REMEDIATION SYSTEM EVALUATION

SILRESIM SUPERFUND SITE
LOWELL, MASSACHUSETTS

Report of the Remediation System Evaluation,
Site Visit Conducted at the Silresim Superfund Site
August 15-16, 2001

Final Report Submitted to Region 1
December 20, 2001

NOTICE

Work described herein was performed by GeoTrans, Inc. (GeoTrans) and the United States Army Corps of Engineers (USACE) for the U.S. Environmental Protection Agency (U.S. EPA). Work conducted by GeoTrans, including preparation of this report, was performed under Dynamac Contract No. 68-C-99-256, Subcontract No. 91517. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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EXECUTIVE SUMMARY

The Silresim Superfund Site is located in an industrial area of Lowell, Massachusetts. This Superfund site addresses contamination associated with a chemical waste reclamation facility that was operated by Silresim Chemical Corporation between 1971 and 1977. USEPA issued a ROD in 1991.

Groundwater contains very high levels of many Volatile Organic Compounds (VOCs), exceeding 500 ppm at multiple locations, in both the shallow and deeper part of the aquifer, extending in all directions from the Silresim property. These high concentrations in groundwater indicate the presence of non-aqueous phase liquids (NAPL's) in the subsurface. The primary focus from a plume management perspective is the VOC's. Groundwater is treated by a pump-and-treat system consisting of groundwater extraction, above-ground treatment, and discharge to the City of Lowell Regional Wastewater Utility. The groundwater treatment plant began operations in 1995. Substantial modifications to the groundwater extraction operations, including the addition of new wells, occurred in early 2001. Soil Vapor Extraction (SVE) for source area remediation has been pilot tested, but results led to a decision not to pursue a full-scale implementation. Possible use of thermally enhanced SVE, such as Six Phase Heating, is being considered.

The RSE team found the site operators and managers to be interested in improving the performance of the system, and found that many actions have previously been taken in pursuit of cost savings and/or technical improvement. Some (but not all) of these previous improvements are summarized below:

- eliminated liquid phase carbon step by increasing the operating temperature of the air stripper to enhance removal of methylene chloride, which also resulted in more aerobic effluent (which eliminated an odor problem);
- reduced the operating temperature of the thermal oxidizer from 1600 degrees F to 1500 degrees F, resulting in a savings in natural gas usage without compromising effectiveness;
- installed an automated blending system for polymer in the Metals Removal System, eliminating the need for weekend staff;
- improved the autodialer system to allow for faster problem recognition and resolution;
- reduced groundwater analytical monitoring frequency and process analytical monitoring frequency;
- instituted a semi-annual preventative maintenance program to increase operating efficiency; and
- performed bench-scale testing of polymers to provide better sludge settling rates, resulting in less solids loading to the filters and less frequenting backwashing of the filters.

The RSE team also commends Site Managers for their realistic evaluation of the inability of the current system to meet ROD objectives, and for implementing changes to the extraction strategy in 2001 (based on recently-performed groundwater modeling) in an attempt to limit downward migration of contaminants due to pumping at deep wells and to improve the extent of groundwater capture.

A primary recommendation by the RSE team is that site managers continue to seek improvements to the system and the remedy, as has been done in the past. Several additional recommendations are intended to enhance system effectiveness:

- A “target capture zone” for each layer in the groundwater flow model should be established, based on plume extent and site management objectives. Estimated cost for this activity is $5,000.

- Enhanced particle tracking techniques are suggested that will allow more accurate and three-dimensional capture zones predicted by the model to be superimposed on the “target capture zone” for each model layer. Estimated cost for this activity is $10,000.

- To increase confidence in model-predicted capture zones, the predictive accuracy of the model should be evaluated by comparing model predicted values of drawdown to those observed in the field. Estimated cost for this activity is $25,000.

- Periodic monitoring of sediments in East Pond and River Meadow Brook for the most mobile constituents associated with the site (i.e., VOC’s) is recommended, perhaps once every two years. This might cost $10,000 per year.

- Site managers should verify that no other basements (other than Lowell Iron and Steel) are of concern within the footprint of plume, and verify that use of the basements on Lowell Iron and Steel has not increased, and if it has, that proper precautions (i.e., ventilation) are being implemented. This should be performed within existing budget.

The RSE team agrees with several existing recommendations to reduce costs (reduced site security, cost/benefit analysis for additional drying of sludge), some of which have already been implemented. Finally, given the high cost of this system ($1.4 million per year), and the likelihood that it will operate indefinitely even if ROD objectives are modified, the RSE team recommends that site managers invest in an evaluation of potential remedial alternatives on a regular basis (at least every 3-5 years) as new remedial technologies are developed and/or improved. This type of analysis is currently being performed, and therefore can be performed in the future within the current budget.

A summary of recommendations, including estimated costs and/or savings associated with those recommendations, is presented in Section 7.0 of the report.

PREFACE

This report was prepared as part of a project conducted by the United States Environmental Protection Agency (USEPA) Technology Innovation Office (TIO) and Office of Emergency and Remedial Response (OERR). The objective of this project is to conduct Remediation System Evaluations (RSEs) of pump-and-treat systems at Superfund sites that are "Fund-lead" (i.e., financed by USEPA). RSEs are to be conducted for up to two systems in each EPA Region with the exception of Regions 4 and 5, which already had similar evaluations in a pilot project.

The following organizations are implementing this project.

Organization	Key Contact	Contact Information
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The project team is grateful for the help provided by the following EPA Project Liaisons.

Region 1	Darryl Luce and Larry Brill	**Region 6**	Vincent Malott
Region 2	Diana Cutt	**Region 7**	Mary Peterson
Region 3	Kathy Davies	**Region 8**	Armando Saenz and Richard Muza
Region 4	Kay Wischkaemper	**Region 9**	Herb Levine
Region 5	Dion Novak	**Region 10**	Bernie Zavala

They were vital in selecting the Fund-lead pump-and-treat systems to be evaluated and facilitating communication between the project team and the Remedial Project Managers (RPM's).

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 PURPOSE

In the *OSWER Directive No. 9200.0-33, Transmittal of Final FY00 - FY01 Superfund Reforms Strategy, dated July 7,2000*, the Office of Solid Waste and Emergency Response outlined a commitment to optimize Fund-lead pump-and-treat systems. To fulfill this commitment, the US Environmental Protection Agency (USEPA) Technology Innovation Office (TIO) and Office of Emergency and Remedial Response (OERR), through a nationwide project, is assisting the ten EPA Regions in evaluating their Fund-lead operating pump-and-treat systems. This nationwide project is a continuation of a demonstration project in which the Fund-lead pump-and-treat systems in Regions 4 and 5 were screened and two sites from each of the two Regions were evaluated. It is also part of a larger effort by TIO to provide USEPA Regions with various means for optimization, including screening tools for identifying sites likely to benefit from optimization and computer modeling optimization tools for pump and treat systems.

This nationwide project identifies all Fund-lead pump-and-treat systems in EPA Regions 1 through 3 and 6 through 10, collects and reports baseline cost and performance data, and evaluates up to two sites per Region. The site evaluations are conducted by EPA-TIO contractors, GeoTrans, Inc. and the United States Army Corps of Engineers (USACE), using a process called a Remediation System Evaluation (RSE), which was developed by USACE. The RSE process is meant to evaluate performance and effectiveness (as required under the NCP, i.e., and “five-year" review), identify cost savings through changes in operation and technology, assure clear and realistic remediation goals and exit strategy, and verify adequate maintenance of Government-owned equipment.

The Silresim Site was chosen based on initial screening of the pump-and-treat systems managed by USEPA Region 1 and discussions with the Project Liaison for that Region. This report provides a brief background on the site and current operations, a summary of the observations made during a site visit, and recommendations for changes and additional studies. The cost impacts of the recommendations are also discussed.

