REMEDIATION SYSTEM EVALUATION

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GREEN REMEDIATION EVALUATION

SHEPLEY'S HILL LANDFILL
DEVENS, MASSACHUSETTS

Report of the Remediation System Evaluation
Site Visit Conducted at the Shepley's Hill Landfill Site
April 8, 2009

Final Report
August 21, 2009

NOTICE

Work described herein was performed by GeoTrans, Inc. (GeoTrans) for the U.S. Environmental Protection Agency (U.S. E.P.A). Work conducted by GeoTrans, including preparation of this report, was performed under Work Assignment #58 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared part of a pilot project conducted by the United States Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (U.S. EPA OSRTI). The objective of this pilot project is to conduct independent, expert reviews of soil and ground water remedies with public funding with the purpose of optimizing the remedy for protectiveness, cost-effectivenss, and sustainability. The project contacts are as follows:

Organization	Key Contact	Contact Information
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1.0 INTRODUCTION

1.1 PURPOSE

During fiscal years 2000 and 2001 independent reviews called Remediation System Evaluations (RSEs) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (i.e., those sites with pump and treat systems funded and managed by Superfund and the States). Due to the opportunities for system optimization that arose from those RSEs, EPA OSRTI has incorporated RSEs into a larger post-construction complete strategy for Fund-lead remedies as documented in *OSWER Directive No. 9283.1-25, Action Plan for Ground Water Remedy Optimization*. A strong interest in sustainability has also developed in the private sector and within Federal, State, and Municipal governments. Consistent with this interest, OSRTI has developed a Green Remediation Primer (http://cluin.org/greenremediation/) and now considers green remediation during independent evaluations.

Lessons learned from the RSEs conducted to date indicated potential value in conducting independent reviews at Responsible Party (RP) and Federal Facility sites on behalf of EPA. As a result, the EPA OSRTI Technology Innovation and Field Services Division is also conducting independent evaluations at sites that are nominated by the EPA Regions with the purpose of reviewing remedy protectiveness, cost-effectiveness, and project sustainability.

The process involves a team of expert hydrogeologists and engineers that are independent of the site, conducting a third-party evaluation of remedy selection or remedy design. It is a broad evaluation that considers the goals of the remedy, site conceptual model, available site data, performance considerations, protectiveness, cost-effectiveness, closure strategy, and sustainability. The evaluation includes reviewing site documents, potentially visiting the site for one day, and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Sustainability

The recommendations are intended to help the site team identify opportunities for improvements. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the evaluation team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders.

The Shepley's Hill Landfill Site (the "site") was selected by EPA OSRTI based on a nomination from EPA Region 1. The site is located in Devens, Massachusetts. Operation of the P&T system is a contingency remedy for the 1995 Record of Decision. System operation began in September 2005. EPA Region 1 requested a third-party review to evaluate the hydraulic capture provided by the P&T system, evaluate the system with respect to the green remediation core elements, and evaluate the potential for developing renewable energy at the site to power the remedy. This report provides a brief background of the site, findings with respect to the P&T capture zone, detailed findings related to green remediation, and recommendations related to improving protectiveness, cost-effectiveness, sustainability, and renewable energy.

1.2 Team Composition

The RSE team consists of the following individuals:

Name	Affiliation	Phone	Email
Doug Sutton	GeoTrans, Inc.	732-409-0344	dsutton@geotransinc.com
Rob Greenwald	GeoTrans, Inc.	732-409-0344	rgreenwald@geotransinc.com
Kathy Yager*	U.S. EPA OSRTI	617-918-8362	Yager.kathleen@epa.gov

** Project coordinator(s)*

1.3 Documents Reviewed

The following documents were reviewed. The reader is directed to these documents for additional site information that is not provided in this report.

- Record of Decision (ROD) – September 1995
- Explanation of Significant Difference (ESD) – April 2005
- Five-Year Review – September 2005
- Remedial Design and Remedial Action Workplan, Final 100% Submittal, Groundwater Extraction Treatment, and Discharge Contingency Remedy, May 2005
- Operations and Maintenance Manual for the Shepley's Hill Landfill Arsenic Removal Water Treatment Plant, November 2006
- 2007 Annual Report, August 2008
- Supplemental Groundwater and Landfill Cap Assessment for Long-Term Monitoring and Maintenance, December 2008
- Draft Supplemental Landfill Gas Monitoring Well Work Plan, December 2008
- 2008 Annual Report, May 2009
- MODFLOW files for run "SHL002" (the initial 2-layer model adapted from the "run412" variant used in design of the extraction system) and for run "SHL004" (the 3-layer model by AMEC used for the 2008 "Supplemental" and "Annual" reports)
- Various communications

1.4 Persons Contacted

The following individuals associated with the site were present for the visit:

Name	Affiliation	Phone	Email
Ginny Lombardo	U.S. EPA Region 1 (RPM)	(617) 918-1754	Lombardo.Ginny@epamail.epa.gov
Bill Brandon	U.S. EPA Region 1 (Hydro.)		
David Reault	ECC (O&M contractor)		
Fred Santos	ECC (O&M contractor)		
Hui Liang	MADEP		

1.5 Basic Site Information and Scope of Review

1.5.1 Location

Shepley's Hill Landfill encompasses approximately 84 acres in the northeast corner of the main post of the former Fort Devens (Figure 1-1 in Attachment A), which is located approximately 35 miles northwest of Boston, Massachusetts. The landfill is bordered to the northeast by Plow Shop Pond, to the west by Shepley's Hill, to the south by recent commercial development, and to the east by land formerly containing a railroad roundhouse. Nonacoicus Brook, which drains the pond, lies to the north of the landfill.

1.5.2 Potential Sources

The primary contaminant in groundwater at this site is arsenic. There is some uncertainty regarding the specific initial source of the arsenic. Possibilities include one or more of the following:

- Soils derived from bedrock beneath the landfill
- Bedrock beneath the landfill
- Bedrock exposed at the surface on Shepley's Hill, located just west of the landfill, that could serve as a source of arsenic in groundwater that subsequently flows below the landfill
- Waste material within the landfill

Reducing conditions caused by degradation of the buried waste promotes the dissolution of the arsenic in groundwater beneath the landfill. If the potential bedrock source is in the form of sulfide minerals, oxidizing conditions favor dissolution, but once in solution the reducing conditions can allow the arsenic to remain mobile.

1.5.3 Hydrogeologic Setting

Landforms in the vicinity at the site are remnants of previous glacial activity, and are characterized by bedrock hills and bedrock valleys filled predominantly with glacial till. Shepley's Hill, located just west of the landfill, is an example of a bedrock hill covered by a thin veneer of glacial material. The landfill is sited in an area of overburden east of Shepley's Hill. Several cross-sections are included in Attachment A. The depth to bedrock is approximately 90 to 100 ft at the landfill. Depth to groundwater is approximately 15 to 20 ft.

A water table map for the overburden is included in Attachment A. Groundwater flow is generally to the north. Based on that water level map, hydraulic gradient is variable, with value of approximately 0.005 ft/ft near the northen end of the landfill. The recent groundwater modeling at the site uses a hydraulic conductivity value of approximately 45 ft/day for the overburden material. Groundwater ultimately discharges to surface water. Some groundwater flowing beneath the southeast corner of the landfill discharges to the Red Cove area of Plow Shop Pond. Groundwater that flows to the north, if not captured by the P&T wells located just north of the landfill, will generally discharge to Nonacoicus Brook, which ultimately discharges to Nashua River. During the RSE site visit, it was stated that groundwater will generally not discharge to the portion of Plow Shop Pond north of Red Cove, because in that portion of Plow Shop Pond surface water levels are generally higher than aquifer water levels.

1.5.4 POTENTIAL RECEPTORS

Risk to human health could exist if groundwater downgradient of the landfill was utilized for drinking water, but the groundwater is reportedly not used for drinking. The following text is taken from the AMEC report dated December 23, 2008:

> "The results of a residential survey, municipal water supply records obtained from the Town of Ayer in March 2008, and a survey conducted by USEPA in 2000 confirm that groundwater in the residential area north of the landfill is not currently used as a drinking water source by any property."

That same report also states the following:

> "Because of the degree of heavy urbanization in the area located immediately north of the landfill along Scully Road, Molumco Road, Shirley Street, and West Main Street to Good Blood Drive, and south of Nonacoicus Brook along Old West Main Street (along roadways including Kyle Avenue, Antietam Street, Cooke Street, and Saratoga Street), it is unlikely that groundwater located beneath the residential and commercial land in this area would be considered suitable for drinking water use. It is noted that this area is designated by the State of Massachusetts as a "Non-Potential Drinking Water Source Area" (NPDWSA) (MAGIS, 2006, http://maps.massgis.state.ma.us/21e), and unlikely to be used as a future drinking water source. The land use in the Shepley's Hill Landfill area is not used for residential or commercial purposes nor would ever be developed for such use due to the existence of the waste disposal landfill. Accordingly, it is unlikely that groundwater beneath the 84-acres landfill would be used as a source of drinking water. Furthermore, this is supported by MassDEP policy (MassDEP, 1997b) which considers groundwater beneath landfills less than 100 acres in size and are surrounded by urban uses such as exist at this site, exempt from consideration as a potential drinking water source."

The adequacy of the institutional controls is reportedly being discussed by site stakeholders.

A public supply well called the MacPherson Well is located approximately 0.75 miles to the northwest of the landfill. The modeling analysis in the AMEC report concludes that Macpherson well is not impacted by groundwater emanating from Shepley's Hill Landfill, for both the actual usage rate and for the maximum permitted rate.

Surface water is a potential receptor, although the site conceptual model presented in reports indicates that arsenic may precipitate out of the groundwater before ultimately discharging to surface water (as the groundwater becomes more oxygenated).

1.5.5 CONTAMINANT FATE AND TRANSPORT

An overview of the fate and transport of arsenic in groundwater at the site, as it pertains to this evaluation, has been summarized in Sections 1.5.2 to 1.5.4. There is ongoing work at the site to establish which of the potential sources of the arsenic impacts predominate, to establish the extent of capture provided by the P&T extraction wells, and to establish if arsenic precipitates before discharging to surface water north of the site.

2.0 SYSTEM DESCRIPTION

The 100% Design was completed in May 2005. The system began operating in September 2005 but was interrupted due to higher than expected methane in the process water. Methane sensors were installed in the building, the process tanks exposed to air were covered and vented outside of the building, and the building electrical was updated. The system resumed operation in March 2006 at 25 gpm, which is half of the intended design capacity of 50 gpm. The primary reason for the reduced flow rate was to determine the impact of groundwater extraction on the wooded wetlands to the north of the site. However, when the system flow rate was increased to 50 gpm in July 2007, it was apparent that the systemwas incapable of maintaining an average flow rate of 50 gpm. Although the primary treatment system components were designed with a hydraulic capacity of 50 gpm, the entire treatment system was originally incapable of providing the design treatment capacity of 50 gpm due to size or performance of other ancillary components and aspects of the maintenance process. A series of modifications from the original design have been made to allow the system to operate at or near 50 gpm as of April 2009.

2.1 EXTRACTION SYSTEM

The extraction system consists of two extraction wells each designed to provide the maximum system flow rate of 50 gpm. Each well has a 5 HP electric submersible pump (reference the O&M manual rather than the 100% design) with a variable frequency drive (VFD). EW-1 and EW-4 are 6-inch diameter wells that are 88 feet and 98 feet deep, respectively, with 25-foot screen intervals. The extraction rates for the wells are designed to maintain a setpoint in the microfiltration feed tank, and the rates are automatically controlled by the programmable logic controller (PLC) and the VFD. At the time of the evaluation, the VFD frequency for typical pump operation was 33 Hz indicating that the pumps were operating at about half of their rated speeds.

2.2 TREATMENT SYSTEM

The primary contaminant of concern for the site is arsenic, and the treatment system is designed to remove the arsenic through co-precipitation with iron and microfiltration. Iron and arsenic are present in their reduced states (ferrous iron and the arsenite ion) in the treatment plant influent at concentrations of approximately 70 mg/L and 3.2 mg/L, respectively. Manganese is also present in the influent at a concentration of 2 mg/L and is not a contaminant of concern or a critical element of arsenic removal. The treatment system is housed in a 40-foot by 40-foot steel building and consists of the following components:

- Chlorine dioxide addition
- Ferric chloride addition (not used)
- Coagulation using in-line rapid mixing
- Contact tank
- Microfiltration unit rated for 50 gpm
- Clearwell
- Finished water pumping
- Discharge to the Devens POTW

The chlorine dioxide oxidizes the iron, arsenic, and manganese, and the resulting solids are filtered by the microfiltration unit, which backwashes every 14 minutes for 1.5 minutes. The backwashed water and solids are processed by the following components:

- Lamella-plate clarifier for solids thickening
- Bag filtration and discharge of lamella decant water
- Solids dewatering with a filter bottom container
- Recycle of filter bottom drainage to the clarifier through building sump

More details regarding the operation of these system components are provided in Section 4.0 of this report.

2.3 MONITORING PROGRAM

Ground Water Monitoring

The groundwater monitoring program includes a total of 67 monitoring wells. Hydraulic monitoring is conducted at all 67 monitoring wells on a semi-annual basis. Water quality sampling (including analysis for arsenic) is conducted at 38 monitoring wells in the Fall (October) and 16 of those 38 wells are sampled in the Spring (April). The analytical parameters are appropriately limited to field parameters, selected inorganic parameters, and seven metals (including arsenic, iron, and manganese).

Process Monitoring

The effluent is sampled on a quarterly basis for metals and other parameters that have an effluent limit for discharge to the POTW. The discharge limits are discussed in Section 3.2. The effluent is sampled annually for VOCs, SVOCs, and pesticides. The influent is sampled annually for VOCs.

