0	$40,000
-Regulatory Process	$25,000	$0		$0	$25,000
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$105,000**	**$1,327,000**		**$17,364,221**	**$17,469,221**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume pumping rate cut by approximately 33%
Assume steam cut 33%, materials cut by 33%
Assume electric cut 20%
Assume no new wells

Table 4-3. Scenario 2, Kentucky: cut pumping by 33 percent, five new wells.

Screening Analysis

Site: **Kentucky**
Scenario: **2) Cut rate by 33%, 5 new wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$160,000	20	$2,093,651	$2,093,651
-Materials (pH adjustment)	$0	$67,000	20	$876,716	$876,716
-Maintenance	$0	$50,000	20	$654,266	$654,266
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$250,000	20	$3,271,330	$3,271,330
-Analytical	$0	$0	20	$0	$0
-Steam	$0	$800,000	20	$10,468,257	$10,468,257
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$25,000	$0		$0	$25,000
-Transport Modeling	$0	$0		$0	$0
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$40,000	$0		$0	$40,000
-Regulatory Process	$25,000	$0		$0	$25,000
-New wells/pipes/equipment	$100,000	$0		$0	$100,000
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$205,000**	**$1,327,000**		**$17,364,221**	**$17,569,221**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume pumping rate cut by approximately 33%
Assume steam cut 33%, materials cut by 33%
Assume electric cut 20%
Assume 5 new wells @ $20K/well

Table 5-1. Current system, Tooele.

Screening Analysis

Site: **Tooele**
Scenario: **Current System**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$1,000,000	20	$13,085,321	$13,085,321
-Materials (Sodium Metaphosphate)	$0	$200,000	20	$2,617,064	$2,617,064
-Maintenance	$0	$30,000	20	$392,560	$392,560
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$500,000	20	$6,542,660	$6,542,660
-Analytical	$0	$80,000	20	$1,046,826	$1,046,826
-Other 1	$0	$0	20	$0	$0
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$0	$0		$0	$0
-Optimization	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$0	$0		$0	$0
-Regulatory Process	$0	$0		$0	$0
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$0**	**$1,810,000**		**$23,684,431**	**$23,684,431**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
None

Table 5-2. Scenario 1, Tooele: cut pumping by 33 percent, no new wells.

Screening Analysis

Site: **Tooele**
Scenario: **1) Cut rate by 33%, no new wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$800,000	20	$10,468,257	$10,468,257
-Materials (Sodium Metaphosphate)	$0	$133,333	20	$1,744,705	$1,744,705
-Maintenance	$0	$30,000	20	$392,560	$392,560
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$500,000	20	$6,542,660	$6,542,660
-Analytical	$0	$80,000	20	$1,046,826	$1,046,826
-Other 1	$0	$0	20	$0	$0
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$10,000	$0		$0	$10,000
-Transport Modeling	$30,000	$0		$0	$30,000
-Optimization	$25,000	$0		$0	$25,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$40,000	$0		$0	$40,000
-Regulatory Process	$40,000	$0		$0	$40,000
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$145,000**	**$1,543,333**		**$20,195,007**	**$20,340,007**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume pumping rate cut from 7500 gpm to 5000 gpm (33%)
Assume electric cut 20%
Assume materials cut 33%

Table 5-3. Scenario 2, Tooele: cut pumping by 33 percent, five new wells.

Screening Analysis

Site: **Tooele**
Scenario: **2) Cut rate by 33%, 5 new wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$800,000	20	$10,468,257	$10,468,257
-Materials (Sodium Metaphosphate)	$0	$133,333	20	$1,744,705	$1,744,705
-Maintenance	$0	$30,000	20	$392,560	$392,560
-Discharge Fees	$0	$0	20	$0	$0
-Annual O&M	$0	$500,000	20	$6,542,660	$6,542,660
-Analytical	$0	$80,000	20	$1,046,826	$1,046,826
-Other 1	$0	$0	20	$0	$0
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$10,000	$0		$0	$10,000
-Transport Modeling	$30,000	$0		$0	$30,000
-Optimization	$25,000	$0		$0	$25,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Engineering Design	$40,000	$0		$0	$40,000
-Regulatory Process	$40,000	$0		$0	$40,000
-New wells/pipes/equipment	$1,500,000	$0		$0	$1,500,000
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$1,645,000**	**$1,543,333**		**$20,195,007**	**$21,840,007**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume pumping rate cut from 7500 gpm to 5000 gpm (33%)
Assume electric cut 20%
Assume materials cut 33%
Assume 5 new wells at $300K/well

Table 6-1. Current system, Offutt: one new core well, 100 gpm at LF wells.