A report on the overall results from the RSEs conducted at Silresim and other Fund-lead pump-and-treat systems throughout the nation will also be prepared and will identify lessons learned and typical costs savings.

1.2 TEAM COMPOSITION

The team conducting the RSE consisted of the following individuals:

Bill Crawford, Chemical Engineer, USACE HTRW CX
Rob Greenwald, Hydrogeologist, GeoTrans, Inc. (EPA TIO’s contractor)
Lindsey Lien, Environmental Engineer, USACE HTRW CX
Doug Sutton, Water Resources Engineer, GeoTrans, Inc.

1.3 DOCUMENTS REVIEWED

Author	Date	Title/Description
USEPA	9/19/1991	Record of Decision
USACE	11/18/1998	Operational and Functional Completion Report for Management of Migration Remedy Operable Unit
Foster Wheeler	7/1999	ROD Remedy Review
USEPA	9/1999	Five Year Review
Foster Wheeler	5/23/00	GW Monitoring and GW Treatment System O&M Status Report, November 6, 1999 - February 5, 2000
Foster Wheeler	8/2000	Final Activity Plan for Additional Site Investigations and Revision of the Site Cleanup Goals
Foster Wheeler	9/2000	Final Management of Migration and Source Removal Strategy Work Plan
Foster Wheeler	9/8/01	GW Monitoring and GW Treatment System O&M Status Report, February 6, 2000 - August 5, 2000
Foster Wheeler	3/22/01	GW Monitoring and GW Treatment System O&M Status Report, August 6, 2000 - February 5, 2001
Foster Wheeler	6/27/2001	Groundwater Modeling Report
ACOE	8/13/2001	GWTP Cost Summary (handed out during RSE visit)
Foster Wheeler	8/14/2001	Silresim Operation Efficiency Improvements and Cost Reduction Measures

1.4 PERSONS CONTACTED

The following individuals were present for the site visit:

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1.5 SITE LOCATION, HISTORY, AND CHARACTERISTICS

1.5.1 LOCATION

The Silresim Superfund Site is located at 86 Tanner Street in an industrial area of Lowell, Massachusetts, approximately one mile south of the central business district. The original facility consisted of approximately 4.5 acres (Silresim property). However, the Superfund Site is geographically defined by the extent of contamination, which extends beyond the Silresim property and includes approximately 16 acres of groundwater and seven acres of soil. The Site vicinity is illustrated of Figure 1-1. The former Silresim property is bordered by Lowell Iron and Steel Company to the north, the B&M railroad yard and tracks to the east/northeast, an automobile salvage yard to the south, and Tanner Street to the west. Residential areas are located to the south, east, and northeast, and the closest residences are approximately 300-500 ft from the Silresim property boundary. River Meadow Brook is located approximately 400 ft west of the Silresim property boundary. East Pond is located several hundred feet southeast of the Silresim property boundary.

1.5.2 POTENTIAL SOURCES AND PREVIOUS ACTIONS

This Superfund site addresses contamination associated with a chemical waste reclamation facility that was operated by Silresim Chemical Corporation between 1971 and 1977. Wastes were accepted at the facility in drums, tank trucks, railroad cars, and other containers. These substances included halogenated solvents, oily wastes, alcohols, plating wastes, metal sludges and pesticide wastes. The Record of Decision (ROD) estimates that the facility handled approximately three million gallons of waste per year. The Silresim Chemical Corporation filed for bankruptcy in 1977 and abandoned the property in January 1978. At that time there were approximately 30,000 decaying drums on the property, covering virtually every open area of the property (see Figure 1-2). Investigations revealed that the property had been poorly maintained and revealed evidence of numerous spills, leakage of drums, discharges to city sewers, and runoff to adjacent properties.

From 1978 to 1982 the State secured the property and minimized immediate threats to public health and the environment by constructing a fence, hiring 24-hour security, removing drums and tanks, and constructing berms and absorbent-filled trenches. In 1983-1984 EPA removed all structures remaining on the property, extended the fence, and placed a clay cap over the property. Crushed stone was placed over areas of surficial soil contamination adjacent to the cap's northern and southern borders and at the northeast corner of the site. In 1986 EPA expanded the fence to enclose an area of surficial soil contamination at the southeast corner of the site, and place crushed stone around the perimeter of the expanded fence line. There have also been periods of SVE extraction (pilot test in 1995-96, and Phase 1 SVE in 1998-99) for the purpose of source removal. This site was placed on the NPL in 1982. EPA issued an Administrative Order by consent to the Silresim Site Trust in 1985. EPA issued a ROD in 1991.

1.5.3 HYDROGEOLOGIC SETTING

The Silresim property is underlain by glacial outwash deposits (20 to 100 ft thick) over bedrock (thin discontinuous layers of glacial till immediately overlay the bedrock). The glacial outwash deposits, which are silty sands and silts of lacrustine origin, average 80 ft in thickness but thin to the north because bedrock elevation increases to the north. Localized stratigraphy has been described according to the following five layers (one or more layers are absent at some locations), from top to bottom:

Layer	Approximate Thickness (ft)
Unconsolidated Overburden Layer (Unconfined Aquifer)	~ 8 to 12 ft
Upper Varved Clayey Silt Aquitard	~15 to 20 ft
Semi-Confined Silty Sand Aquifer	~ 25 ft
Lower Varved Clayey Silt Aquitard	~30 ft
Till/Weathered Bedrock Aquifer	~15 ft

Depth to groundwater is approximately 6-10 ft. In the Unconfined Aquifer, the major flow direction from the Silresim property is north and northwest towards major sewer lines located several hundred feet north and west of the property, with a component of flow to the south or southeast towards East Pond (see Figure 1-3). For the sewer line that is north of the property, water level maps from 1988 (pre-pumping) indicated flow from both the north and the south, indicating that the sewer is a potential point of groundwater discharge. In a report dated September 2000, Foster Wheeler estimated groundwater velocity in shallow groundwater at approximately 30 ft/yr.

For the deeper semi-confined aquifer, flow appears to be towards the north-northwest, and southerly flow is not apparent from the water levels. Foster Wheeler estimated groundwater velocity in the lower semi-confined aquifer at approximately 10 ft/yr.

Pre-pumping vertical gradients were significantly downward. These downward gradients may be augmented by standing water in detention areas after heavy rain or snowmelt, and also by ponded water that sometimes results near the boundary of the current cap.

1.5.4 DESCRIPTION OF GROUND WATER PLUME

Groundwater contains very high levels of many Volatile Organic Compounds (VOC's). Plume maps have generally been drawn for Total VOC's rather than individual compounds (see Figure 1-3 for the shallow zone and Figure 1-4 for the deeper zone). Total VOC's exceed 500 ppm at multiple locations in both the shallow and deeper part of the aquifer. Some individual VOC's with maximum groundwater concentrations exceeding 100 ppm are 111-TCA, 1,2-DCA, 1,2-DCE, acetone, cis-1,2-DCE, methylene chloride, and TCE. These high concentrations in groundwater indicate the presence of non-aqueous phase liquids (NAPL's) in the subsurface. NAPL's have in fact been identified in some wells (during the RSE visit, a jar of free-phase liquid collected from a previous SVE well location was passed around).

The total VOC plume in both the shallow and deeper part of the aquifer extend in all directions from the Silresim property, consistent with groundwater flow directions that are predominantly to the north/northwest as well as to the southeast in the shallow aquifer. The plume in each aquifer, as interpreted by Foster Wheeler, extends beyond the sewer lines to the north and west of the property. This could be due to flow under the sewer lines, or contaminant sources on the other side of the sewer line.

In addition to the VOC's, there are some exceedances of groundwater standards for several semivolatile compounds (SVOC's) and metals, and some detections of pesticides/PCB's. However, the primary focus from a plume management perspective is the VOC's.