3.0 SYSTEM OBJECTIVES, PERFORMANCE, AND CLOSURE CRITERIA

3.1 CURRENT SYSTEM OBJECTIVES AND CLOSURE CRITERIA

The remedial objectives for the Shepley's Hill Landfill Operable Unit are:

- Protect potential residential receptors from exposure to contaminated groundwater migrating from the landfill having chemicals in excess of Maximum Contaminant Levels (MCLs).
- Prevent contaminated groundwater from contributing to the contamination of Plow Shop Pond sediments in excess of human-health and ecological risk-based concentrations.

The 1995 ROD selected remedy for groundwater was a natural reduction in the risk resulting from the installation of the landfill cap and attainment of cleanup goals by January 2008. The required incremental reductions in risk were not achieved, and the Five-Year Review in 2000 concluded that "the contingency remedy of groundwater extraction with subsequent discharge to the Town of Ayer POTW should be re-evaluated by the Army. Although groundwater extraction has the potential to contain groundwater contaminants, it will not prevent the release of arsenic from aquifer materials and would need to be performed for an indeterminate length of time." The primary performance objective of the system is to contain the arsenic plume in the vicinity of the base boundary near the north end of the landfill.

The cleanup levels established for the site are summarized below, and it is inferred that effective containment would result in concentrations meeting these cleanup levels within a short distance downgradient of the north end of the landfill.

Chemical of Concern	Cleanup Level (ug/L)	Selection Basis
Arsenic	10	MCL
Chromium	100	MCL
1,2-Dichlorobenzene	600	MCL
1,4-Dichlorobenzene	5	MMCL
1,2-Dichloroethane	5	MCL
Lead	15	Action Level
Manganese	1,715	Background
Nickel	100	MCL
Sodium	20,000	Health Advisory
Aluminum	6,870	Background
Iron	9,100	Background

MCL – Maximum Contaminant Level
MMCL – Massachusetts Maximum Contaminant Level
Note: MCL for arsenic prior to January 23, 2006 was 50 ug/L

3.2 TREATMENT PLANT OPERATION STANDARDS

Information subsequent to the ROD indicated that the Ayer POTW did not have the capacity to accept the extracted water. Therefore, an Explanation of Significant Differences modified the discharge point to the Devens POTW and required treatment to remove arsenic to levels that meet the Devens POTW permit requirements. The effluent requirements for the treatment system are summarized below.

Parameter	Effluent Limitation[1]
Antimony	10 mg/l
Arsenic	0.20 mg/l[2]
Beryllium	0.30 mg/l
Cyanide (total)	0.30 mg/l
Chromium (total)	2.0 mg/l
Cadmium	0.038 mg/l
Copper	1.0 mg/l
Lead	0.25 mg/l
Nickel	1.0 mg/l
Silver	0.0146 mg/l
Zinc	0.75 mg/l
Selenium	2.5 mg/l
Mercury	0.001 mg/l
Total BOD	400 mg/l
TSS	400 mg/l
Total Toxic Organics	5.0 mg/l
TPH	100 mg/l
Fats, Oils and Grease	100 mg/l
pH (units)	5.5-9.5

1. Recently updated effluent limitation is based on MassDevelopment Industrial Wastewater Discharge Permit (Devens POTW Permit #20) acceptance criteria.
2. Maximum daily loading for arsenic shall not exceed 0.07 lbs.

The Army established the MCL (10 ug/L) as a more stringent standard for the arsenic in the effluent. Additionally, the POTW established the following action levels for arsenic in the treatment system effluent:

- An arsenic effluent concentration exceeding 30 ug/L requires weekly sampling for one month
- An arsenic effluent concentration exceeding 50 ug/L, requires weekly sampling for one month plus an investigation into the reason for the elevated discharge.

4.0 FINDINGS

4.1 GENERAL FINDINGS

The observations provided below are not intended to imply a deficiency in the work of the system designers, system operators, or site managers but are offered as constructive suggestions. These observations have the benefit of being formulated based upon operational data unavailable to the original designers. Furthermore, it is likely that site conditions and general knowledge of ground water remediation have changed over time.

Although the primary treatment system components were designed with a hydraulic capacity of 50 gpm, the entire treatment system was originally incapable of providing the design treatment capacity of 50 gpm due to size or performance of other ancillary components and aspects of the maintenance process. However, the operations team has made important modifications that have allowed the system to operate much closer to its intended rate. The treatment plant is operated effectively and efficiently. The building is clean, the treatment process has been optimized as a matter of practice, and appropriate health and safety measures appear to have been implemented.

4.2 SUBSURFACE PERFORMANCE AND RESPONSE

4.2.1 PLUME CAPTURE

A capture zone analysis was conducted in the 2007 Annual Report (by ECC) using several lines of evidence including a numerical groundwater flow model for the site. That modeling analysis showed favorable capture at the north end of the landfill based on a flow rate of 50 gpm from the remedy wells. However, a subsequent analysis performed by AMEC described in the “Supplemental Groundwater and Landfill Cap Assessment for Long-Term Monitoring and Maintenance” (December, 2008) included results from an updated groundwater flow model, and those results suggested that much of the water leaving the north end of the landfill is not captured at a target rate of 50 gpm (see Figure 5-9 from the AMEC report included in attachment A). This information was re-stated in the 2008 Annual Report (by EEC).

Subsequent to the RSE site visit, the RSE team was provided with MODLOW files for simulation SHL004, which is the recently “calibrated model” by AMEC that is the basis for the particle tracking analysis presented in the 2008 “Supplemental” Report and 2008 Annual Report.

Observations by the RSE team regarding plume capture are included below.

- The evaluation in the 2007 and 2008 Annual Reports by ECC utilize an approach with multiple lines of evidence as recommended in *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems* (USEPA, 2008). However, the “Target Capture Zone” is not clearly established, which is one of the important preliminary steps suggested in that guide. One obvious issue that requires clarity is whether or not the Target Capture Zone for the remedy only deals with groundwater at the north end of the landfill. Another issue is that the text suggests (e.g., in Section 5.1.2 of the 2008 Annual Report) that the impacted portion of the aquifer at the extraction wells is less than 444 feet wide, based on approximate distance from SMH-96-5B toSHL-23. The implication is that the Target Capture Zone is less than 444 ft wide. However, the width of the landfill is significantly greater than 444 feet, and in fact it appears to be more than 1000 ft wide in places. A Target Capture Zone should be clearly defined to indicate if groundwater beneath the whole footprint of the landfill is included, or just a portion.

- One of the lines of evidence presented in the 2007 and 2008 Annual Reports is the “capture zone width calculation” for 50 gpm of groundwater extraction. The calculation is provided based on two aquifer thicknesses (impacted portion of 50 ft and full saturated thickness of 90 ft). The latter appears to be more appropriate, since it is presumed that the extraction wells capture water from the un-impacted portion. The estimated capture zone width for that case was 424 ft, which is less than the 444 ft “plume width” mentioned in the text. However, as noted above, the 444 ft width is significantly less than the width of the landfill footprint. Furthermore, the capture zone width calculation as performed usually has a safety factor of 1.5 to 2.0 incorporated to account for other sources of water to the extraction wells (i.e., surface water, net recharge, upward flow from bedrock). This would reduce the estimated capture zone width to somewhere in the range of 212 to 283 ft rather than 424 ft. This simple calculation suggests that 50 gpm may not be sufficient.

- The AMEC report (December, 2008) does not sufficiently document convergence and mass balance results. Inspection of the modeling files for run SHL004 (i.e., referred to by AMEC as the calibrated model) indicates that the model has a mass balance error of 36%. This mass balance error is unacceptably high by any modeling standards (a mass balance error of less than 0.05% is generally desired). The cause of the mass balance error appears to be the use of an abnormally low value for acceleration parameter in the SIP package of 0.01. This causes the iterations to dampen to such an extent that heads change very little from one iteration to the next, such that the model “converges” (based on the head convergence criteria) but to a head field that is not accurate. This inaccuracy in the head field is manifested in the poor mass balance results that are observed. The RSE team was able to generally duplicate the water level and particle tracking results of run SHL004 using a different set of initial heads (since the initial heads used by AMEC were not provided to the RSE team by the time the analysis was performed). Then, the RSE performed a run using different solution parameters in the SIP package such that the model converged with an acceptable mass balance error (0.04%), and the simulated water levels and particle tracks were vastly different from the original run. Note the model run by the RSE team is not necessarily an accurate model, since it has not been calibrated to site conditions. However, the exercise clearly demonstrates that the model runs described in the AMEC report are impacted by the solution parameters chosen and resulting mass balance error.

- Based on the observation above regarding the mass balance error, the RSE concludes that all modeling results based on the SHL004 simulations are not reliable or meaningful. It is not appropriate to make figures of simulated water levels or particle tracking results based on a model simulation with an unacceptable mass balance error. Any statements or conclusions in the 2008 “Supplemental” or “Annual” reports that are based on modeling results should be considered to be unreliable.

- Given the complex hydrogeology of this site, a reliable flow model is an essential component of a capture zone evaluation. To develop a reliable model further recalibration will be required. The calibration should then compare simulated versus observed water levels, and simulated versus observed drawdown due to pumping (which was the general approach performed by AMEC), but must utilize a model that both converges and achieves an acceptable mass balance.

- During model recalibration, the modeling team might want to consider assigning inactive cells to portions of the model domain expected to go dry, and to abandon use of the rewetting capability of MODFLOW which often causes convergence issues. Also, the current model assumes no recharge beneath the landfill footprint, and this assumption should be verified with site stakeholders and/or addressed via sensitivity analysis with the revised model.

- The comparison of observed and simulated drawdown in the AMEC report is a commendable approach. However, there is no explanation provided as to why the zone of model predicted drawdown greater than 0.5 ft extends so far to the south (see Figure 5-8 of the AMEC report). If this persists after the mass balance error is corrected, this result should be explained based on boundary conditions and parameters assigned in the model.

- The model recalibration may include revising the specification of net recharge, which may be an important parameter with respect to capture. Consideration should be given to installing transducers in a few key wells and monitoring water levels continuously to determine aquifer responses to recharge and provide a basis for potentially refining the assignment of net recharge through model calibration.

- The current AMEC model indicates that the extraction wells capture water only from the west side of the landfill footprint and not the eastern side. The RSE team believes this is likely an artifact of the spurious simulated water levels (related to unacceptable mass balance error discussed above), and this result may be different after the model is revised. Nevertheless, a more precise definition of a "Target Capture Zone" is required to understand if that is acceptable or unacceptable.

- The use of reverse particle tracking as illustrated on Figure 5-9 of the AMEC report is not ideal for illustrating the three-dimensional capture zone. A more effective approach would be to release particles in each cell within the area of interest at a specified depth (such as the middle of layer 1) and track them forward. These particle locations can then be symbolized based on where they end up (i.e., a different symbol for each recovery well, the pond, the creek, etc.). Then that same analysis can be preformed by starting the particles at different elevations (e.g., bottom of layer 1, and middle of layer 2, and perhaps even the upper portion of layer 3 which represents bedrock). This is important to illustrate how similar or different the zone of capture is with respect to depth (which may be complex based on the fact that the extraction wells are only screened in layer 2 and there is vertical anisotropy). This approach would more accurately illustrate the three-dimensionality of the capture zone.

As implied in the first bullet listed above, clarification of a "Target Capture Zone" is an important issue, and it should have two components: 1) clarify the desired capture zone at the north end of the landfill; and 2) clearly state that the system is not intended to capture impacted groundwater discharging to Plow Shop Pond from the southeast portion of the landfill if that is in fact the case. It should also be noted that although the treatment system has been modified to allow it to operate reliably at its intended design capacity of 50 gpm, downtime due to backwashing, cleaning, and sludge dewatering reduce the average flow to less than 45 gpm. Therefore, actual capture may be more limited than depicted in these previous capture zone analyses that assume a rate of 50 gpm. Modeling the average flow rate may ultimately be more appropriate.

4.2.2 GROUNDWATER CONTAMINANT CONCENTRATIONS

Arsenic is the primary contaminant of concern that is driving risk, and the arsenic concentrations in groundwater are more than 400 times the MCL in some locations. Arsenic contamination appears to be highest in the deeper portion of the overburden. Arsenic groundwater concentrations within the footprint of the landfill are not expected to decrease in a timely manner to natural background concentrations due to an ongoing contribution of arsenic related to the landfill (e.g., potential arsenic sources within the landfill and/or dissolved arsenic released from native rock due to reducing conditions associated with the landfill). The sampling record is too short to observe a meaningful trend in arsenic concentrations downgradient of the P&T system, particularly at flow rates close to the target rate of 50 gpm.

4.3 COMPONENT PERFORMANCE

4.3.1 EXTRACTION SYSTEM

The extraction system has functioned as designed and reportedly can provide up to 50 gpm from each of the extraction wells. These maximum extraction rates, however, are not typically employed from either well. The wells operate at approximately 25 gpm each during the normal treatment cycle but will drop to approximately 0 gpm during backwash cycles and plant shut downs for microfilter cleaning and solids dewatering. Based on the operating procedures at the time of the evaluation, the extraction rate drops to 0 gpm as follows:

- Approximately 77 hours per month during the backwash cycle
- Approximately 24 hours per month for solids draining
- Approximately 12 hours per month for microfilter cleaning

Therefore, while a flow rate of 50 gpm is maintained during normal plant operation, the average flow rate over the course of the month is approximately 42 gpm. Further increases in average flow rate may be expected by potentially reducing the backwashing frequency.