Screening Analysis

Site: **Offutt**
Scenario: **Current System (Add 1 new core zone well, pump 200 gpm from 4 wells)**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (Labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (Core & LF 150 gpm, 20 yrs)	$0	$60,000	20	$785,119	$785,119
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 50 gpm, 10 yrs)	$0	$20,000	10	$162,156	$162,156
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$0	$0		$0	$0
-Optimization	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$0	$0		$0	$0
-New wells/pipes/equipment	$40,000	$0		$0	$40,000
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$87,000**	**$122,000**		**$1,496,859**	**$1,583,859**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV).
The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

Assumptions
Toe well can be shut off in 10 yrs

Table 6-2. Scenario 1, Offutt: reduce toe well pumping by 33 percent, no additional toe wells.

Screening Analysis

Site: **Offutt**
Scenario: **1) Reduce pumping at toe by 33%, no additional toe wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (Core & LF 150 gpm, 20 yrs)	$0	$60,000	20	$785,119	$785,119
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 33 gpm, 10 yrs)	$0	$13,333	10	$108,102	$108,102
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$15,000	$0		$0	$15,000
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$20,000	$0		$0	$20,000
-New wells/pipes/equipment	$40,000	$0		$0	$40,000
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$137,000**	**$115,333**		**$1,442,804**	**$1,579,804**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV).
The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume LF pumping (100 gpm) and core pumping (50 gpm) is fixed
Assume toe pumping (50 gpm) can be cut by 33%

Table 6-3. Scenario 2, Offutt: reduce toe well pumping by 33 percent, two additional toe wells.

Screening Analysis

Site: **Offutt**
Scenario: **2) Reduce pumping at toe by 33%, 2 new toe wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (Core & LF 150 gpm, 20 yrs)	$0	$60,000	20	$785,119	$785,119
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 33 gpm, 10 yrs)	$0	$13,333	10	$108,102	$108,102
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$15,000	$0		$0	$15,000
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$20,000	$0		$0	$20,000
-New wells/pipes/equipment	$40,000	$0		$0	$40,000
-Increased Monitoring	$0	$0		$0	$0
-Two New Wells Near Toe	$80,000	$0		$0	$80,000
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$217,000**	**$115,333**		**$1,442,804**	**$1,659,804**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV). The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume LF pumping (100 gpm) and core pumping (50 gpm) is fixed
Assume toe pumping (50 gpm) can be cut by 33%

Table 6-4. Scenario 3, Offutt: do not install new core well.

Screening Analysis

Site: **Offutt**
Scenario: **3) Don't install core well, increase toe well pumping**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (LF 100 gpm, 20 yrs)	$0	$40,000	20	$523,413	$523,413
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 75 gpm, 20 yrs)	$0	$30,000	20	$392,560	$392,560
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$15,000	$0		$0	$15,000
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$20,000	$0		$0	$20,000
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$97,000**	**$112,000**		**$1,465,556**	**$1,562,556**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV).
The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Assume LF pumping (100 gpm) and no core pumping
Assume toe pumping of 75 gpm for containment, required for 20 yrs

Table 6-5. Scenario 4, Offutt: do not install new core well, two additional toe wells.

Screening Analysis

Site: **Offutt**
Scenario: **4) Don't install core well, increase toe well pumping, 2 new Toe wells**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (LF 100 gpm, 20 yrs)	$0	$40,000	20	$523,413	$523,413
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 75 gpm, 20 yrs)	$0	$30,000	20	$392,560	$392,560
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$15,000	$0		$0	$15,000
-Optimization	$15,000	$0		$0	$15,000
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$20,000	$0		$0	$20,000
-New wells/pipes/equipment	$0	$0		$0	$0
-Increased Monitoring	$0	$0		$0	$0
-Two New Wells Near Toe	$80,000	$0		$0	$80,000
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$177,000**	**$112,000**		**$1,465,556**	**$1,642,556**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV).
The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

Assumptions
Assume LF pumping (100 gpm) and no core pumping
Assume toe pumping of 75 gpm for containment, required for 20 yrs

Table 6-6. Scenario 5, Offutt: pumping at LF wells reduced fifty percent.