2.0 SYSTEM DESCRIPTION

2.1 SYSTEM OVERVIEW

Groundwater is treated by a pump-and-treat system consisting of groundwater extraction, above-ground treatment, and discharge to the City of Lowell Regional Wastewater Utility. The groundwater treatment plant began operations in 1995. Substantial modifications to the groundwater extraction operations, including the addition of new wells, occurred in early 2001. Details are provided below.

2.2 EXTRACTION SYSTEM

The system originally consisted of 25 extraction wells, each separately piped to a groundwater treatment plant. The original 25 extraction wells were screened in different vertical zones as follows:

13 shallow aquifer
2 moderate overburden
9 deeper overburden
1 bedrock

Each well was designed to pump at approximately 1 gpm. Historically, average production from each shallow wells was approximately 0.3 gpm per well, while average production from moderate and deep wells was approximately 1.5 gpm per well.

According to the latest O&M Report (thru February 5, 2001) six new wells were placed into service on February 2, 2001, and the overall pumping strategy was revised in an attempt to limit the downward migration of contaminants by focusing extraction in the shallow aquifer. There are six new wells (numbers 26-31), and these wells were to operate with 10 of the original wells (numbers 2-8 and 11-13) for a total of 16 operating wells. During the RSE visit, it was stated that Well 17 is also now operating.

All of the wells currently operating are shallow wells, with the exception of old Well 17 and new Well 31. Well 31 is located north of the property and is screened from above the first aquitard down to bedrock. The purpose of Well 31 is to intercept deep and shallow groundwater contamination that is already beyond the operating shallow extraction wells. EW-17 is intended to augment the capture zone for deeper groundwater, and is also located beyond the extent of the shallow wells. The new shallow wells are screened somewhat deeper than the older shallow wells, to increase the potential for greater water production.

2.3 GROUNDWATER TREATMENT SYSTEM

The treatment plant was originally designed to handle 36,000 gallons per day (25 gallons per minute) of contaminated groundwater from the extraction wells. The original system consisted of the following:

- phase separation (currently by-passed)
- equalization tank

- metals removal
- multi-media filtration
- preheat of the air stripper liquid feed
- air stripping
- liquid granulated activated carbon polishing of the stripper effluent (recently eliminated)
- thermal oxidation of stripper off gases
- discharge of the treated aqueous stream to the City of Lowell POTW

The phase separator has never recovered product and has been by-passed, and the liquid phase carbon polishing step was eliminated by increasing the operating temperature of the air stripper.

With the modifications to groundwater extraction described in Section 2.2, the plant currently is operating at about 10 gpm. The plant has recently been upgraded to 35 gpm capacity, which required upgrading to 2-inch piping, although there is no plan to operate the plant in excess of current rates (approximately 10 gpm) at this time.

2.4 MONITORING SYSTEM

Originally groundwater monitoring was performed quarterly, but that has been reduced to twice per year, with one of the two events more comprehensive than the other. In the last comprehensive round (November 2000 to January 2001) 68 monitoring wells were sampled, in addition to most of the extraction wells associated with the P&T system. Most wells were sampled for only VOC's, but select wells were also sampled for SVOC's, PCB's, pesticides, and TAL metals.

Maximum flow rates at individual wells are measured weekly, to determine if performance is declining (usually occurs within one month to one year). The thermal oxidizer efficiency is monitored once per month, to make sure that efficiency exceeds a 95% guideline. Other parameters within the plant are sampled "as needed" to assess treatment equipment performance.

Influent concentration to the plant is determined monthly. Effluent to the POTW was originally sampled weekly and then monthly, but based on an agreement with the POTW (based on previous monitoring data) that sampling is now performed quarterly.

The latest O&M report (March 22, 2001) contains an excellent summary of well locations and well construction (Table A-4) which clearly indicates for each monitoring well and each extraction well the aquifer zone screened, the well coordinates, the top and bottom of screen elevation, the top of casing, ground elevation, and well depth.

3.0 SYSTEM OBJECTIVES, PERFORMANCE AND CLOSURE CRITERIA

3.1 CURRENT SYSTEM OBJECTIVES AND CLOSURE CRITERIA

The ROD, issued in 1991, identified a remedy that consists of two major elements:

- management of migration (MOM)
- source control

The objectives of the remedy were to achieve the following:

- prevent direct contact and incidental ingestion exposure to contaminated surficial soils both on and off of the Silresim property
- prevent future migration of contaminated groundwater to a hypothetical water supply well, thereby reducing risks from ingestion of contaminated drinking water
- prevent contaminated groundwater discharge to surface waters, thereby reducing risks from dermal absorption and ingestion exposures to contaminated surface water and sediments
- prevent contaminated groundwater flow towards buildings, thereby reducing risks from inhalation exposures

The objectives of the groundwater extraction system were to:

- halt further migration of contaminated groundwater towards receptors
- capture as much of the contaminant plume as possible
- achieve drawdowns across the site in support of the source control remedy

Groundwater cleanup levels are MCL-based, and contaminant-specific soil cleanup goals were established to prevent leaching and achieve MCL's in site groundwater.

In July 1999, a detailed review of ROD objectives was provided in the "ROD Remedy Review" report. That report concluded that "a number of potentially serious limitations and deficiencies currently exist with respect to meeting the ROD goals and objectives identified for the site." That report specifically recommends a re-evaluation of site objectives. One major component of a potential ROD revision would account for re-classification of the aquifer from Class 1 (source of potable water supply) to a lower classification associated with "low use and value". Therefore, it is possible that the ROD objectives will be modified in the near future.

3.2 TREATMENT PLANT OPERATION GOALS

Treatment plant operation goals include the following:

- maximize the influent flow rate while maintaining a VOC influent concentration that is within the design capacity of the treatment system
- meet discharge permit requirements, the most significant of which is 2.13 ppm TTO (sum of detected pesticides/PCB's, semi-volatiles, and volatiles), as well as pH of effluent between 6 and 9

Acetone has historically been elevated in plant effluent, and based on discussions with the POTW, the current levels of acetone in plant effluent is acceptable because it is easily biodegradable within the POTW.

3.3 ACTION LEVELS

Site cleanup levels and treatment plant effluent levels are described in Sections 3.1 and 3.2.

4.0 FINDINGS AND OBSERVATIONS FROM THE RSE SITE VISIT

4.1 FINDINGS

In general, the RSE team found the system to be well operated and maintained. The observations and recommendations given below are not intended to imply a deficiency in the work of either the designers or operators, but are offered as constructive suggestions in the best interest of the EPA and the public. These recommendations obviously have the benefit of the operational data unavailable to the original designers.

The RSE team found the site operators and managers to be interested in improving the performance of the system, and found that actions have previously been taken in pursuit of costs savings (many of which are detailed below). The RSE team also found that considerable attention has been given by Site managers in assessing the appropriateness of original remedial objectives (i.e., the ROD Remedy Review Report, July 1999), and Site managers are aware that the system is unlikely to achieve ROD objectives and that revised objectives may be appropriate. Finally, considerable attention has been paid (and continues to be paid) on evaluating alternatives that may lead to remediation of soils in the source area, such that a groundwater remedy of infinite duration can be avoided.

4.2 SUBSURFACE PERFORMANCE AND RESPONSE

4.2.1 WATER LEVELS AND CAPTURE ZONES

Some water level maps have been constructed in the past, but they are not sufficiently detailed to evaluate the capture zones achieved by the extraction system. Initially, areal capture zones were calculating using analytical solutions for extractions wells in a uniform flow field. However, as stated in the ROD Remedy Review report (i.e., with respect to the original extraction strategy), "given the site-specific variance in aquifer parameters, the cyclic pumping nature in the shallow wells, and the low flow pumping rates relative to saturated thickness in the deeper wells, it is likely that contaminated groundwater [was] escaping the theoretical capture zones." The five-year review conducted in 1999 also notes that, with respect to the original extraction strategy, "there has been extensive plume migration beyond the extraction well array." Predicted capture zones for the modified extraction strategy (which was implemented in February 2001) were evaluated with a MODFLOW groundwater flow model coupled with particle tracking. The RSE team noted during the site visit that the particle tracking analysis presented in the Groundwater Modeling Report is not really sufficient to demonstrate capture for the implemented strategy, and recommendations for augmenting that modeling and particle tracking analysis are presented in Section 6.1.1 of this report.