4.3.2 CHEMICAL ADDITION, MIXING, AND CONTACT TIME

Chlorine dioxide is generated on-site with Altivia Millenium III Model C150-VF uint (now manufactured by Siemens), which mixes chlorine gas with a 25% sodium chlorite solution. Chlorine gas is stored on site in 150-pound cylinders in a vacuum storage cabinet that is vented through the roof of the building. Sodium chlorite is stored within the building in a 2,500 gallon polyethylene tank. The chemicals are mixed and then fed into the process water with a 0.75 HP feed pump. Excess chlorine gas is also mixed with the process water through an eductor rather than being vented through the roof. Temperatures in the building near the sodium chlorite tank are reportedly maintained at or above 68 F to prevent crystallization. A chlorine dioxide dosage of approximately 70 mg/L in the process water is maintained. This translates to a usage of approximately 35 pounds of chlorine dioxide per day, which requires approximately 23 pounds of chlorine gas per day and 18 gallons of 25% sodium chlorite per day.

Mixing is provided in the 3-inch PVC line with a Lightnin Line Blender model LBS-1, which has a 0.5 HP motor. Chemical feed is temporarily discontinued during backwash cycles to avoid corrosion of the inline mixer.

Contact time is provided within the feed tank to the microfiltration unit and within an auxiliary 330-gallon tank that was added in March 2009. Together, these two tanks provide an approximate contact time of 6 minutes for the chlorine dioxide to react with the metals before entering the microfiltration unit.

The tanks have 0.5 HP mixers to ensure the process flow stays well mixed and solids do not gather in the tanks. Prior to the addition of the auxiliary contact tank, oxidation (primarily of the manganese) was reportedly occurring within the filter or in the clearwell after the filter (which would then be introduced to the filter during the backwash cycle). This "delayed" manganese oxidation was causing premature fouling of the filter and an increased frequency of microfilter cleaning.

4.3.3 MICROFILTRATION

The microfilter is a Pall Aria Model AP-2, provided with 8 Microza modules for a flux rate of 17 gallons per square foot per day at 50 gpm and 20 gallons per square foot per day at 60 gpm. At the time of the evaluation site visit, the microfilter backwashed on a timed cycle of approximately 14 minutes. The backwash cycle includes air scouring. Each backwash event generates approximately 67 gallons of solids laden water discharged to the lamella plate clarifier for thickening.

The unit consists of a 3 HP feed pump and a 3 HP backwash pump. The VFD for the feed pump is set at 61% during forward flow and the VFD for the backwash pump is set at 59% for the first 60 seconds and 71% for the following 30 seconds.

A manual Clean-In-Place (CIP) operation is required periodically for the microfilter to prevent long-term fouling of the filter membranes. The CIP procedure has been modified based on system operation experience, including the addition of a larger hot water heater in March 2009 to provide adequate hot water for an efficient CIP. Prior to March 2009, the CIP events were 30 hours each every two weeks, and after the March 2009 adjustments, the CIP events have been reduced to 12 hours each less than once per month.

4.3.4 SOLIDS HANDLING

Solids handling consists of pumping the backwashed solids to the lamella clarifier for solids settling. The thickened solids (estimated to be approximately 1% solids) are then mixed with polymer and pumped with a 0.75 HP progressive cavity pump to a 15 cubic yard filter bottom roll-off container. Decant water from the clarifier was originally recycled to the head of the plant, but in March 2009, a bag filter unit was added to allow this water to be filtered and directly discharged, eliminating the recycle flow and freeing plant capacity to treat extracted water. The filter-bottom roll off receives and dewaters solids from approximately 1.25 million gallons of treated water before reaching capacity. For 12 hours prior to arranging for solids disposal, the treatment plant is shutdown to allow the solids to dewater. Solids are then collected with a vactor (sewer cleaning) truck and hauled to Turnkey Landfill in Rochester, New Hampshire.

Approximately 1,600 pounds of solids are generated from treating 1.25 million gallons of water, and the invoices for waste disposal indicate between 8 and 10 tons of material is disposed of each time, suggesting a solids fraction of 8% to 9% by weight. The 8 to 10 tons of material translates to less than 8 to 10 cubic yards of volume. As a result, solids are transferred off-site for disposal at relatively high water content and in relatively small batches.

4.3.5 DISCHARGE

Treated water from the microfilter is discharged to the Devens POTW. Two 5 HP pumps operating in alternating mode pump the water through a 3-inch discharge line that runs the length of the landfill from north to south to the Devens sewer. The discharge line is on top of the landfill, is protected by only 18 inches of cover, and must be drained in the winter if the system is not operating to avoid freezing within the line.

4.4 Components Or Processes That Account For Majority of Annual Costs

O&M costs are approximately $500,000 per year under a fixed-price contract. A summary of available information is provided below with additional explanation in the following subsections. All costs assume operation at a flow rate of approximately 45 gpm.

Item Description	**Approximate Annual Cost**
Project Management, Reporting, O&M Labor	Confidential
Electricity	$25,000
Chemicals	
• Sodium chlorite	$40,000
• Chlorine gas	$11,000
• Other (polymer, sodium hypochlorite, citric acid)	$5,000
Waste Disposal	$74,000
Water Discharge	$81,000
Other	Confidential
Total Estimated Annual Cost	**$500,000**

4.4.1 Utilities

Electricity usage information for the period from March 2008 through March 2009 was provided and suggested an annual usage of approximately 120,000 kWh. Electricity usage from June through November of 2008 averaged approximately 7,000 kWh per month, and the electricity usage for the months of December through May average approximately 13,000 kWh per month. The difference of 6,000 kWh per month is likely attributed to electrical heating and is equivalent to approximately 8.3 kW of continuous electrical resistive heating provided by the four 3 to 5 kW electric heaters provided in the building. The baseline value of 7,000 kWh per month would be attributed to motor operation for the various extraction and treatment system pumps and mixers.

The above annual electrical usage information coincides to a period when the system was operating at an average flow rate of approximately 35 gpm. Now that the system is expected to operate at a higher flow rate of near 45 gpm (an approximate 30% increase), the electrical usage for motor operation will likely also increase. It is reasonable to assume that the increase will be approximately 30% of the 7,000 kWh per year assumed for operations other than heating, or 2,100 kWh per year. The electricity usage for heating should remain unchanged. Therefore, moving forward, the total electrical usage during six non-heating months is likely 9,100 kWh (which is consistent with the motor sizes and VFD settings observed during the evaluation site visit) and the total electrical usage during six heating months is likely 15,100 kWh. Using the 2008 rate for electricity (approximately $0.17 per kWh), the electrical cost will likely be approximately $25,000 per year, and approximately $6,000 of that $25,000 will be for building heating.

4.4.2 Non-Utility Consumables and Disposal Costs

This category comprises a large percentage of the treatment plant costs and includes cost for sodium chlorite use, chlorine gas use, other chemical use, and waste disposal.

Estimated sodium chlorite use at an average system flow rate of approximately 45 gpm is approximately 6,400 gallons per year at approximately 10 pounds per gallon for a total of approximately 64,000 pounds per year. At an average price of approximately $0.63 per pound of sodium chlorite (including transportation costs), this translates to approximately $40,000 per year for sodium chlorite.

Estimated chlorine gas use at an average system flow rate of approximately 45 gpm is approximately 6,400 pounds per year. At an average price of approximately $1.67 per pound, this usage translates to approximately $11,000 per year.

At a system flow rate of approximately 45 gpm, solids from the filter bottom roll-off container will be emptied approximately once every 1.25 million gallons of water treated (approximately once every 17 days or approximately 21 times per year). At an average cost of approximately $3,500 per event, this translates to approximately $74,000 per year in waste disposal.

The POTW costs are reportedly approximately $90,000 per year based on treating the permit limit of 72,000 gallons per day (50 gpm). This translates to approximately $3.40 per 1,000 gallons treated. The evaluation team did not review the fee structure for the permit, but assumes that treating 45 gpm should result in an annual cost of approximately $81,000 per year.

4.4.3 Labor

The operator indicated that approximately 20 hours of labor are billed to the site each week. Additional labor is directed toward project management and reporting. Cost information for this category was not requested or provided at the request of the site contractor given that the contract is a fixed-price contract.

4.4.4 Chemical Analysis

Chemical analysis costs were not directly quantified but are assumed to be fairly low for the process water sampling given that samples are collected quarterly.

4.5 Approximate Environmental Footprint of the Remedy

4.5.1 Energy, Air Emissions, and Greenhouse Gases

Direct energy usage for the site includes electricity, diesel associated with waste hauling, diesel associated with chemical delivery, and gasoline associated with operator labor. Air emissions, including emissions of greenhouse gases, would result from this direct energy usage at the site along with the emissions associated with manufacturing of site-related chemicals, disposing of waste, discharging water to the POTW, and site emissions of methane from the extracted water and landfill gas. Table 4-1 summarizes these items and estimates the emissions of greenhouse gases (in carbon dioxide equivalents) plus nitrogen oxides and sulfur dioxide. Greenhouse gases are of global concern, and the other three pollutants are of more local concern as they adversely affect local/regional air quality. Briefly, nitrogen oxides (NOx) are respiratory irritants and precursors to ground level ozone. Sulfur dioxide is also a respiratory irritant and is a precursor to acid rain. Emissions of other pollutants may also be of concern, but these common pollutants, were selected because emissions information is more readily available for them and they may be adequate indicators for other potential air emissions.

The results from Table 4-1 are summarized below.

Item	Carbon Footprint (lbs CO_2e/yr)	Percent Contribution of Carbon Footprint	
		P&T Only	**P&T + LFG**
Energy			
Electricity	191400	52%	41%
Diesel	25168	7%	5%
Gasoline	5928	2%	1%
Energy Subtotal	**222,496**	**60%**	**48%**
Materials			
Sodium chlorite	32000	9%	7%
Chlorine gas	3712	1%	1%
Other chemicals	7500	2%	2%
Materials subtotal	**43,212**	**12%**	**9%**
Waste Disposal & Direct Emissions			
Non-hazardous landfill disposal	12852	3%	3%
POTW	45000	12%	10%
Methane from water	46200	12%	10%
Disposal subtotal	**104,052**	**28%**	**23%**
P&T System Subtotal	**369,760**	**100%**	**80%**
LFG Emissions**			
Carbon dioxide	0		
Methane	92400		20%
LFG emission subtotal	**92400**		**20%**
Total	**462,160**		**100%**

** More than 50% of the carbon footprint associated with diesel is associated with the transport of sodium chlorite and more than 30% of the diesel carbon footprint is associated with transport of waste for disposal.*

*** The provided landfill emissions rate assumes an average air flow rate of 1 cfm from the landfill. This flow rate has not been calculated. Values are presented so that the relative potential magnitude of the carbon footprint of the landfill could be compared with that of the P&T system. The carbon dioxide emitted from the landfill is not included because degradation of the waste to carbon dioxide would occur regardless of whether or not it was in a landfill.*

The above table suggests that the following items are the largest contributors to the carbon footprint and would merit the most attention when looking for carbon footprint reductions:

- Electricity usage (which is directly tied to the system flow rate)
- Sodium chlorite (including the footprint from the diesel used for transport)
- Discharge to the POTW
- Methane emissions from the process water
- Methane from landfill gas emissions

4.5.2 WATER RESOURCES

The GWTP plant currently uses approximately 2400 gpd of potable water for chlorine dioxide generation and approximately 150 gpd for polymer dilution. In addition, bi-monthly CIPs on the microfiltration system uses approximately 600 gallons of potable water. The treatment plant's only discharge is the plant effluent; ultimately any potable water used in system processes is discharged within the system effluent.

The primary consideration for water resources at this site is the impact of the remedy on local groundwater and surface water resources. The remedy is designed to protect groundwater and surface water resources, and attempts to do so by extracting and treating water. The treated water is further discharged to the POTW and then to a receiving surface water body. It is not reinjected or reused for a beneficial purpose.

Studies conducted during system startup concluded that groundwater extraction of 25 to 50 gpm did not adversely affect the wooded wetlands north of the site. It is unclear if a higher extraction rate (if implemented to improve capture) would adversely affect these wetlands.

Groundwater migrating from the area of the landfill to the east discharges to Plow Shop Pond, and groundwater migrating from the area of the landfill to the north discharges to Nonacoicus Brook, which is located approximately 1,200 feet downgradient of the landfill. The approximate area of impacted groundwater between the landfill boundary and these surface water boundaries is approximately 60 acres. Residential properties in this area were surveyed for private wells, and no wells were reported by the respondents; however, the aquifer is considered a potential source of drinking water. Much of the overlying land is designated as Natural Heritage Endangered Species Project Rare Wetland Wildlife Habitat Areas.

Arsenic (along with other metals) is found in groundwater and sediments of Nonacoicus Brook above guidelines.

4.5.3 LAND AND ECOSYSTEMS

The existing remedy appears to have little impact on the local and terrestrial ecosystems, with the exception of vehicle and foot traffic associated with groundwater sampling or cap repairs. Traffic is generally confined to a paved road leading to the treatment plant. Noise, particularly associated with chemical deliveries and waste disposal is one of the few impacts operation may have on the immediate surroundings. Under normal operations, little or no chlorine gas is emitted to the atmosphere that would affect local ecosystems. If the treatment system requires substantial modifications to increase capacity, construction associated with the remedy may impact local land and ecosystems.

4.5.4 MATERIALS USAGE AND WASTE DISPOSAL

System operation includes substantial use of manufactured chemicals, including 64,000 pounds of sodium chlorite, which (based on the brand name Akta Klor 25) is likely manufactured in either Fairmont City (IL), Wichita (KS), or Vanceboro (NC), all of which are distant from the site. The manufacturing process is reportedly energy intensive and represents substantially more processing than that of sodium hypochlorite (common bleach).