Screening Analysis

Site: **Offutt**
Scenario: **5) Cut pumping at LF wells in half**

Discount Rate: 0.05

	Up-Front Costs	Annual Costs	# Years	Total of Annual Costs	Total Costs
O&M Costs					
-Electric	$0	$2,000	20	$26,171	$26,171
-Materials	$0	$0	20	$0	$0
-Maintenance (Labor)	$0	$12,000	20	$157,024	$157,024
-Discharge (Core & LF 100 gpm, 20 yrs)	$0	$40,000	20	$523,413	$523,413
-Annual O&M	$0	$3,000	20	$39,256	$39,256
-Analytical	$0	$25,000	20	$327,133	$327,133
-Discharge (Toe Well, 50 gpm, 10 yrs)	$0	$20,000	10	$162,156	$162,156
-Other 2	$0	$0	20	$0	$0
-Other 3	$0	$0	20	$0	$0
Costs of Analysis					
-Flow Modeling	$0	$0		$0	$0
-Transport Modeling	$15,000	$0		$0	$15,000
-Optimization	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
System Modification Costs					
-Fixed Construction/All Scenarios	$47,000	$0		$0	$47,000
-Regulatory Process	$20,000	$0		$0	$20,000
-New wells/pipes/equipment	$40,000	$0		$0	$40,000
-Increased Monitoring	$0	$0		$0	$0
-Other 1	$0	$0		$0	$0
-Other 2	$0	$0		$0	$0
-Other 3	$0	$0		$0	$0
Total Costs	**$122,000**	**$102,000**		**$1,235,153**	**$1,357,153**

Note: All costs are in present-day dollars. The discount rate is applied to annual costs to calculate the Net Present Value (NPV).
The PV function in Microsoft Excel was utilized to calculate NPV, with payments applied at the beginning of each year.

<u>Assumptions</u>
Reduce LF wells from 100 to 50 gpm

APPENDIX A:

SAMPLE CALCULATIONS USING DIFFERENT VALUES FOR DISCOUNT RATE

The discount rate accounts for the fact that future money is generally worth less than present-day money. The basis of the discount rate is that money, if not spent today, can typically be invested at a rate that exceeds inflation.

If the discount rate is 0 percent, spending $1M today has the same cost as spending $100K/yr (indexed to present-day dollars) for 10 yrs. However, if the discount rate is greater than 0 percent, spending $1M today is more costly than spending $100K/yr (indexed to present-day dollars) for 10 yrs. The reason is that the funds not spent each year are assumed to be invested at a rate exceeding inflation (by an amount equal to the discount rate).

In the case studies presented in the main report, a discount rate of 5 percent was utilized. Discount rate is a parameter that must be estimated for future years, and therefore is subject to uncertainty. In some cases a discount rate of 0 percent may be appropriate (e.g., money not spent today is not open for investment at rates exceeding inflation).

To illustrate the impact of the discount rate on cost calculations, the screening results for the Tooele Case Study (Section 5 of the Report) are compared to results generated with different values for discount rate (Table A-1). The comparison illustrates that the total dollar estimate for each scenario is higher when the discount rate is lower, because future dollars are not discounted as much. For the same reason, net savings indicated for Scenario 1 and Scenario 2 (relative to the baseline scenario) are greater when the discount rate is lower (again, savings each year are not discounted as much when discount rate is lower).

(See Table A-1 on Next Page)

Table A-1. Tooele screening calculations for different values of discount rate.

Discount Rate = 0.0%

	Up-Front Costs ($)	Annual Costs ($/yr)	Sum of Annual Costs, 20 yrs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$1,810,000	$36,200,000	$36,200,000
Scenario #1	$145,000	$1,543,333	$30,866,660	$31,011,660
Scenario #2	$1,645,000	$1,543,333	$30,866,660	$32,511,660

Discount Rate = 2.5%

	Up-Front Costs ($)	Annual Costs ($/yr)	Sum of Annual Costs, 20 yrs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$1,810,000	$28,921,793	$28,921,793
Scenario #1	$145,000	$1,543,333	$24,660,750	$24,805,750
Scenario #2	$1,645,000	$1,543,333	$24,660,750	$26,305,750

Discount Rate = 5.0%

	Up-Front Costs ($)	Annual Costs ($/yr)	Sum of Annual Costs, 20 yrs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$1,810,000	$23,684,431	$23,684,431
Scenario #1	$145,000	$1,543,333	$20,195,007	$20,340,007
Scenario #2	$1,645,000	$1,543,333	$20,195,007	$21,840,007

Discount Rate = 7.5%

	Up-Front Costs ($)	Annual Costs ($/yr)	Sum of Annual Costs, 20 yrs ($ NPV)	Total Cost ($ NPV)
Baseline Scenario	$0	$1,810,000	$19,835,932	$19,835,932
Scenario #1	$145,000	$1,543,333	$16,913,507	$17,058,507
Scenario #2	$1,645,000	$1,543,333	$16,913,507	$18,558.507