4.2.2 CONTAMINANT LEVELS

Contaminant levels associated with VOC's at this site are extremely high over a large area that extends well beyond the property boundary (see Figures 1-3 and 1-4). This provides evidence that the plume has spread from its original source on the property. The most recent O&M report evaluates three-dimensional plume patterns for individual contaminants, and concludes that individual contaminants have different extent, both horizontally and vertically, such that the Silresim contamination should not be viewed as one continuous plume.

Influent concentrations to the plant are measured in TTO (sum of detected PCB's/Pesticides, SVOC's, and VOC's). Typical influent is on the order of 100-200 ppm TTO, but has at times been as high as 400 ppm TTO. During the RSE site visit, the system operator stated that influent concentrations as high as 300 ppm TTO on a consistent basis might be a concern with respect to meeting discharge requirements.

4.2.3 NATURAL ATTENUATION POTENTIAL

Given the high concentrations in groundwater, which are indicative of the presence of NAPL's, there is no chance that monitored natural attenuation at this site can adequately achieve ROD objectives (or potentially modified ROD objectives) in the absence of active remediation

4.2.4 SOURCE AREA REMEDIAL APPROACHES

In 1995-1996, an SVE pilot test was conducted as per ROD requirements. The pilot test consisted of three SVE techniques: conventional SVE, heated air injection with SVE, and high vacuum or multiphase SVE. Approximately 2 tons of VOCs were removed during the pilot test. It was concluded that SVE would not attain cleanup levels specified in the ROD, but that SVE might allow enhanced mass removal. Therefore, a "Phase 1" SVE system was implemented in 1998-1999. During the 15-month implementation, approximately12 tons of VOCs were removed (compared to approximately 50 tons removed to date by the groundwater treatment plant) . Although this was a large amount of mass removed, the system was relatively hard to keep operating on a long-term basis. Some of the problems with SVE include low permeability soils, a high water table, high soil moisture contents, and short circuiting though gravel placed beneath the clay cap. It was decided that, since SVE was not expected to fully remediate the soil contamination, that money would be better spent on other potential alternatives, and the system was therefore shut down (although it still remains in place). Soil VOC concentrations exceed ROD cleanup standards by up to four orders of magnitude. More recently, six-phase heating has been considered as a potential source removal option, and a pilot test may be performed in Spring 2002.

4.3 COMPONENT PERFORMANCE

4.3.1 EXTRACTION-WELL PUMPS AND PIPING

Pumping rates are evaluated weekly to determine if performance is declining and maintenance is required. Flow meter readings (Signet Flowmeters) are sometimes verified with buckets. Typically maintenance of wells is required within one month to one year. Acetic acid is used for well rehabilitation, in conjunction with "pigging" the 3/4-inch polypropylene pipes from the well back to the treatment plant. At one point an iron sequestering "biocide"agent was tried, but it caused excess biological growth that clogged the air stripper, and was therefore determined to be counter-productive. All pipes and pumps are also cleaned during scheduled semi-annual shutdowns.

4.3.2 PHASE SEPARATION

Although the presence of NAPL's is suggested by the high VOC concentrations in groundwater and has in fact been observed at a few locations, free product was never separated out by the phase separation component of the system. Therefore, that part of the system is now bypassed so that extracted water goes directly into an equalization tank.

4.3.3 EQUALIZATION TANK

The equalization tank is 3000 gallons. Offgas from the equalization tank is directed to the thermal oxidizer. Planned maintenance shutdowns to remove accumulated sludge in process tanks and pumping it through the filter press has reduced the volume of waste material sent off-site.

4.3.4 METALS REMOVAL SYSTEM

The metals removal system (MRS) primarily addresses iron and manganese, and includes a pH Adjustment/Flocculation Tank, Gravity Settler, Chemical Feed Equipment, and Sludge Pumping. This equipment provides precipitation and removal of suspended solids and metals from the groundwater stream. Sodium hydroxide is used to raise the pH, followed by a polymer addition. Sludge produced by the MRS has historically been filter pressed twice per week (performed in level B). The sludge is slightly hazardous (just above TCLP levels) due to the high concentrations of VOC's, and is shipped to a hazardous waste facility in Canada. A modification is being considered to allow additional drying of the sludge, which will reduce sludge volume and potentially make the sludge non-hazardous. A cost/benefit analysis is planned for this potential modification, to see if the extra cost for sludge drying yields a greater cost reduction in sludge handling and disposal. Sodium hypochlorite is added to the effluent to prevent fouling of the air stripper.

An improvement already implemented at the site is an automated polymer blending system, which eliminated the need for daily polymer preparation. This resulted in the elimination of the need for weekend staffing at the plant. Also, bench scale tests of several different polymers resulted in better settling rates of the sludge, which resulted in less loading of solids to the multi-media filters and less backwashing requirements (from once per 4-6 hours to once every 10+ hours).

4.3.5 MULTI-MEDIA FILTERS AND pH ADJUSTMENT

The purpose of the filters is to remove total suspended solids. The media has only required changing once in five years, and appears to be effective. After the filters, the pH is lowered to keep remaining solids in solution, which prevents clogging of the heat exchanger.

4.3.6 AIR STRIPPER (INCLUDING PRE-HEATING)

VOC's and SVOC's are removed from groundwater by the air stripper, which operates at approximately 300 cfm. Groundwater is pumped to the top of the Air Stripper, and air blown into the bottom of the stripper removes organics from the water. The water flows by gravity though the stripper packing and is discharged to the effluent tank. Offgas from the stripper is sent to the thermal oxidizer.

A heat exchanger, located upstream of the air stripper, is used to raise the temperature of the water to approximately 120-130 degrees F prior to the air stripper. This allows the air stripper to effectively remove methylene chloride, which previously had passed through the air stripper and onto the carbon, where it subsequently de-sorbed (sometimes causing effluent concentration violations). Consideration is currently being given to augment the existing packed column air stripper with the installation of a low profile-tray air stripper, which would eliminate the need to preheat the feedwater and therefore lower natural gas usage while maintaining or improving removal efficiency for SVOCs.

Originally, fouled air stripper packing was discarded and disposed of off-site. On-site cleaning of the packing with 15% hydrochloric acid was initiated, which allowed beneficial reuse of the packing and eliminated an unnecessary waste stream.

4.3.7 GRANULAR ACTIVATED CARBON SYSTEM (ELIMINATED)

By increasing the operating temperature of the air stripper, which improves stripping of methylene chloride, liquid-phase GAC is no longer required to meet discharge requirements. In addition to removing the costs of carbon, this has resulted in an additional benefit because the carbon caused anaerobic conditions in the effluent tank, which in turn caused an odor problem that required chlorination. Now that GAC has been removed, this step is no longer required.

4.3.8 THERMAL OXIDIZER

Air is pulled from the outlet of the air stripper by the oxidizer fan, is preheated in the heat exchanger, and flows through the thermal oxidizer. The hot gas from the thermal oxidizer preheats the incoming air and is further cooled in a water quench tower to 180 degrees F prior to entering the caustic (sodium hydroxide) scrubber. Acid formed during the combustion process is removed from the air stream in the caustic scrubber. The cooled clean gas is discharged through the scrubber stack to the atmosphere. A 95% Destructive Rate Efficiency for the thermal oxidizer is required by the State. A temperature reduction from 1600 degrees F to 1500 degrees F has resulted in a reduction in natural gas usage, without causing efficiency to fall below the 95% guideline.