Approximately 6,400 pounds of chlorine gas is used by the system each year. The chlorine gas is locally available.

Life-cycle inventories for sodium hypochlorite (related to but less intensive to manufacture than sodium chlorite) and chlorine gas are publicly available from www.nrel.gov/lci, documenting the environmental impacts associated with the manufacturing processes of these chemicals. Other chemical and material use at the site, including polymer, bag filters, and citric acid are each individually relatively minor in comparison to the sodium chlorite and chlorine gas use.

Each year approximately 189 tons of solids are disposed of in a landfill as non-hazardous waste.

4.6 RECURRING PROBLEMS OR ISSUES

The treatment plant as designed and constructed appeared to have had several flaws that prevented it from operating at capacity in a consistent and reliable manner. The operations contractor made the following critical improvements that appear to allow the system to operate as intended:

- Addition of a 330-gallon feed tank to provide additional contact time for chlorine dioxide to react with iron, manganese, and arsenic prior to entering the microfilter

- Addition of a larger hot water heater to provide ample hot water for the microfilter CIPs

- Addition of a bag filter on the clarifier supernatant to allow direct discharge of this supernatant to the POTW rather than recycling it through the microfilter

- Replacement of the original 0.33 HP chlorine dioxide feed pump with a 0.75 HP feed pump

4.7 REGULATORY COMPLIANCE

The treatment plant typically meets the internal goal of 10 ug/L of arsenic in the discharged water and the system has met the requirements of the discharge permit.

4.8 SAFETY RECORD

The site team did not report any incidents or near misses to the evaluation team.

5.0 RECOMMENDATIONS

Cost estimates provided herein 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. The costs and sustainability impacts of these recommendations are summarized in Tables 5-1 and 5-2.

5.1 RECOMMENDATIONS TO IMPROVE EFFECTIVENESS

5.1.1 REVISIONS GROUNDWATER FLOW MODEL AND UPDATED CAPTURE ZONE EVALUATION

Given the complex hydrogeology of this site, a reliable flow model is an essential component of a capture zone evaluation. The RSE team strongly recommends that the groundwater flow model be revised using solution technique parameters that achieve convergence and an acceptable mass balance error (ideally less than 0.05%). Once that is accomplished, model recalibration should be performed by comparing simulated versus observed water levels, and simulated versus observed drawdown due to pumping. Given that the model is already constructed, and calibration data sets for water levels and drawdown due to pumping already exist, recalibration of the model plus particle tracking simulations based on that model should require on the order of $25,000. A revised capture zone evaluation should include clarification and documentation of the Target Capture Zone (based on stakeholder agreement which will likely require some meetings) and should also be based on results from the revised flow model. This effort may require on the order of $20,000.

5.1.2 POTENTIAL OPTIONS FOR INCREASING PLUME CAPTURE WITH EXISTING SYSTEM

The December 2008 Supplemental Report (and 2008 Annual Report) included a revised capture zone analysis using a site groundwater flow model that indicates the P&T system does not fully capture impacted water leaving the property boundary (see Attachment A for Figure 5-9 from that report). The RSE team believes this is likely an artifact of the spurious simulated water levels (related to unacceptable mass balance error discussed earlier), and this result may be different after the model is revised. However, if the revised model ultimately supports the conclusion that capture provided by the extraction wells is not sufficient, then the RSE team might suggest several potential approaches for increasing plume capture, which are briefly described below.

Reinject Treated Water

Reinjecting treated water can increase or decrease plume capture depending on the location of the reinjection with respect to the location of extraction. Generally, reinjecting water within the plume or upgradient of the plume can reduce capture zone width (due to increased hydraulic gradients), whereas reinjecting an appropriate distance downgradient of the extraction system can increase capture zone width in the vicinity of the extraction and some distance upgradient of the extraction (due to reduced hydraulic gradients caused by the reinjection) . The hydrogeology of the site is too complex to definitively determine the most appropriate location for reinjection, and the revised model should likely be used to determine the optimal locations. The advantages and disadvantages of two potential locations are as follows:

- Reinjecting approximately 100 to 200 feet downgradient of the extraction wells (actual distance and location to be determined by modeling) would likely broaden the width of the capture zone in the vicinity of the wells. This location has the likely added benefit of perhaps lower iron and manganese concentrations to reduce the potential for well fouling. Depending on the nature of the surface soils and the available space, infiltration basins or subsurface infiltration galleries with cleanouts may be the most effective approach. Reinjection wells would also be a possibility but would likely be more prone to fouling.

- Reinjecting immediately upgradient of Plow Shop Pond (e.g., from SHL-19 to SHL-20) would likely divert impacted groundwater from flowing into Plow Shop Pond or at least reduce the amount of impacted groundwater discharging to Plow Shop Pond. Some of this diverted water may be directed toward the extraction system, but much of it may be directed downgradient to the east of the extraction system. If extraction wells were later planned east of the existing extraction network, this upgradient injection would be counterproductive.

Reinjecting the treated water has the added benefit of avoiding the discharge to the POTW, which could eliminate between $81,000 and $90,000 per year in discharge costs. Some of this savings would be offset by the capital to install the reinjection system and to maintain the reinjection system. Water quality routinely meets the discharge criteria; therefore, there should not be significant expense in further improving treatment to meet the criteria for reinjection. The cost for a reinjection system, depending on the design, could likely be paid back within 2 to 3 years with the savings from the avoided discharge costs. In concept, the concern with injecting water with a chlorine residual should be of minimal concern for water quality (assuming sufficient distance is present between the injection points) given the ample amount of iron and manganese that would consume that residual prior to discharge to surface water. The more practical concern is the potential for fouling reinjection wells or the aquifer as additional iron and manganese precipitates in the presence of chlorine residual from the treatment process.

With respect to sustainability, reinjecting the water will reduce flow to the POTW and therefore eliminate the footprint from POTW operation associated with the diverted capacity. This may be as much as 12% of the carbon footprint of the P&T system as suggested in Section 4.5.1. Furthermore, reinjecting the water avoids a net withdrawal of water from the area between the landfill and Nonacoicus Brook, though the water in this area will likely not be of sufficient quality for beneficial use for many years.

Redirect Clean Water Around the Landfill

Figure 5-9 from the December 2008 Supplemental Report (see Attachment A of this report) indicates substantial groundwater flow from recharge on Shepley's Hill migrating through the landfill and then either to the extraction network, Plow Shop Pond, or downgradient to Nonacoicus Brook. It is assumed that a revised model would provide similar results in that regard. If the amount of water discharging from Shepley's Hill through the landfill is reduced then less groundwater would flow through the landfill, and the capture zone could widen substantially. This could be accomplished by pumping clean recharge water from Shepley's Hill before it flows through the landfill and either reinjecting it downgradient of the extraction system, discharging it to Plow Shop Pond, or discharging it to Nonacoicus Brook. It should be noted that recharge from the hill may flow primarily through the fractured rock and discharge upward to overburden beneath the landfill cap. In this event, interception of the recharge from the hill would require a line of *bedrock* wells along the east side of the hill (i.e., west side of the landfill). Because Shepley's Hill and the associated water table in this location is higher than the described discharge points, much of this flow could be accomplished by gravity to avoid the electrical costs and environmental footprint of operating pumps. The water that would be extracted from Shepley's Hill would naturally be expected to discharge to these locations. This approach would therefore not upset the natural water balance in the region or degrade the water of the receiving units. Studies are currently underway to characterize the water quality (arsenic concentrations in groundwater) on Shepley's Hill, and the results of these studies should be considered when exploring this option.

The revised site groundwater flow model could be used to evaluate this option, potential locations for clean water extraction, and the optimal flow rates.

5.1.3 Potential Options for Increasing System Capacity, If Necessary

If the above options are not sufficient to provide adequate capture and an increased extraction rate is needed, the treatment plant could require substantial modifications to achieve the necessary capacity. Higher flow rates could reportedly be extracted from each of the existing extraction wells, and a spare line was included during building construction to accommodate flow from another well. Depending on the amount the flow rate is increased, modifications to system piping, process water pumps, and feed pumps would be needed. In addition, the following major modifications would also be needed.

- Additions to the existing microfilter unit to increase its capacity or a second microfiltration unit in parallel would be needed to increase system capacity. Alternatively, a large clarifier could be added outside or in a separate building to provide primary solids separation through settling. Pressure filters with a higher capacity could then replace the microfiltration unit. Proper consideration and design would need to be given to an outdoor clarifier to accommodate freezing temperatures in the winter.

- Modified solids handling would also likely be necessary, including a larger solids thickening tank. Given the increase in solids generation, a larger filter bottom roll-off would be needed, but it would probably be more practical to operate a filter press rather than continue with the filter bottom roll-off. This would entail purchasing the filter press, mounting it above a lined roll-off, installing an additional or larger air compressor, and air-operated diaphragm pump. Another cost consideration for using a filter press is whether a sludge with higher solids content, roughly 30%, would be considered a hazardous waste. The current sludge generated by the FBRO, roughly 10% solids, is a non-hazardous waste. More information regarding modified solids handling is discussed in Section 5.2.

The above modifications would be substantial and costly, but it is possible that the equipment (except a large clarifier, if this option is chosen for solids separation) may fit in the existing building, albeit with much more cramped conditions.

5.2 Recommendations to Reduce Costs

5.2.1 Alternative Discharge Options

The potential cost savings associated with reinjection are documented above in Section 5.1.2. Similar cost savings might be realized by discharging to surface water, but would likely require either a several day residence time in a lined impoundment or chemical treatment (e.g., ascorbic acid) to neutralize residual chlorine. Although there may be a preference to avoid long-term chemical addition, the impoundment would need to be quite large (approximately 100 feet in diameter) given the available space and would be subject to freezing and operational problems during the winter. The capital cost for providing a discharge line to surface water and providing the capacity for chlorine neutralizing chemicals might be on the order of $75,000. Cost savings from avoiding POTW charges would be on the order of $90,000 per year but these savings would be offset by the cost of chemicals and increased sampling. Annual savings might be on the order of $70,000 per year.

5.2.2 ALTERNATIVE CHEMICAL USAGE

Sodium chlorite is one of the most costly items for this P&T, and it may be worth identifying an appropriate alternative to the current chemical and/or vendor. Two particular options could be considered and further investigated. First, the site is using Akta Klor 25 at a price of $0.43 per pound plus an additional $0.20 per pound for freight. The high freight cost may be due to the long distances between the manufacturers and the site. The www.nsf.org identifies manufacturers of various chemicals used for water treatment, and three locations in the country were identified for manufacturing Akta Klor 25: Fairmont City (IL), Wichita (KS), and Vanceboro (NC). The closest of these is Vanceboro, NC at over 700 miles from the site.

Although Akta Klor 25 may be specified by the vendor of the chlorine dioxide generator, other 25% sodium chlorite solutions may be appropriate, and speaking with other sodium chlorite vendors/manufacturers would be helpful. A lower price for freight, and possibly for the chemical, may be identified. ECC reported that they have made several attempts to identify alternative sodium chlorite vendors, but have not successfully identified an option to date that significantly lowers delivery costs. ECC indicates this is primarily due to the fact that the tank size at the site (2500 gallons) is smaller than the minimum delivery requirements (5000 gallons) of a typical tanker truck.

Another possibility would be to revisit the use of sodium hypochlorite as the oxidant. During the bench scale testing for the system design, sodium hypochlorite performed better than chlorine dioxide in terms of iron and arsenic removal. However, the chemical was abandoned because of the concern that it did not oxidize and precipitate the manganese. Hypochlorite is known to oxidize manganese at sufficient doses, but longer contact time may be needed prior to filtration. During the bench scale testing, the jar tests for hypchlorite were described as being immediately filtered after hypochlorite addition. The results showed excellent iron and arsenic removal but poor manganese removal. For the chlorine dioxide testing, chlorine dioxide and hypochlorite were tested together with chlorine dioxide added after hypochlorite. The contact time was not provided and was not described as immediate. This approach of using the same jar allowed the hypochlorite to continue reacting with the manganese, making it difficult to discern if the hypochlorite or chlorine dioxide (or both) was responsible for the oxidation. The system design and original construction failed to even provide adequate contact time for the chlorine dioxide. The current extended contact time, or perhaps even slightly longer (but still practical) time may allow use of hypochlorite instead of chlorine dioxide. With sufficient and practical contact time, sodium hypochlorite at the appropriate dose may be an appropriate oxidant. If this is the case, chemical costs and carbon footprint could be reduced. Bench scale tests should be conducted to determine the dosage of sodium hypochlorite to estimate the potential cost savings and reduction in carbon footprint. If sodium hypochlorite is used, the chlorine dioxide generation system and chlorine tanks could be removed from the building. This might provide extra room that could be valuable if expanding the plant capacity is necessary. There is also an added safety benefit of not using chlorine gas. However, sodium hypochlorite is a much weaker oxidant, and it is possible that providing sufficient storage and a chemical addition system for the sodium hypochlorite might present addition capital expenses that could be prohibitive.

5.2.3 MODIFIED SOLIDS HANDLING

Solids handling is another costly aspect of the treatment system and also has a relatively high footprint when diesel for transport is included. The approach to using a filter bottom roll off container has the benefit of passive dewatering that does not require operator attention, except for discontinuing system operation for 12 hours while the roll off dewaters. However, there are a few technical limitations to this approach and associated substantial subcontract costs.

- The filter-bottom roll-off is relatively small and apparently can only store up to 9 tons of material (less than 9 cubic yards), partially due to the practice of letting it dewater before transport. This results in relatively frequent disposal events, each with substantial "fixed" costs.