4.3.9 EFFLUENT TANK

The wastewater stream from the air stripper is pumped to the effluent storage tank where it is sampled and analyzed prior to discharge to the POTW or reused as filter backwash. A permanently installed pH probe is used to monitor pH of the final effluent.

4.3.10 CONTROLS

The system is highly automated. Autodialers were recently upgraded to increase the number of alarm notifications to the plant operators during unstaffed hours, which allows quicker problem identification. This translates to quicker response time and therefore less downtime. Also, the system can be remotely monitored and restarted. Genesis software is utilized in conjunction with PC-Anywhere.

4.4 COMPONENTS OR PROCESSES THAT ACCOUNT FOR MAJORITY OF COSTS

Foster Wheeler has been the O&M contractor, and the Army Corp of Engineers (ACOE) has been the management contractor. The total budget for the current year (Year 6) is $1.42 million per year, plus $39,000 per year for project management by ACOE. Breakdown according to task categories specified in the site budget are as follows:

Task	Budget For Current Year ($/yr)
01 - GWTP Operations	$364,300
02 - Utilities & Supplies	$257,500
03 - Sampling & Analysis	$162,527

Task	Budget For Current Year ($/yr)
04 - Waste Handling & Disposal	$ 63,191
05 - Record Keeping & Reporting	$ 65,087
06 - Project Management (O&M Contractor)	$377,964
07 - Out of Scope Upgrades/Improvements	$125,000
PM Allocation (ACOE)	$38,850
TOTAL	**$1,454,419**

The RSE team has separated the costs from the current "Year 6 Budget" into approximate costs by category, as follows:

$775,000	Labor (O&M, sampling, reports, meetings, PM, MIS, H&S, etc.)
$125,000	Laboratory analysis
$ 65,000	Security, snow removal, groundskeeping
$125,000	Utilities
$140,000	Non-utility consumables (including trailer rental)
$ 60,000	Disposal costs
$ 40,000	ACOE project management
$125,000	Annual upgrades/improvements

Some breakdown of these costs are provided below.

4.4.1 LABOR

The plant is currently operated by two people 10 hours per day, 5 days per week, at a cost of approximately $160,000 per year. Additionally, there is a technician with rotating responsibilities (operation, sampling, etc.) and a full-time administrator in the trailer. There are also labor costs associated with project management, monitor well sampling, reporting, semi-annual shutdowns and associated maintenance, information management, monthly meetings, and other project support. These additional labor requirements total nearly $615,000 per year. Thus, the combined labor requirements cost approximately $775k/yr.

4.4.2 LABORATORY ANALYSIS

Laboratory support for process monitoring accounts for approximately $70,000 per year. Laboratory costs for groundwater monitoring, air sampling, and waste disposal sampling are approximately $55,000 per year.

4.4.3 SECURITY, SNOW REMOVAL, GROUNDSKEEPING

Security historically cost approximately $7,000 per month, but that cost should be reduced in the future based on previous recommendations that 24-hour security is no longer required (the Year 6 Budget assumed 24-hour security for only part of the year, based on that previous recommendation) . Snow removal and groundskeeping are approximately $20,000 per year.

4.4.4 UTILITIES

Natural gas is the largest utilities cost, at approximately $80,000 per year. This is primarily related to operation of the thermal oxidizer and preheating the air stripper feed water. Natural gas is also used to heat the building to 62 degrees F in winter. Electricity costs are approximately $25,000 per year (pumps, air stripper, lighting, etc.). Telephone, water, and sewer are approximately $20,000 per year.

4.4.5 NON UTILITY CONSUMABLES

Trailer rental costs approximately $20,000 per year (this cost is also being eliminated by the purchase of a fixed permanent trailer for the site in exchange for the two existing rental trailers). Chemicals used in the treatment process account for approximately $20,000 per year. Parts, tools, lab equipment, and health and safety equipment cost approximately $73,000 per year. Office supplies cost approximately $2,000 per year.

4.4.6 DISPOSAL COSTS

The largest disposal costs are associated with disposal of sludge from the Metals Removal System (MRS), and disposal of PPE, which combined cost approximately $40,000 per year.

4.5 RECURRING PROBLEMS OR ISSUES

In the past, there had been frequent failure (approximately every six weeks) of a pH probe and transmitter used to measure effluent. In August 2000 the pH sensor and transmitter were changed to a Great Lakes Instrument device, with significant improvement.

There have been problems with corrosion of the heat exchanger. A new unit was placed into service in 2001 (under warranty), and there is hope that this unit will not experience the same problems.

The site has instituted two scheduled shutdowns per year, which include preventative maintenance on many system components. This has increased operational efficiency and reduced the number of unplanned shutdowns.

4.6 REGULATORY COMPLIANCE

The plant regularly meets its permitted discharge requirements, and has a good working relationship with the POTW. As previously stated, the POTW has allowed an exception to be made for high levels of acetone in the discharge, since it is easily biodegraded within the POTW.

4.7 TREATMENT PROCESS EXCURSIONS AND UPSETS, ACCIDENTAL CONTAMINANT/REAGENT RELEASES

None identified during the RSE site visit.

4.8 SAFETY RECORD

The system has an excellent safety record. There has been only one minor accident since 1994, which involved a third-party contractor lifting a heavy object.

5.0 EFFECTIVENESS OF THE SYSTEM TO PROTECT HUMAN HEALTH AND THE ENVIRONMENT

5.1 GROUND WATER

The five-year review conducted in 1999 notes that, with respect to the original extraction strategy, "there has been extensive plume migration beyond the extraction well array." In addition, concerns were raised that some of the deeper extraction wells might be drawing contaminants downward from the shallow zone. Therefore, a new pumping strategy was implemented in early 2001 (see Section 2.2). However, it is not clear that the current system adequately captures all groundwater that exceeds current cleanup goals. According to the 5-year review, "the selected remedy is not likely to achieve all of the Remedial Action Objectives set forth in the ROD...the remedy selected in the ROD is not expected to be protective of human health and the environment. However, immediate threats have been addressed and current conditions at the site are protective of human health and the environment."

Cleanup objectives for groundwater may be modified in the future based on updated risk assessment methodologies and/or assumptions, including the reclassification of the aquifer with respect to the low potential for groundwater use.

5.2 SURFACE WATER

Based on plume maps contained in previous site reports, contaminated groundwater has migrated towards East Pond (to the southeast) and River Meadow Brook (to the west). Sampling has been performed in these bodies of water several times, and a screening ecological field survey was conducted in 2000. The conclusion by Foster Wheeler was that no conclusive link was established between constituents in these water bodies and constituents at the Silresim Site. The RSE team believes that past and future migration of site-related constituents to these surface water bodies and related sediments is a possibility, and some form of routine monitoring (especially for sediments) should be conducted into the future.

5.3 AIR

There have been concerns raised regarding air quality risks in the basement of the operations building and the administration building at Lowell Iron and Steel, an adjacent property. Air samples were collected in 1999 and 2000, and a risk assessment was performed. The risk assessment indicated cancer risks in the administration building, and non-cancer risks were determined in both buildings for the conservative "Reasonable Maximum Exposure (RME)" scenario, but not for the less conservative "Central Tendencies Exposure (CTE)" scenario. The conclusion was that further air monitoring for VOC's in the basements, and ventilation in the basements, should be performed if there is a need for more intensive utilization of the basement space. The RSE team did not discuss air quality issues in detail during the RSE visit, but generally agree that the very high concentrations of VOC's in groundwater merit concern with respect to air quality in basements within the footprint of the plume (it was stated during the RSE site visit that these were the only known basements "in the area", and site managers indicate they will confirm that information).

5.4 SOILS

Direct exposure to impacted soils has been mitigated by previous remedial actions at the site (capping, placement of rocks, etc.). However, impacted soils remain at the site, such that long-term institutional controls restricting contact with such soils will need to be in force for an indefinite period of time.

5.5 WETLANDS

Not considered as part of the RSE.

6.0 RECOMMENDATIONS

As noted throughout this report, the RSE team found the site operators and managers to be interested in improving the performance of the system, and found that many actions have previously been taken in pursuit of cost savings and/or technical improvement. Some (but not all) of these previous improvements are summarized below:

- eliminated liquid phase carbon step by increasing the operating temperature of the air stripper to enhance removal of methylene chloride, which also resulted in more aerobic effluent which eliminated an odor problem;

- reduced the operating temperature of thermal oxidizer from 1600 degrees F to 1500 degrees F, resulting in a savings in natural gas usage without compromising effectiveness;

- installed an automated blending system for polymer in the Metals Removal System, eliminating the need for weekend staff;

- improved the autodialer system to allow for faster problem recognition and resolution;

- reduced groundwater analytical monitoring frequency and process analytical monitoring frequency;

- reduced staffing from 24-hours per day , seven days per week manned operations to current staffing levels per cooperation and negotiations with the Lowell POTW, substantially reducing labor cost.

- instituted semi-annual preventative maintenance program to increase operating efficiency; and

- performed bench-scale testing of polymers to provide better sludge settling rates, resulting in less solids loading to the filters and less frequenting backwashing of the filters.

The RSE team also commends Site Managers for their realistic evaluation of the inability of the current system to meet ROD objectives, and for implementing changes to the extraction strategy in 2001 (based on recently-performed groundwater modeling) in an attempt to limit downward migration of contaminants due to pumping at deep wells and to improve the extent of groundwater capture.

During the RSE site visit is was mentioned that a settlement with potentially responsible parties for this site has provided the funding for the remediation efforts. The RSE team believes that the resulting pool of funds has caused site managers to consider life-cycle costs at this site more than at other fund-lead P&T sites, because their goal has been to complete the remediation using those funds. This is consistent with previous actions by site managers to reduce costs when possible, and also to invest in source remediation options that might limit the groundwater remediation timeframe. It should be noted, however, that some of the costs to date at this site have been allocated towards identifying and implementing source remediation efforts, and that annual O&M costs could potentially be reduced in the future if the site remedy is reformulated as a containment-only system (i.e., with little or no chance of source area remediation). The

RSE team, however, is not specifically recommending a reformulation of objectives to "containment-only" at this time.

A primary recommendation by the RSE team is that site managers continue to seek improvements to the system and the remedy, as has been done in the past. The RSE team concurs with the investigation of Six Phase Heating as a potential means of source removal. Several additional recommendations are provided below. Cost estimates provided have levels of certainty comparable to those done for CERCLA Feasibility Studies (-30/+50%), and these cost estimates have been prepared in a manner consistent with EPA 540-R-00-002, A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, July 2000.

6.1 RECOMMENDATIONS TO ENSURE EFFECTIVENESS

6.1.1 AUGMENT EVALUATION OF GROUNDWATER CAPTURE

Capture zones for the modified extraction strategy (which was implemented in February 2001) were predicted prior to implementation with a MODFLOW groundwater flow model, coupled with particle tracking. The RSE team noted during the site visit that the particle tracking analysis presented in the Groundwater Modeling Report is not sufficient to demonstrate capture for the implemented strategy. Furthermore, an attempt has not yet been made to validate the predictions of the groundwater flow modeling with field measurements subsequent to implementation of the strategy. Finally, it is difficult to interpret the extent of actual groundwater capture on the basis of measured water levels (in the form of potentiometric surface maps). Therefore, the RSE team recommends the following:

- A "target capture zone" for each layer in the groundwater flow model should be established, based on plume extent and site management objectives, so that predicted capture zones based on particle tracking results can be superimposed on the "target capture zone" to evaluate the effectiveness of the specific extraction scenario being simulated. Estimated cost for this activity is $5,000.

- Particle tracking should be performed in forward tracking mode, with one particle released in each cell of the model, in each model layer. The "endpoint" file can then be processed to determine each initial particle location that ultimately is captured by one of the extraction wells, in each model layer. These locations can then be plotted, one layer at a time, superimposed on the "target capture zone" for that model layer. Estimated cost for this activity is $10,000.

- To increase confidence in model-predicted capture, the predictive accuracy of the model should be evaluated by comparing model predicted values of drawdown to those observed in the field. Two different pumping strategies have been employed to date, such that good "pre-pumping" and "post-pumping" water level measurements should exist for at least two different pumping scenarios (if not, water levels can be taken during scheduled plant shutdowns, and then again once pumping has been re-instated for several weeks). The model can then be revised (parameter values, boundary conditions) to improve predictive accuracy based on these comparisons to real data, and capture zones re-evaluated with particle tracking after the model is revised. Estimated cost for this activity is $25,000.

6.1.2 PERIODIC MONITORING OF SEDIMENTS IN EAST POND AND RIVER MEADOW BROOK

Because the groundwater plume has historically migrated towards these surface water bodies, and because groundwater concentrations are extremely high, and because capture zone of the current extraction system is not firmly established, periodic monitoring of sediments in these surface water bodies for the most mobile constituents associated with the site (i.e., VOC's) is recommended, perhaps once every two years. This might cost $10,000 per year.

6.1.3 AIR MONITORING IN BASEMENTS

As discussed in Section 5.3, the RSE team did not discuss air quality issues in detail during the RSE visit, but generally agree that the very high concentrations of VOC's in groundwater merit concern regarding air quality in basements within the footprint of the plume (it was stated during the RSE site visit that these were the only known basements "in the area". The RSE team recommends that site managers verify that no other basements are of concern within the footprint of plume. The RSE team also recommends that site managers routinely verify that use of the basements on Lowell Iron and Steel has not increased, and if it has, that proper precautions (i.e., ventilation) are being implemented. This should be performed within existing budget.

6.2 RECOMMENDATIONS TO REDUCE COSTS

6.2.1 REDUCE SITE SECURITY

The RSE team agrees with an existing recommendation by site managers to reduce site security by installing a monitored security system. This is projected to save approximately $90,000 per year. This reduction has been completed as of August 31, 2001.

6.2.2 COST/BENEFIT ANALYSIS FOR SLUDGE DRYING

Sludge generated in the Metals Removal System is slightly hazardous due to the high concentrations of VOC's (specific constituents that exceed TCLP standards were not identified during the RSE visit) , and is shipped to a hazardous waste facility in Canada. A modification is being considered to allow additional drying of the sludge, which will reduce sludge volume and potentially make the sludge non-hazardous. A cost/benefit analysis for this potential modification has been previously recommended by site managers, to see if the extra cost for sludge drying yields a greater cost reduction in sludge handling and disposal. The RSE teams agrees with this recommendation.

6.2.3 CONTRACTING CONSIDERATIONS

During the RSE visit it was suggested that in the future the O&M contract may be re-bid as a lump-sum contract, as opposed to the current contract which is cost-reimbursable. If this occurs, the RSE team suggests that the lump-sum contract be limited to those items that are definitely expected to be incurred (e.g., operator labor, sampling and analysis, reporting, etc.). Other items for which costs to be incurred are less certain (i.e., disposal costs, replacement parts, etc.) should remain cost-reimbursable, because such costs will be included in a lump-sum bid whether or not they are actually incurred (i.e., to the disadvantage of USEPA).

Because this is a complex site with proactive site management (preventative maintenance, pilot testing of remedial alternatives, evaluation of remedial objectives, etc.) the labor costs associated with site management and operation is high. The RSE team does not have specific recommendations for reducing these costs, although it is likely these labor costs could be substantially reduced in the future if an effective "containment-only" approach is adopted (i.e., less resources would be required to evaluate and/or implement source area remediation under that strategy).