- A vactor truck (sewer cleaning truck) is needed to extract the material from the roll-off. This is labor intensive, and the vactor truck also has relatively limited capacity. This capacity also results in relatively frequent disposal events, even if a larger roll-off is used.

- The vactor truck requires washing after each event.

- There is still a relatively high water content (e.g., 10% solids) even after dewatering, which increases disposal costs for a given amount of solids disposal.

The following table analyzes the cost for waste disposal of solids generated from treating 4 million gallons of water using the current solids handling process and using a filter press assuming the press yields approximately 30% solids. With this approach three disposal events are required with the current solids handling process and one disposal event (with several press pulls) is required with the filter press approach.

Item	**Filter-Bottom Roll-Off (3 events)**	**Pressed Solids in a Roll-Off (1 event)**
Labor for transferring material to transport truck	$900	$0
Roll-off spot and rental	$0	$750
Truck and operator for pickup	$3,000	$1,000
Disposal	$3,600	$1,200
Vactor truck washout	$2,000	$0
Surchages/tax	$1,000	$400
Press pulls (one per week for 8 weeks)	$0	$4,000
Total	**$10,500**	**$7,350**

The above table suggests a savings of approximately $3,000 over an approximate 55 day period, which could translate to savings of approximately $20,000 over the course of a year. Significant capital would be required, including the purchase of a new air compressor, diaphragm pump, a larger solids storage/thickening tank, and a filter press. The capital associated with making these modifications (perhaps approximately $100,000) might be paid off in approximately 5 years.

Significant reductions could also be realized with respect to the environmental footprint. The footprint for waste transport would be approximately one third of the current footprint. In addition, the carbon and land footprints associated with disposal in the landfill would also be reduced by approximately one third.

Overall, a reduction of approximately 18,000 pounds of carbon dioxide might be realized per year. A detailed analysis has not been conducted; however, it is likely that a "carbon payback" (i.e., completely offsetting the carbon associated from making the modifications with annual carbon reductions from the modified process) might also be on the order of 5 years.

5.3 RECOMMENDATIONS FOR TECHNICAL IMPROVEMENT

5.3.1 MEASURE SPECIFIC CAPACITY OF WELLS

The extraction wells were each designed to provide the full system capacity of 50 gpm, but the wells only run at approximately 25 gpm each to reach the design capacity of the system. Given the high iron concentrations and potential microbial activity associated with a landfill, fouling of the wells is a possibility. Fouling can become progressively worse with little warning if specific capacity is not measured and tracked. As a well fouls, the system controls may slightly increase the VFD frequency on the extraction pumps to counter the small increase in total dynamic head associated with the falling water level in the well. However, this may be a very small change and the fouling could become quite substantial, to the point where well rehabilitation is no longer practical. Measuring the specific capacity on a monthly basis by measuring the water level in the well while the well is operating at a normal extraction rate is suggested. A 20% decrease in the specific capacity would suggest the need for well maintenance. ECC indicates they plan to begin monthly recording of extraction well water levels in August 2009. However, they also indicate that such data could be complicated due to the backwashing that occurs with the system (currently the wells pump at 54 gpm for 15 minutes and are idle for 90 seconds while the microfilter backwashes).

5.3.2 DISCONTINUE ADDITION OF SODIUM HYPOCHLORITE TO MICROFILTRATION CLEAR WELL

Sodium hypochlorite is currently added to the clear well of the microfiltration unit in accordance with the manufacturer's instructions. This provides additional chlorine residual during backwashing, and is likely good common practice for potable water treatment facilities to avoid bacteria growth. Given that this is not a potable water system, the addition of sodium hypochlorite in this location is likely not merited. Minimal savings would be expected, but the (perhaps) unnecessary use of chemicals could potentially be avoided.

5.4 CONSIDERATIONS FOR GAINING SITE CLOSE OUT

This evaluation specifically focused on the efficiency of the operating system and did not consider remedy alternatives that could lead to faster site closure.

5.5 RECOMMENDATIONS FOR IMPROVED SUSTAINABILITY

Many of the recommendations provided in the preceding sections for protectiveness and cost-effectiveness consider sustainability. The following recommendations are presented with sustainability as the primary driver.

5.5.1 Use of Water Source Heat Pump for Building Heat

Heating the building with inefficient electrical heat costs approximately $6,000 per year, uses approximately 36,000 kWh of electricity per year, and generates approximately 47,500 pounds of carbon dioxide per year. More efficient building heat could be provided with a water source heat pump tied to the system effluent. This is the same technology as ground source or geothermal heat pumps except that heat would be transferred to and from the system effluent rather than to the subsurface. Water source heat pumps operating with an influent concentration of approximately 45 F would be approximately four times more efficient than heating with electrical resistive heating. In addition, there is the flexibility of choosing hydronic or forced air distribution. Hydronic heating (heated water in radiators) might lend itself to more localized zone heating along the building floor rather than forced-air heating provided from above as is currently the practice. The water source heat pump should reduce electrical usage by approximately 75% yielding savings of approximately $4,500 per year and a carbon footprint reduction of approximately 35,000 pounds per year. Capital improvements would require a water source heat pump capable of providing approximately 30,000 btus per hour of heat, a heat exchanger to allow heat transfer with the effluent without sending the effluent directly through the heat pump, piping, feed pump, and a heat distribution system. The evaluation and sizing of the system is fairly straightforward, and the option would only make sense if the water for the geothermal system is the water that is already extracted and treated (precluding the need to design and install closed loops or standing column wells). The capital costs (approximately $15,000) for this system would likely be paid back with savings in approximately 3 years.

5.5.2 Use Solar Spark Flares to Combust Passive Methane Emissions

The passive methane emissions from the landfill gas and from the extracted water constitute a large portion of the carbon footprint, perhaps 33% or more of the total footprint for this part of the site. Solar spark flares can be installed on passive vents to combust the methane. Although carbon dioxide is produced, the carbon dioxide is a substantially weaker greenhouse gas than methane, and carbon dioxide would be the natural fate of the organic material degraded within the landfill. Solar spark flares can be placed on individual vents at a cost of approximately $5,000 per vent or the vents can be combined into a smaller number of vents and spark flares installed on the smaller number of vents. Based on the data presented in Table 6-3 of the 2008 Draft Supplemental Report, the following seven landfill gas vents would be the primary candidates for this technology: GV-9, GV-13, GV-14, GV-15, GV-16, GV-17, and GV-18. Although these vents are all at the southern end of the landfill, it is more sustainable (e.g., lower carbon footprint and less damaging to the local ecosystem) to provide a flare for each vent rather than pipe them together. Providing individual flares for these seven vents plus the methane vent for the process water (at approximately $40,000 total) would likely be comparable in cost or slightly cheaper than tying several vents together. The solar spark flares work by providing a regular, repeating spark to ignite methane when the concentrations are over the lower explosive limit. This is a good option for conditions at this landfill, where there are high methane values during periods of low barometric pressure (which will ignite), but non detectable levels once the barometric pressure increases (there will be no ignition during those periods of time). A solar panel keeps the battery for the sparking unit charged. Flame arrestors are installed to prevent the flame from entering the vent.

5.6 CONSIDERATIONS FOR RENEWABLE ENERGY AT THE SITE

Cost Analysis for Solar

A cost analysis for a 100 kW photovoltaic system capable of providing 90% of the P&T system's electricity is included in Attachment B. The analysis uses local solar intensity (Worcester, MA), commonly used photovoltaic efficiency parameters, and local electrical rates. The payback period, assuming rebates from the Commonwealth Solar Incentive Program are available, is approximately 15 years. Although a 125 kW system would provide 100% of the P&T system's electricity demand, the 100 kW size was specifically chosen to optimize the system size and financial payback. The rebate values are lower for systems over 100 kW. In the absence of any rebates, the payback is over 20 years.

The site is invoiced for power by MassDevelopment, but it is unclear what utility is providing electricity to MassDevelopment. If it is one of the investor-owned utilities that pays into the Massachusetts Renewable Energy Trust, then the rebate should be available for the site. As a public entity, the site stakeholders cannot benefit from the 30% Federal Tax Credit offered for photovoltaic systems or tax benefits that would accrue from depreciating the equipment. However, the site team might consider discussing the matter with MassDevelopment to see if they or another private third-party would be willing to build, own, and operate the system for a small fee so that the benefits of the 30% Federal Tax Credit and depreciation could be realized. For a private party, realizing the benefits of the 30% Federal Tax Credit and depreciation could result in a payback that is closer to 10 years.

The cost analysis does not consider selling the renewable energy credits ("green tags") generated by the system because it is assumed that the renewable energy credits would be retained by the site so that the generated renewable energy is credited to the site rather than sold to another entity. If renewable energy was generated on-site but the renewable energy credits were sold to another party, the "ownership" of the renewable energy would be transferred to the party purchasing the renewable energy credits.

Cost Analysis for Wind

A cost analysis for a 100 kW wind turbine capable of providing 80% of the P&T system's electricity is included in Attachment B. The analysis uses local (Worcester, MA) wind speed and power density information, appropriate system efficiency parameters, and local electrical rates. The payback period, assuming grants from the Commonwealth Wind Incentive Program are available, is approximately 12 years. This simple cost analysis includes some costs for generic permitting, but up-front costs could be higher if significant effort is required for town meetings, achieving variances, etc., and such costs (if significant) could potentially increase the payback period of the system by several years. In the absence of these rebates, the payback is approximately 20 years.

The site is invoiced for power by MassDevelopment, but it is unclear what utility is providing electricity to MassDevelopment. If it is one of the investor-owned utilities that pay into the Massachusetts Renewable Energy Trust, then the rebate should be available for the site. As a public entity, the site stakeholders cannot benefit from the 30% Federal Tax Credit offered for small wind systems (i.e., 100kW or smaller) or tax benefits that would accrue from depreciating the equipment. However, the site team might consider discussing the matter with MassDevelopment to see if they or another private third-party would be willing to build, own, and operate the system for a small fee so that the benefits of the 30% Federal Tax Credit and depreciation could be realized. For a private party, realizing the benefits of the 30% Federal Tax Credit and depreciation could result in a payback could be under 10 years.

The cost analysis does not consider selling the renewable energy credits (“green tags”) generated by the system because it is assumed that the renewable energy credits would be retained by the site so that the generated renewable energy is credited to the site rather than sold to another entity. If renewable energy was generated on-site but the renewable energy credits were sold to another party, the “ownership” of the renewable energy would be transferred to the party purchasing the renewable energy credits.

Limitations of Landfill Gas

Landfill gas generation at the site is consistent with an older landfill. Methane is present in the passive vents but at a concentration that is below the concentration needed for power generation with a turbine or engine. In addition, the quantity of generation is sufficiently low that flow is controlled by changes in barometric pressure. Consistent gas extraction would yield substantially lower methane concentrations.

Cost Analysis and Rationale for Green Tags

Renewable energy can also be used to power the P&T system by purchasing “green tags” or renewable energy certificates. The market price is approximately $0.025 per kWh. It would therefore cost approximately an additional $3,600 per year to power the P&T system with renewable energy that is generated elsewhere in the country. Comparing this option to the wind and solar options described above, this option would have no upfront capital costs but would cost approximately an additional $36,000 over the next 10 years (assuming green tag prices do not increase). By comparison, the solar option described above (including the rebates but excluding benefits of tax credits and depreciation) would still be $100,000 from breaking even and the wind option would be approximately $50,000 from breaking even. As a result, over a 10-year time frame, the purchase of green tags may make more financial sense. If the planning horizon is a 20-year period, then the green tag option would cost over $72,000 additional, where as the wind and solar options would be more than $200,000 cash positive.

Table 4.1 Energy and Atmosphere Footpring Analysis

	Quantity	Unit	CO2 equiv (lbs)		NOx		SOx		Energy Usage	
			emission factor (lbs/unit)	total	emission factor (lbs/unit)	total (lbs)	emission factor (lbs/unit)	total (lbs)	conversion factor (btus/unit*)	total (MMbtus)
Energy										
Electricity	145,000	kWh	1.32	191400	0.00086	124.7	0.00236	342.2	9751	1414
Diesel	1144	gallons	22	25168	0.17	194.48	0.0054	6.1776	138700	3
Gasoline	312	gallons	19	5928	0.11	34.32	0.0045	1.404	124200	2
Energy Subtotal				**222,496**		**354**		**350**		**1,419**
Materials										
Sodium chlorite (25% solution)	64,000	pounds	0.5	32000					7000	224
Chlorine gas	6,400	pounds	0.58	3712					7000	26
Other chemicals	$5,000	dollars	1.5	7500					7000	53
Materials subtotal				**43,212**						**302**
Waste Disposal & Direct Emissions										
Non-hazardous landfill disposal	189	tons	68	12852					7000	90
POTW	25	gal x 106	1800	45000	Not calculated. The emissions of NOx and SOx associated with these activities are not necessarily local to the site, and insufficient information is available to provide meaningful results NOx and SOx quantities.				7000	315
Methane from water	2,200	pounds	21	46200						
Disposal subtotal				**104,052**						**405**
P&T System Subtotal				**369,760**						
LFG Emissions										
Carbon dioxide	12,000	pounds	0	0						
Methane	4,400	pounds	21	92400						
LFG emission subtotal				**92,400**						
Total				**462,160**						**2,127**

** energy conversion factor for materials, waste disposal, and POTW treatment is based on btus per pound of carbon dioxide equivalent emitted.*
Mmbtu = 1,000,000 btus

Usage and Emission Factor Notes for Table 4-1.

Unless otherwise specified, information regarding emission factors was obtained from the life-cycle inventory at www.nrel.gov/lci. Costs used in deriving emission factors are consistent with costs during Spring 2009.