6.3 TECHNICAL IMPROVEMENT

The system is well operated, and the RSE team has no recommendations for technical improvement.

6.4 RECOMMENDATIONS TO GAIN SITE CLOSEOUT

6.4.1 CONTINUE TO CONSIDER SOURCE ALTERNATE REMEDIATION STRATEGIES

The report titled "Final Management of Migration and Source Removal Strategy Work Plan" (September 2000) provided a comparative evaluation of potential remedial alternatives for management of plume migration. These alternatives included reduced infiltration, modified groundwater extraction, sheet pile installation, interceptor trench, and a funnel-and-gate wall.

In addition, six-phase heating was evaluated as a source removal alternative. Unlike SVE, which was previously attempted, six-phase heating does not require the dewatering of the treatment area. The RSE team recommends that source removal strategies such as six-phase heating be pilot tested (currently planned for Spring 2002) only after specific metrics are developed to determine whether or not the pilot test is a success (i.e., mass removed per dollar spent must exceed a certain value that should be determined before the test, based on estimated scale-up factors for a full-scale implementation). Site managers must also consider whether or not any source removal strategy will be effective at eliminating the groundwater plume in the long term, even if substantial mass reductions are achieved, due to the uncertainty in removing DNAPL's that are likely present in the subsurface.

Given the high cost of this system ($1.4 million per year), and the likelihood that it will operate indefinitely even if ROD objectives are modified, the RSE team recommends that site managers invest in an evaluation of potential remedial alternatives on a regular basis (at least every 3-5 years) as new remedial technologies are developed and/or improved. This type of analysis is currently being performed, and therefore can be performed in the future within the current budget.

7.0 SUMMARY

The observations and recommendations given below are not intended to imply a deficiency in the work of either the designers or operators, but are offered as constructive suggestions in the best interest of the EPA and the public. These recommendations obviously have the benefit of the operational data unavailable to the original designers.

The RSE process is designed to help site operators and managers improve effectiveness, reduce operation costs, improve technical operation, and gain site closeout. In this report, several recommendations are made with respect to system effectiveness. The RSE team also supports several previous recommendations regarding cost reduction, and also supports continued attempts to identify remedial alternatives that have the potential to enhance capture zones and/or source area remediation.

Tables 7-1 summarizes the costs and cost savings associated with each recommendation. Estimated cost reductions are not calculated for cases where the RSE team supports a previously made recommendation, since the RSE team is not responsible for those recommendations. Both capital and annual costs are presented as well as the expected change in life-cycle costs over a 30-year period for each recommendation both with discounting (i.e., net present value) and without it.

Table 7-1. Cost summary table for individual recommendations

Recommendation	Reason	Estimated Change in			
		Capital Costs	Annual Costs	Life-cycle Costs*	Life-cycle Costs **
6.1.1 Augment evaluation of GW capture	effectiveness	$40,000	$0	$40,000	$40,000
6.1.2 Sediment monitoring	effectiveness	$0	$10,000	$30,000	$16,114
6.1.3 Air monitoring in basements	effectiveness	$0	$0	$0	$0
6.2.1 Reduce site security	cost reduction	previously made recommendation			
6.2.2 Sludge drying	cost reduction	previously made recommendation			
6.2.3 Contracting considerations	cost reduction	$0	not quantified	not quantified	not quantified
6.4.1 Continue considering alternatives	exit strategy	$0	$0	$0	$0

Costs in parentheses imply cost reductions.
For recommendations 6.1.3 and 6.4.1, the RSE feels these items can be performed within the current budget
* assumes 30 years of operation with a discount rate of 0% (i.e., no discount).
** assumes 30 years with a discount rate of 5% and no discounting in the first year.

FIGURES

FIGURE 1-1. SITE LOCATION.

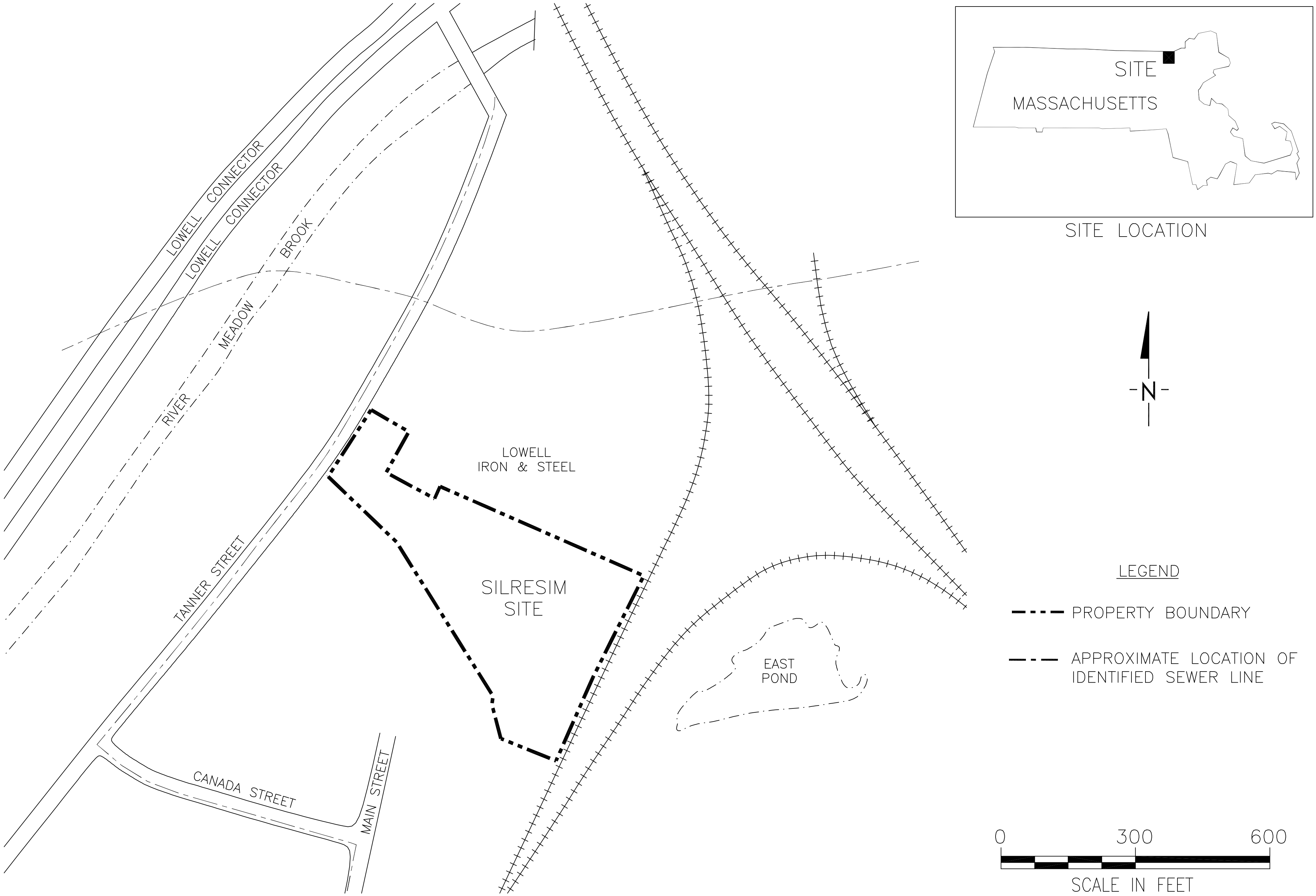
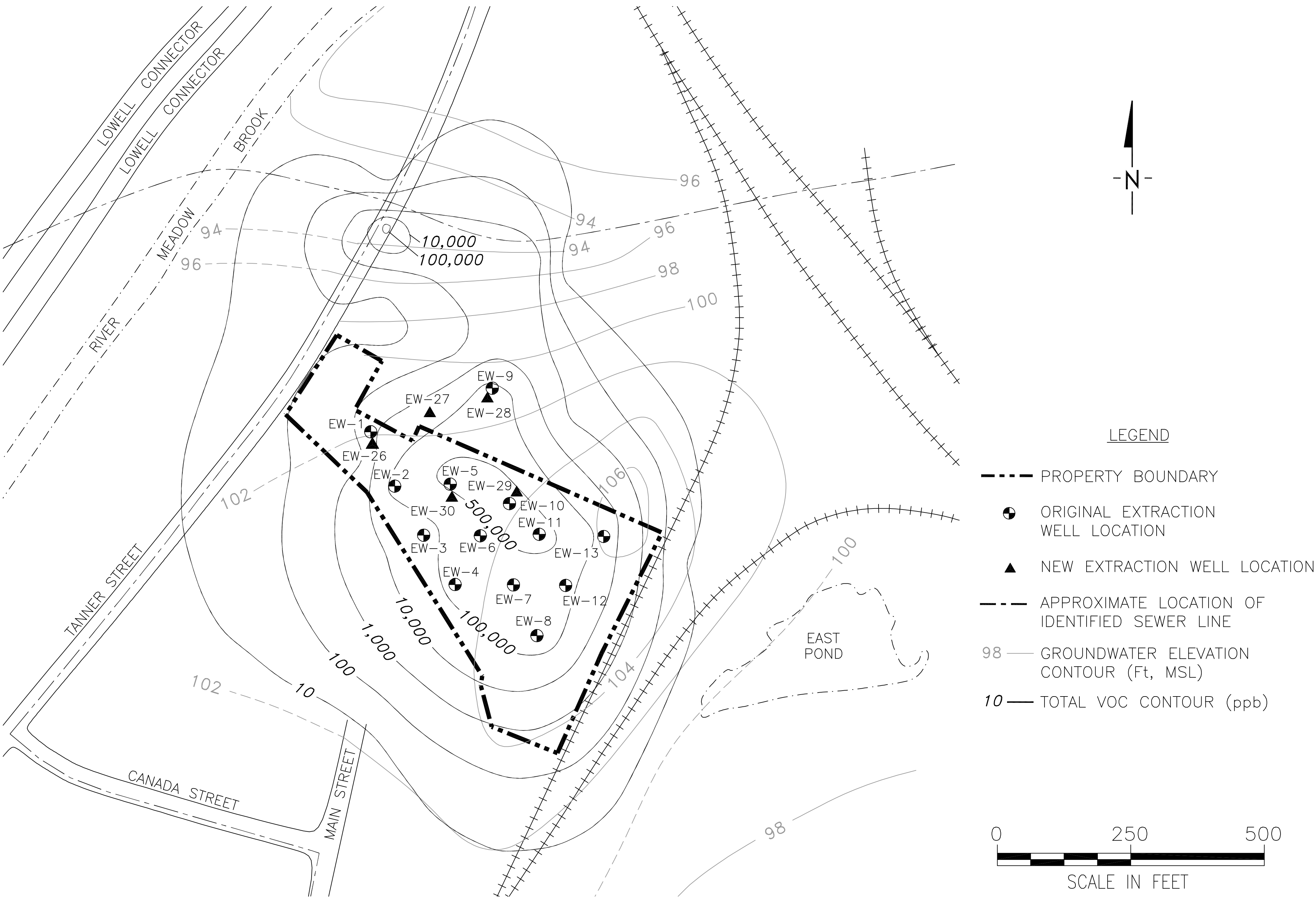