MMbtus (millions of btus)

- Electricity uses conversion of 3,413 btus per kWh and electricity generation efficiency of 35%
- Energy density for diesel is assumed to be 138,700 btus per gallon, consistent with Direct Emissions from Mobile Sources, U.S. EPA Climate Leaders Program, May 2008 EPA430-K-08-004.
- Energy density for gasoline is assumed to be 124,200 btus per gallon, consistent with Direct Emissions from Mobile Sources, U.S. EPA Climate Leaders Program, May 2008 EPA430-K-08-004.
- Energy usage for manufactured items and off-site services based on approximately 7,000 btus per pound of carbon dioxide equivalents, which is representative of the energy per pound of carbon dioxide equivalent from electricity, diesel, and gasoline usage.

Electricity

Quantity – 145,000 kWh used based on scaling up 2008 electricity usage by the expected increase in system flow rate

Emission Factor – 1.32 pounds of carbon dioxide equivalents, 0.00086 pounds of nitrogen dioxide, and 0.00236 pounds of sulfur dioxide per kWh. Based on eGRID2007 for New England (NEWE) output emission rate for non-base-load using equivalency ratios of 21:1 methane to carbon dioxide and 310:1 nitrous oxide to carbon dioxide from http://www.epa.gov/solar/energy-resources/calculator.html

Diesel

Quantity – The sum of the following usages

- 0.023 gallons per ton per mile of transport, for 9 tons of waste transported 85 miles to Turnkey Landfill in Rochester, NH 21 times per year
- Assumed average of 1 gallon of fuel per hour for 5 hours, 21 times per year to extract solids from filter-bottom roll off into vactor truck
- 0.023 gallons per ton per mile of transport, for 29 tons (64,000 pounds) Akta Klor 25 transported 1,000 miles (approximate average distance from nearest manufacturing facilities in Fairmont City, IL and Vanceboro, NC to Devens, MA)
- 0.023 gallons per ton per mile of transport, for 4.5 tons (6,400 pounds plus cylinder) of chlorine gas transported 25 miles (approximate distance from Merrimack, NH to Devens, MA)

Emission Factor – 22 pounds of carbon dioxide per gallon of diesel, consistent with Direct Emissions from Mobile Sources, U.S. EPA Climate Leaders Program, May 2008 EPA430-K-08-004. NOx and SOx emission factors based on www.nrel.gov/lci emissions for transportation with a single-unit, diesel powered truck.

Gasoline

Quantity – 2 gallons of gasoline per trip, three times per week, 52 weeks per year for operator labor. Footprint for groundwater sampling is not included

Emission Factor – 19 pounds of carbon dioxide per gallon of gasoline, , consistent with Direct Emissions from Mobile Sources, U.S. EPA Climate Leaders Program, May 2008 EPA430-K-08-004. NOx and SOx emission factors based on www.nrel.gov/lci emissions for transportation with a single-unit, gasoline powered truck.

Sodium Chlorite

Quantity – 64,000 pounds per year Akta Klor 25 (25% sodium chlorite solution), refer to report text for additional information

Emission Factor – 0.5 pounds of carbon dioxide per pound of 25% sodium chlorite solution based on 1.14 pounds of carbon dioxide per dollar of sodium chlorite (on a dry compound basis) purchased and a purchase price of $0.43 per pound of 25% solution. Relating the carbon dioxide output to the purchase price reflects that a given portion of the cost is spent on energy and raw materials that are obtained or manufactured with fossil fuel energy and that the amount of energy involved in processing scales with the price. The 1.14 pounds of carbon dioxide per dollar is based on the emission factor and cost of sodium hypochlorite (a related compound) for which life-cycle inventory data is publicly available.

Chlorine Gas

Quantity – 6,400 pounds per year, refer to report text for additional information

Emission Factor – 0.58 pounds of carbon dioxide per pound of chlorine gas based on the chlor-alkali life-cycle inventory from www.nrel.gov/lci and distributing the footprint based on the fraction of co-products that is chlorine gas

Other Chemicals

Quantity – Usages were not directly quantified. The emission factor used is based on a percentage of chemical cost directed toward energy from fossil fuels. Approximately $5,000 of chemicals (polymer, sodium hypochlorite, and citric acid) is assumed.

Emission Factor – 1.5 pounds of carbon dioxide per dollar of chemical, based on 15% of the cost of the chemicals resulting from the direct use of fossil fuels or electricity derived from fossil-fuels, and approximately 10 pounds of carbon dioxide emitted per $1 of fossil fuels consumed. 10 pounds would represent a blend of natural gas, diesel, gasoline, and coal.

Non-Hazardous Landfill Disposal

Quantity – 189 tons per year based on 9 tons disposed of 21 times per year

Emission Factor – 68 pounds of carbon dioxide per ton, based on $135 per ton of disposal, 5% of the cost of disposal resulting from the direct use of fossil fuels or electricity derived from fossil-fuels for all activities associated with constructing, operating, closing, and maintaining a landfill, and approximately 10 pounds of carbon dioxide emitted per $1 of fossil fuels consumed. 10 pounds of carbon dioxide would represent a blend of natural gas, diesel, gasoline, and coal.

POTW Discharge

Quantity – 25 million gallons per year based on an average discharge rate of approximately 50 gpm

Emission Factor – 1,800 pounds of carbon dioxide per million gallons discharged, based on $3,600 per million gallons of discharge ($90,000 per year divided 25 million gallons per year), 5% of the cost of discharge resulting from the direct use of fossil fuels or electricity derived from fossil-fuels resulting from the increased flow, and approximately 10 pounds of carbon dioxide emitted per $1 of fossil fuels consumed. 10 pounds would be representative of using diesel fuel as the primary source of energy (for earth moving equipment)

Methane Emissions from Water

Quantity – 2,200 pounds per year of methane released from extracted water based on complete volatilization of methane from water, 10,000 ug/L methane concentration, and 50 gpm flow rate

Emission Factor - 21 equivalent pounds of carbon dioxide emitted per pound of methane emitted

LFG Emissions

Quantity – No measureable emission flow rate has been reported but carbon dioxide and methane are being generated and are detected suggesting emissions are occurring from the passive venting system. Assuming 1 cfm of emissions is occurring from the landfill with 20% carbon dioxide and 20% methane (concentrations are consistent with monitoring results), this would translate to approximately 12,000 pounds of carbon dioxide emitted per year and 4,400 pounds of methane emitted per year. A rate of LFG emissions cannot easily be calculated based on available information, but an average flow rate of 1 cfm is a reasonably low approximation that could be easily scaled if more information becomes available.

Emission Factor – 21 equivalent pounds of carbon dioxide emitted per pound of methane emitted

Table 5-1. Cost Summary Table

Recommendation	Reason	Additional Capital Costs ($)	Estimated Change in Annual Costs ($/yr)	Estimated Change in Life-Cycle Costs $*	Estimated Change in Life-Cycle Costs (net present value) $**
5.1.1 Revisions Groundwater Flow Model and Updated Capture Zone Evaluation	Effectiveness	$45,000	$0	$45,000	$45,000
5.1.2 Potential Options For Increasing Plume Capture With Existing System • Reinject Treated Water • Redirect Clean Water Around The Landfill	Effectiveness	Not Quantified Not Quantified	Not Quantified Not Quantified	Not Quantified Not Quantified	Not Quantified Not Quantified
5.1.3 Potential Options For Increasing System Capacity, If Necessary	Effectiveness	Not Quantified	Not Quantified	Not Quantified	Not Quantified
5.2.1 Alternative Discharge Options	Cost-Effectiveness	$90,000	($70,000)	($1,310,000)	($953,000)
5.2.2 Alternative Chemical Usage	Cost-Effectiveness	Not Quantified	Not Quantified	Not Quantified	Not Quantified
5.2.3 Modified Solids Handling	Cost-Effectiveness	$100,000	($20,000)	($300,000)	($198,000)
5.3.1 Measure Specific Capacity Of Wells	Technical Improvement	$0	Negligible	Negligible	Negligible
5.3.2 Discontinue Addition Of Sodium Hypochlorite To Microfiltration Clear Well	Technical Improvement	$0	Negligible	Negligible	Negligible
5.5.1 Use Of Water Source Heat Pump For Building Heat	Sustainability	$15,000	($4,500)	($75,000)	$52,000

Recommendation	Reason	Additional Capital Costs ($)	Estimated Change in Annual Costs ($/yr)	Estimated Change in Life-Cycle Costs $*	Estimated Change in Life-Cycle Costs (net present value) $**
5.5.2 Use Solar Spark Flares To Combust Passive Methane Emissions	Sustainability	$35,000	$0	$40,000	$40,000
5.6 Considerations For Renewable Energy At The Site • Solar • Wind • Landfill Gas • Renewable Energy Certificates	Sustainability Renewable Energy	$700,000 $396,000*** $550,000 $275,000*** N/A $0	$21,500 – $54,500 $17,500 - $56,000 N/A $3,600+	($242,000) ($302,000) N/A $72,000+	($78,000) ($149,000) N/A $54,000+

Costs in parentheses imply cost reductions
* assumes 20 years of operation with a discount rate of 0% (i.e., no discounting)
** assumes 20 years of operation with a discount rate of 3% and no discounting in the first year
*** with rebates or grants

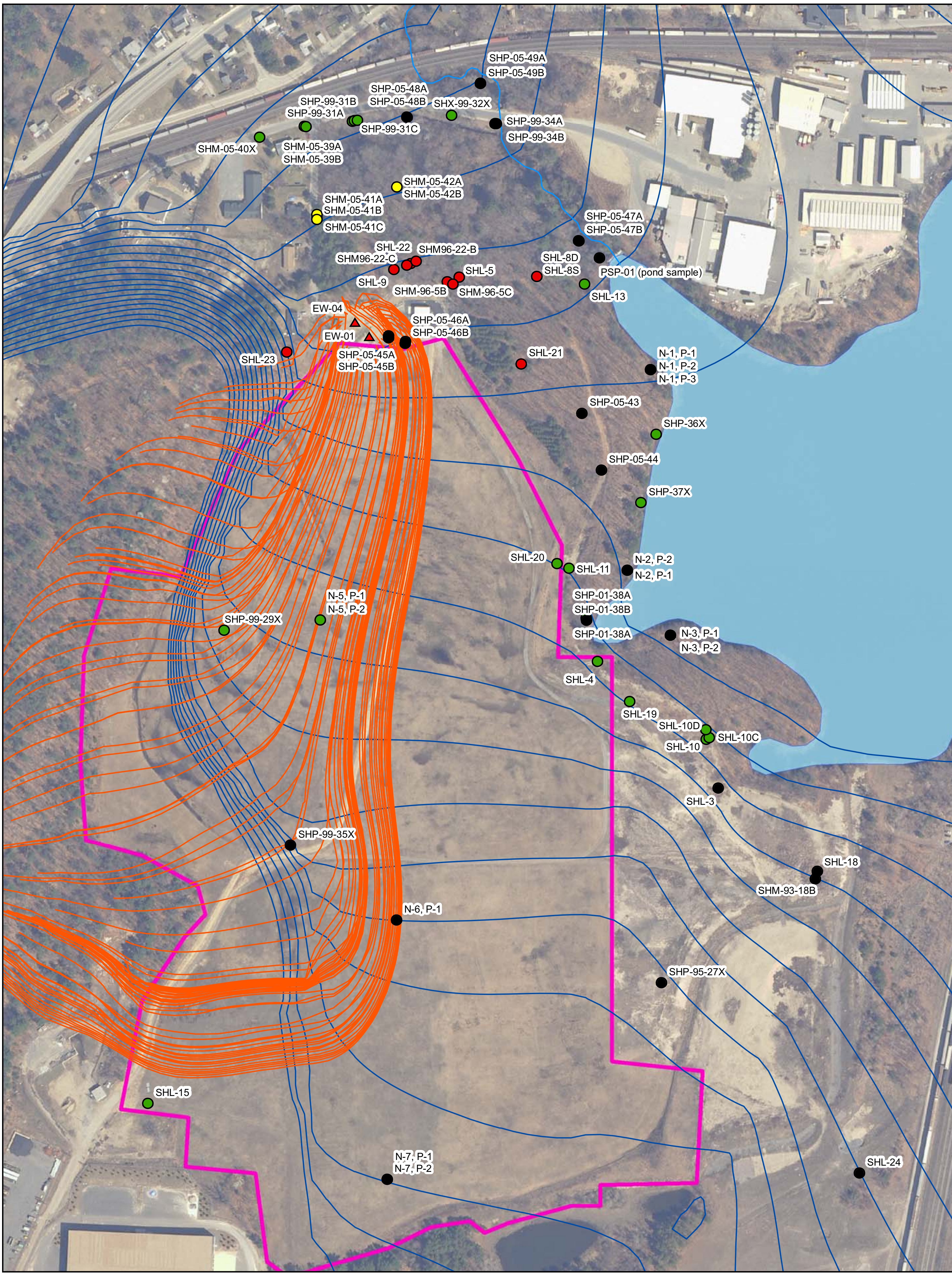
Table 5-2. Sustainability Summary Table for Recommendations

Recommendation	Reason	Effects on Sustainability
5.1.1 Revisions Groundwater Flow Model and Updated Capture Zone Evaluation	Effectiveness	Not quantified
5.1.2 Potential Options For Increasing Plume Capture With Existing System • Reinject Treated Water • Redirect Clean Water Around The Landfill	Effectiveness	Potential to reduce carbon footprint of the P&T by 45,000 pounds (approximately 14% of P&T footprint) Substantially enhance sustainability by reducing the amount of water needing treatment
5.1.3 Potential Options For Increasing System Capacity, If Necessary	Effectiveness	Not quantified
5.2.1 Alternative Discharge Options	Cost-Effectiveness	Potential to reduce carbon footprint of the P&T by approximately 12%
5.2.2 Alternative Chemical Usage	Cost-Effectiveness	Potential to reduce carbon footprint, but bench testing needed in order to quantify effect
5.2.3 Modified Solids Handling	Cost-Effectiveness	Potential to reduce carbon footprint of the P&T by 18,000 pounds (~5% of P&T footprint)
5.3.1 Measure Specific Capacity Of Wells	Technical Improvement	No effect
5.3.2 Discontinue Addition Of Sodium Hypochlorite To Microfiltration Clear Well	Technical Improvement	Small benefit, not quantified
5.5.1 Use Of Water Source Heat Pump For Building Heat	Sustainability	Potential to reduce carbon footprint by approximately 35,000 pounds per year (~9% of P&T footprint)

Recommendation	Reason	Effects on Sustainability
5.5.2 Use Solar Spark Flares To Combust Passive Methane Emissions	Sustainability	Potential to reduce carbon footprint by over 100,000 pounds per year (over 20% of the P&T and LFG footprints combined)
5.6 Considerations For Renewable Energy At The Site • Solar • Wind • Landfill Gas • Renewable Energy Certificates	Sustainability Renewable Energy	Potential to eliminate or substantially reduce footprints associated with electricity usage at the site.

ATTACHMENT A:

Selected Figures from Previous Site Reports



SITE LOCATION

Revised Model Predicted Capture Zone

Supplemental Groundwater and Landfill Cap Assessment

Devens
Ayer, Massachusetts

Notes & Sources: Aerial Imagery: 1:5,000 Color Digital Ortho Images, Mass GIS, 2005.
Based on AMECs "SHL002" operating conditions
model derived from the existing "run412" model developed by CH2M Hill (2005).

LEGEND

- Wells Sampled Quarterly
- Wells Sampled Fall and Spring
- Wells Sampled Fall Only
- Wells Sampled for Hydraulics Only
- Extraction Well
- Model Predicted Capture Zone
- Model Predicted Groundwater Elevations (ft amsl)
- Landfill Boundary

0 300
Feet

N

amec
AMEC Earth & Environmental, Inc.
2 Robbins Road
Westford, MA 01886
(978) 692-9090

FIGURE
5-9

H:\ShepleyLandfill\Task17\MXD\Figure5-9.mxd H:\ShepleyLandfill\Task17\Export\Figure5-9.pdf June 25, 2008 DWN: DJK AP CHKD: BJB

SITE LOCATION

Watertable Elevations
February 20, 2008

Devens
Ayer, Massachusetts

LEGEND

- Groundwater Well
- Extraction Well
- Groundwater Contour (ft msl)
- Topographic Elevation Contour (ft msl)
- Landfill Boundary

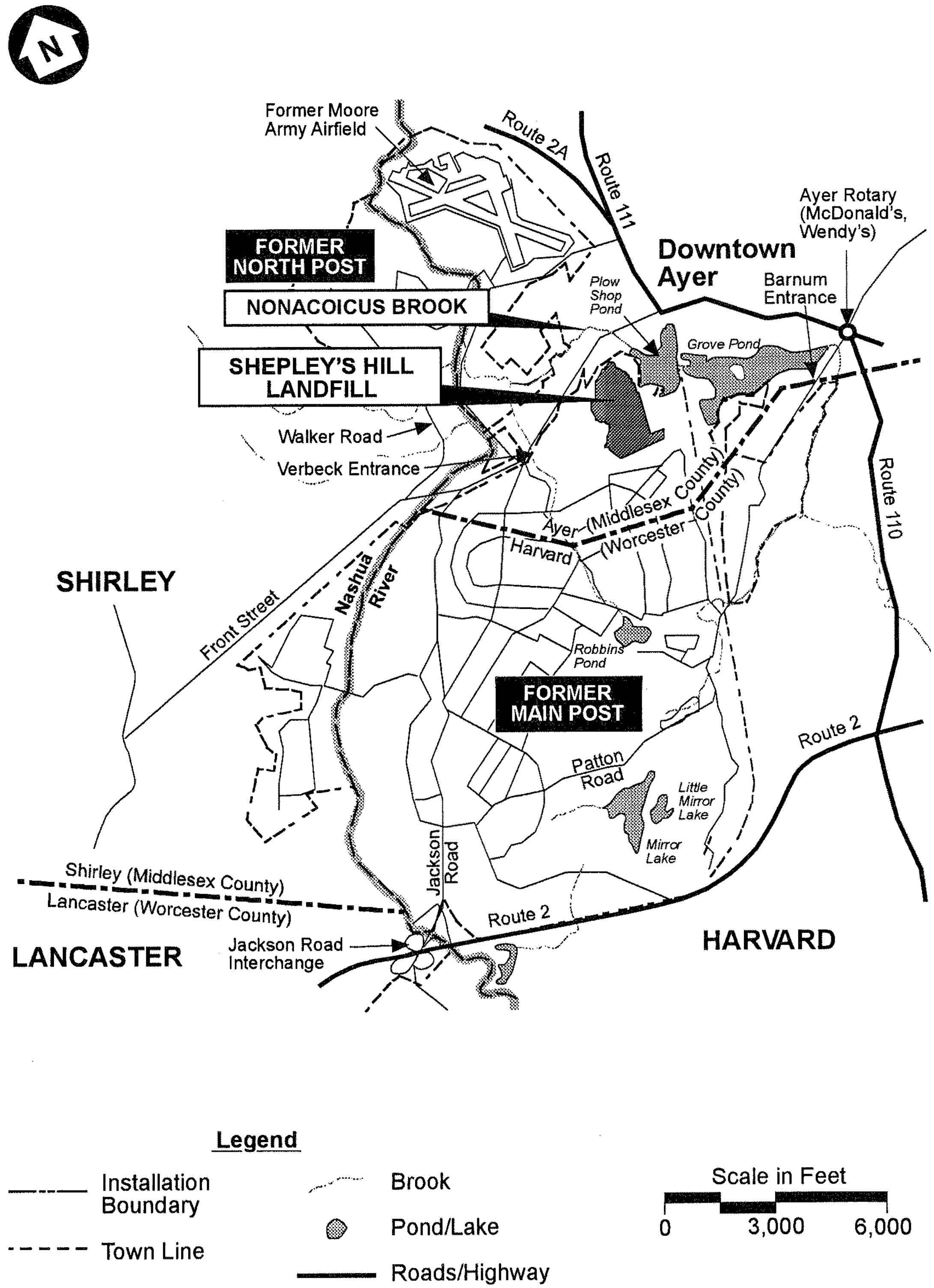
0 300
Feet

amec
AMEC Earth & Environmental, Inc.
2 Robbins Road
Westford, MA 01886
(978) 692-9090

FIGURE
4-1

Notes & Sources: Aerial Imagery: 1:5,000 Color Digital Ortho Images, Mass GIS, 2005.

H:\ShepleyLandfill\Task17\MXD\Figure4-1.mxd H:\ShepleyLandfill\Task17\Export\Figure4-1.pdf June 27, 2008 DWN: KMP DJK AP CHKD: BJB



Harding ESE
A MACTEC Company

Location of Shepley's Hill Landfill
Supplemental Groundwater Investigation
Devens Reserve Forces Training Area
Devens, Massachusetts

FIGURE **1-1**

DRAWN:	JOB NUMBER:	FILE NUMBER:	APPROVED:	DATE:	REVISED DATE:
BGF	45227-993802	W2001097(d)		6/99	2/12/2

Cross Section Locations

Devens
Ayer, Massachusetts

LEGEND

- Well & Boring Locations
- Stream Gauge Locations
- Cross Sections
- Elevation, ft
- Landfill Boundary

SITE LOCATION

NOTES & SOURCES

Aerial Imagery: 1:5,000 Color Digital Ortho Images, Mass GIS, 2005.

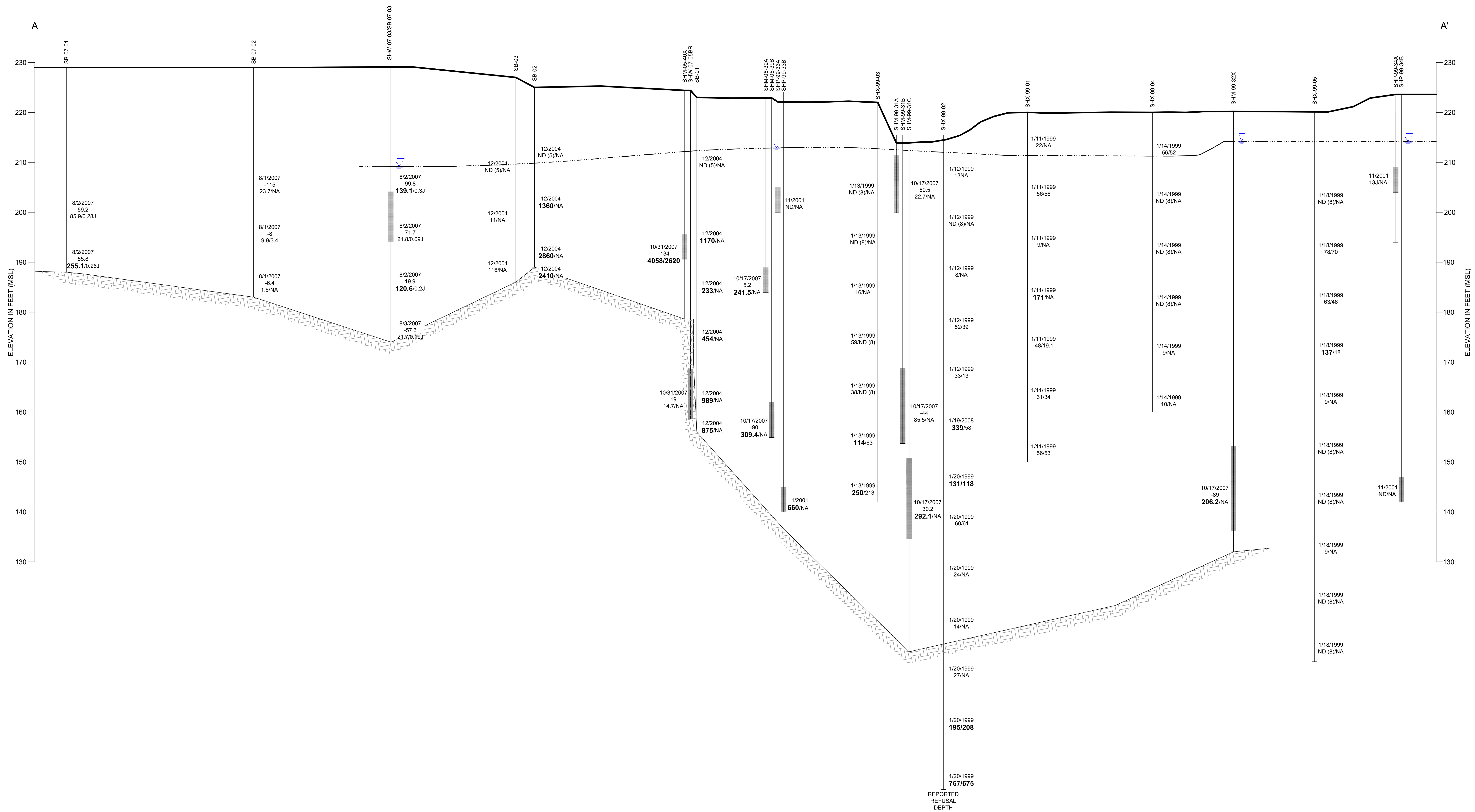
0 200
Feet

amec

AMEC Earth & Environmental, Inc.
2 Robbins Road
Westford, MA 01886
(978) 692-9090

H:\ShepleyLandfill\Task17\MXD\Figure4-2.mxd
H:\ShepleyLandfill\Task17\MXD\Figure4-2.pdf
December 3, 2008 DWN: APC DJK CHKD: KMP

FIGURE
4-2



LEGEND:

SB-07-01BS WELL IDENTIFICATION

GROUND SURFACE

GROUNDWATER OBSERVED

GROUNDWATER ELEVATION

MONITORING WELL

DATE 8/2/2007

ORP (Mv) -128

21.8/0.09J SCREEN

TOTAL AS / DISSOLVED AS (ppb)

NOTE: AS VALUES >100 ppb HIGHLIGHTED IN BOLD

DRAFT

NOTE: THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH THE AMEC EARTH & ENVIRONMENTAL REPORT No. ___ DATED ___.

HORIZONTAL SCALE: 1" = 80'

0 80' 160'

0 20' 40'

VERTICAL SCALE: 1" = 20'

REV	D	M	Y	ISSUE/REVISION DESCRIPTION	ENG.	APPR.
G						
F						
E						
D						
C						
B						
A	00	00	2005	ISSUED FOR CLIENT REVIEW	X.X.	X.X.