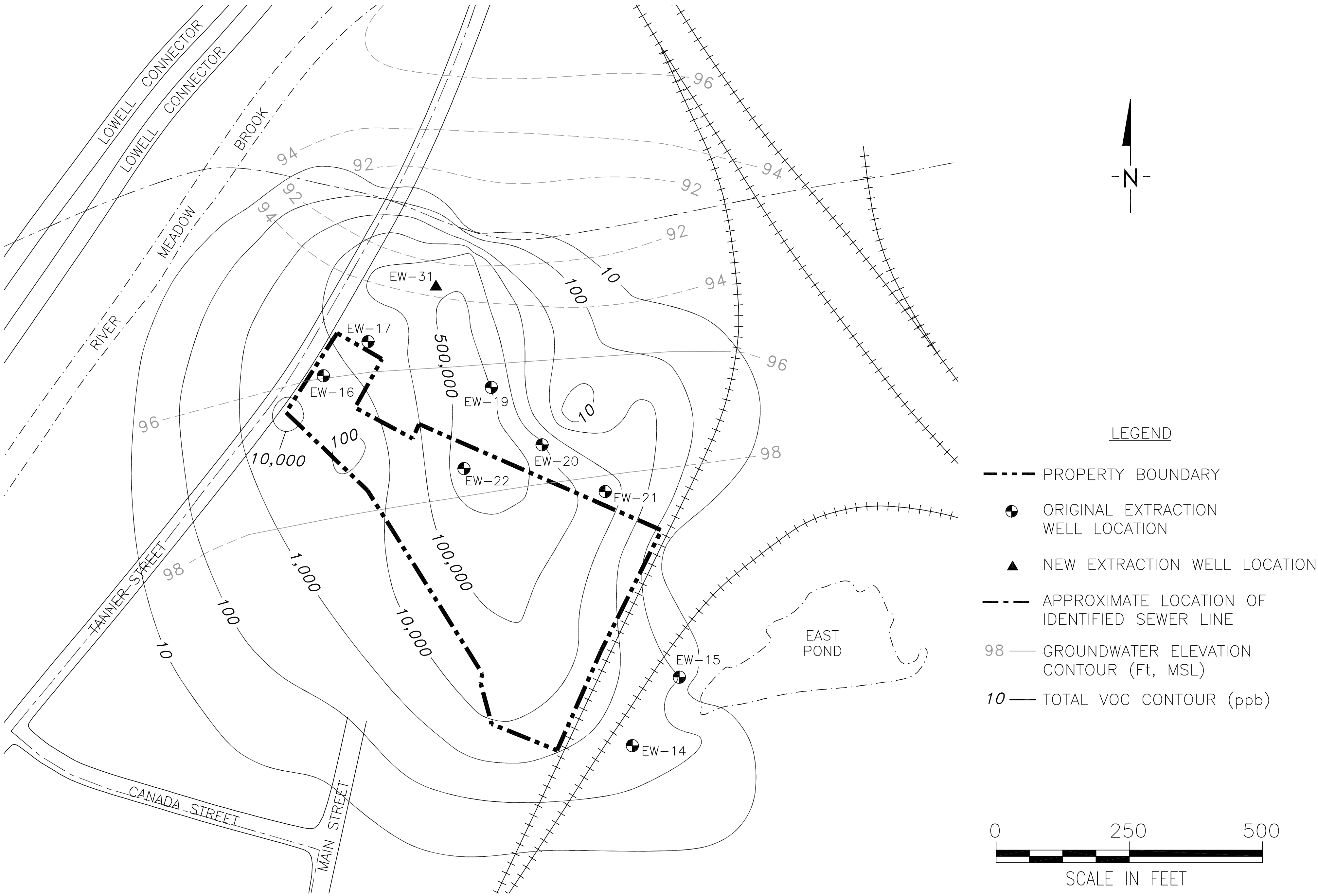
Figure 1-2. Site photograph from period where facility was active.

FIGURE 1-3. TOTAL VOC PLUME (11/00) AND WATER TABLE ELEVATIONS (1988), SHALLOW PORTION OF AQUIFER.



Note: Locations of water level and concentration measurements not indicated on this figure.

FIGURE 1-4. TOTAL VOC PLUME (11/00) AND WATER TABLE ELEVATIONS (1986), DEEPER PORTION OF AQUIFER.



Note: Locations of water level and concentration measurements not indicated on this figure.

Solid Waste and
Emergency Response
(5102G)

542-R-02-008p
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