Client Logo:

Client: USACE

AMEC Earth & Environmental
2 ROBBINS ROAD
WESTFORD, MASSACHUSETTS 01886

www.amec.com/earthandenvironmental

DATUM: N/A

PROJECTION: N/A

DRAWN BY: R. BOWMAN

REVIEWED BY: M. ROBINSON

ORIGINAL SCALE: AS SHOWN

PROJECT: SHEPLEY'S HILL FORT DEVENS, MASSACHUSETTS

TITLE: CROSS SECTION A-A'

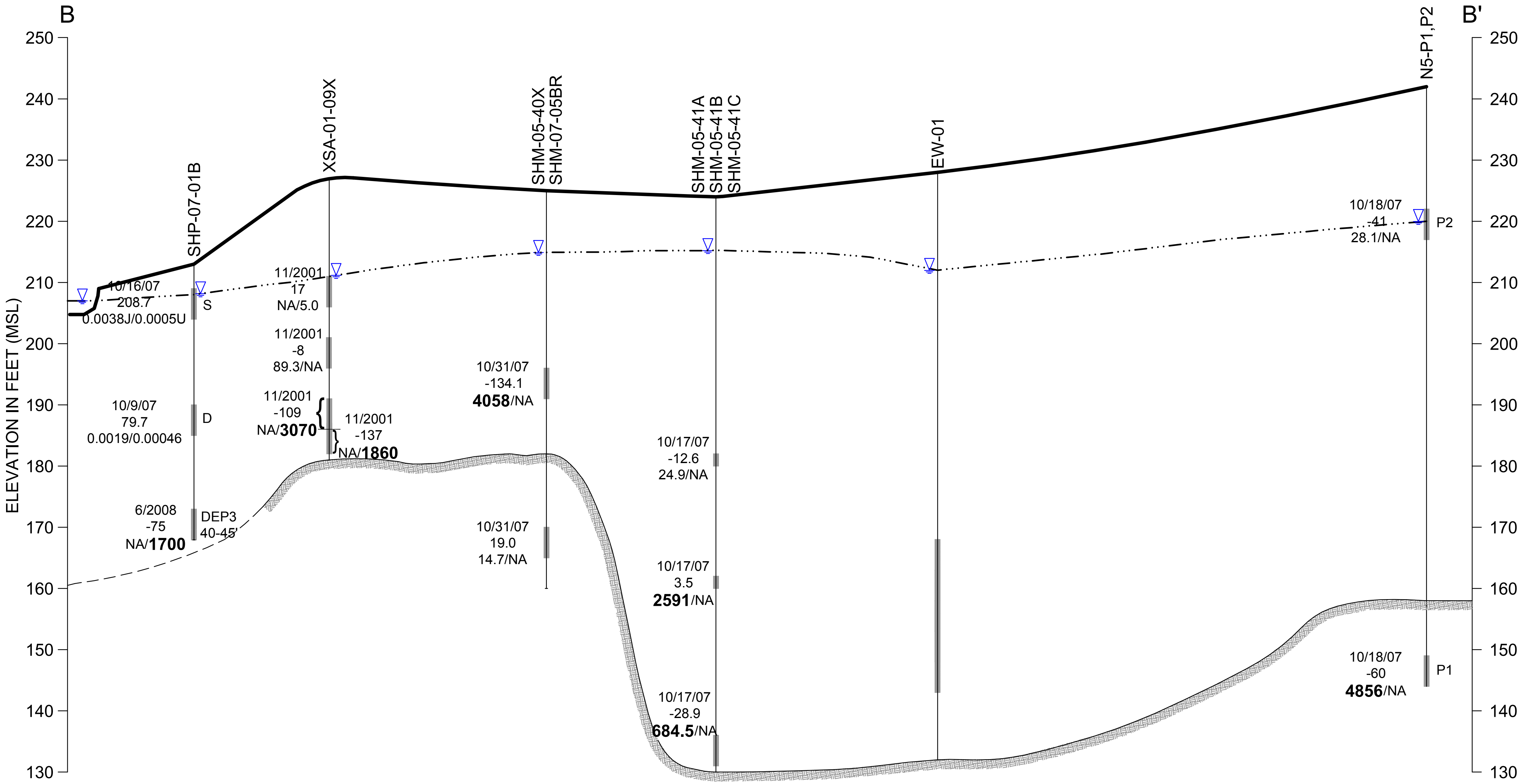
PROJECT NO.: 3-2106-0116

REVISION NO. A

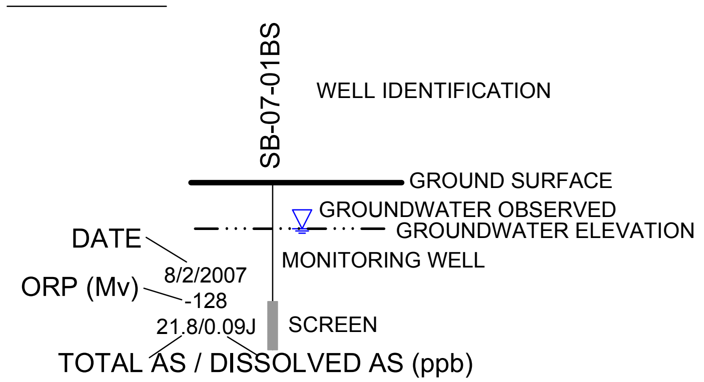
DATE: 23 JUNE 2008

FIGURE NO.: 4-3

SHEET NO.: 4-3



LEGEND:



NOTE: AS VALUES >100 ppb HIGHLIGHTED IN BOLD

HORIZONTAL SCALE: 1" = 200'

0 200' 400'

0 20' 40'

VERTICAL SCALE: 1" = 20'

DRAFT

NOTE: THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH THE AMEC EARTH & ENVIRONMENTAL REPORT No. ________ DATED _______.	CLIENT LOGO	CLIENT: USACE	DRAWN BY: R. BOWMAN CHECKED BY: C. KEATING	PROJECT: SHEPLEY'S HILL FORT DEVENS, MASSACHUSETTS	DATE: 23 JUNE 2008 PROJECT NO: 3-2106-0116
		AMEC Earth & Environmental 2 ROBBINS ROAD WESTFORD, MASSACHUSETTS 01886	DATUM: N/A PROJECTION: N/A SCALE: AS SHOWN	TITLE: CROSS SECTION B-B'	REV. NO.: A FIGURE No. 4-4

P:\USACE\ShepleysHillLandfill\CAD\6-23-08\Cross Section B-B.dwg -- Section B-B' -- Jun. 30, 2008 9:19am -- ron.bowman

ATTACHMENT B:

Economic Analysis for Solar Power and Wind Power

Financial Analysis
Photovoltaic System - Devens, MA

System Power (DC, STC)	100	kW	**Solar Capital Cost**		**$700,000**	
System Efficiency	77%		Grant 1st 25kW		$78,750	Commonwealth Solar Incentive Program
System Power (AC)	77	kW	Grant 25 to 100 kW		$225,000	Utility must pay into the Mass. Renewable Energy Trust
Installed Unit Cost	$7,000	$/kW DC	**Total MTC Grant**		**$303,750**	
			Solar Grant %		43.39%	
Annual Production	126,821	kWh/yr	**Cost After Grants**		**$396,250**	
Electricity Rate	$0.1700	$/kWh	**Net Upfront Cost**		**$396,250**	
			30% fed tax credit		$0	not applicable to military
			max taken in 1st year		$0	not applicable to military
Demand Charge	$0.0000	$/kW	amount remaining		$0	not applicable to military
			Loan Amount	$0		
			Loan Term	0		years
Escalation	5.00%	{annual rate increase}	Interest Rate	0.00%		per year
			Annual Payment	$0		
Estimated SREC value	$0.0000	$/kWh				
			Tax Rate	0.0%		not applicable to military

Year	Cash/Loan	Federal Tax Credit and Depreciation	Tax Deduction on Loan Interest	Avoided Energy Cost Photovoltaic System	Other Federal Credit (per kWh)	REC	Cash Flow	Cumulative Cash Flow
1	($396,250)	$0	$0	$21,560	$0	$0	($374,690)	($374,690)
2	$0	$0	$0	$22,411	$0	$0	$22,411	($352,279)
3	$0	$0	$0	$23,296	$0	$0	$23,296	($328,983)
4	$0	$0	$0	$24,217	$0	$0	$24,217	($304,766)
5	$0	$0	$0	$25,173	$0	$0	$25,173	($279,593)
6	$0	$0	$0	$26,168	$0	$0	$26,168	($253,425)
7	$0	$0	$0	$27,201	$0	$0	$27,201	($226,224)
8	$0	$0	$0	$28,276	$0	$0	$28,276	($197,948)
9	$0	$0	$0	$29,393	$0	$0	$29,393	($168,556)
10	$0	$0	$0	$30,554	$0	$0	$30,554	($138,002)
11	$0	$0	$0	$31,760	$0	$0	$31,760	($106,242)
12	$0	$0	$0	$33,015	$0	$0	$33,015	($73,227)
13	$0	$0	$0	$34,319	$0	$0	$34,319	($38,908)
14	$0	$0	$0	$35,675	$0	$0	$35,675	($3,233)
15	$0	$0	$0	$37,084	$0	$0	$37,084	$33,851
16	$0	$0	$0	$38,549	$0	$0	$38,549	$72,400
17	$0	$0	$0	$40,071	$0	$0	$40,071	$112,471
18	$0	$0	$0	$41,654	$0	$0	$41,654	$154,125
19	$0	$0	$0	$43,299	$0	$0	$43,299	$197,424
20	$0	$0	$0	$45,010	$0	$0	$45,010	$242,434
21	$0	$0	$0	$46,788	$0	$0	$46,788	$289,222
22	$0	$0	$0	$48,636	$0	$0	$48,636	$337,858
23	$0	$0	$0	$50,557	$0	$0	$50,557	$388,414
24	$0	$0	$0	$52,554	$0	$0	$52,554	$440,968
25	$0	$0	$0	$54,630	$0	$0	$54,630	$495,598

Notes:
Avoided energy cost from the photovoltaic system assumes a decay in panel efficiency by 1% per year

DISCLAIMER

Energy demand, usage, and utility costs are estimated. Solar output is estimated based on default/optimal parameters using PVWATTs for Worchester, MA. Actual values may vary depending on facility activities or other factors. No value is assigned to the Renewable Energy Certificates (RECs) because it is assumed that RECs will be retained to apply renewable energy to the facility rather than to sell it to another party. Net metering up to the full capacity of the photovolataic system is assumed but should be confirmed with the inidividual utility.

Financial Analysis
Wind System - Devens, MA

System Name Plate Power	100	kW	**Installed Cost**	**$550,000**	
System Efficiency	35%		Maximum FS Grant	$275,000	Commonwealth Wind Incentive Program
Average System Power (AC)	35	kW			Utility must pay into the
					Mass. Renewable Energy Trust
Average Annual Wind Speed	9.0	mph	**Total MRET Grant**	**$275,000**	
			Grant %	50.00%	
Approx. Wind Power Density	110	w/m2			
Swept Area by Turbine	345	m2			
Annual Production	116,355	kWh/yr	**Cost After Grants**	**$275,000**	
Electricity Rate	$0.1700	$/kWh	**Net Upfront Cost**	**$275,000**	
			30% fed tax credit	$0	not applicable to military
			max taken in 1st year	$0	not applicable to military
Demand Charge	$0.0000	$/kW	amount remaining	$0	not applicable to military
			Loan Amount	$0	
			Loan Term	0	years
Escalation	5.00%	{annual rate increase}	Interest Rate	0.00%	per year
			Annual Payment	$0	
Estimated SREC value	$0.0000	$/kWh			
			Tax Rate	0.0%	not applicable to military

Year	Cash/Loan	Federal Tax Credit and Depreciation	Tax Deduction on Loan Interest	Avoided Energy Cost Wind System	Other Federal Credit (per kWh)	REC	Cash Flow	Cumulative Cash Flow
1	($275,000)	$0	$0	$17,453	$0	$0	($257,547)	($257,547)
2	$0	$0	$0	$18,326	$0	$0	$18,326	($239,221)
3	$0	$0	$0	$19,242	$0	$0	$19,242	($219,979)
4	$0	$0	$0	$20,204	$0	$0	$20,204	($199,775)
5	$0	$0	$0	$21,214	$0	$0	$21,214	($178,560)
6	$0	$0	$0	$22,275	$0	$0	$22,275	($156,285)
7	$0	$0	$0	$23,389	$0	$0	$23,389	($132,896)
8	$0	$0	$0	$24,558	$0	$0	$24,558	($108,337)
9	$0	$0	$0	$25,786	$0	$0	$25,786	($82,551)
10	$0	$0	$0	$27,076	$0	$0	$27,076	($55,475)
11	$0	$0	$0	$28,429	$0	$0	$28,429	($27,046)
12	$0	$0	$0	$29,851	$0	$0	$29,851	$2,805
13	$0	$0	$0	$31,343	$0	$0	$31,343	$34,148
14	$0	$0	$0	$32,911	$0	$0	$32,911	$67,059
15	$0	$0	$0	$34,556	$0	$0	$34,556	$101,615
16	$0	$0	$0	$36,284	$0	$0	$36,284	$137,899
17	$0	$0	$0	$38,098	$0	$0	$38,098	$175,997
18	$0	$0	$0	$40,003	$0	$0	$40,003	$216,000
19	$0	$0	$0	$42,003	$0	$0	$42,003	$258,003
20	$0	$0	$0	$44,103	$0	$0	$44,103	$302,107
21	$0	$0	$0	$46,309	$0	$0	$46,309	$348,415
22	$0	$0	$0	$48,624	$0	$0	$48,624	$397,039
23	$0	$0	$0	$51,055	$0	$0	$51,055	$448,095
24	$0	$0	$0	$53,608	$0	$0	$53,608	$501,703
25	$0	$0	$0	$56,288	$0	$0	$56,288	$557,991

Notes:
Avoided energy cost from the wind system assumes average O&M costs of $0.02/kWh

DISCLAIMER

Energy demand, usage, and utility costs are estimated. System efficiency considers vendor power curves based on the typical local wind speeds. Average wind speed and approximate wind power density were determined from a preliminary review of data from a local weather station in Worcester, MA. Actual site conditions may vary. No value is assigned to the Renewable Energy Certificates (RECs) because it is assumed that RECs will be retained to apply renewable energy to the facility rather than to sell it to another party. Net metering up to the full capacity of the wind system is assumed but should be confirmed with the inidividual utility.