Promotion of Renewable Energy and Energy Efficient Applications for Waste Remediation Sites in Massachusetts

October 11th, 2018

An Interactive Qualifying Project (IQP) Report
Submitted to the faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the
Degree of Bachelor of Science

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Abstract

Thousands of contaminated properties and waste sites in the United States cause groundwater pollution. Groundwater remediation systems often rely on electricity generated from non-renewable energy, namely burning fossil fuel. The Massachusetts Department of Environmental Protection (MassDEP) has been promoting energy efficiency and renewable energy sources to reduce greenhouse gas emissions associated with groundwater remediation. Our team utilized MA waste site data, MassDEP databases and remedial monitoring reports, a site visit, and interviews to determine if green and efficient energy applications are viable in the remediation process. Gains in energy efficiency from system component modifications and use of solar power can effectively reduce greenhouse gas emissions.

Executive Summary

Thousands of contaminated properties and industrial waste sites in the United States cause air, water and soil pollution. Waste sites can negatively impact public health through pollution of groundwater, the main source of drinking water for people (Maibach, 2015). Waste sites can range from toxin-ridden soil near abandoned chemical facilities to small oil spills at gas stations. Most potential groundwater contamination sources include gasoline storage tanks, septic systems, landfills, chemicals such as pesticides and fertilizers and other uncontrolled hazardous wastes (The Groundwater Foundation, 2018).

In 1980, the Environmental Protection Agency (EPA) established the federal superfund program, which provides guidelines for classifying the most hazardous waste sites throughout the nation, and enables the EPA to identify and hold accountable the parties responsible for the contamination (United States Environmental Protection Agency, n.d.). Using this as framework, the Commonwealth of Massachusetts created The State Superfund Law which allows the MA government to take designated actions (described in the Massachusetts contingency plan) in response to any site containing a risk of oil or hazardous material release (The General Court of the Commonwealth of Massachusetts, 2018).

The Massachusetts Department of Environmental Protection regulates and monitors cleanup and remediation processes in MA. They have aided in identifying 47,759 hazardous waste sites throughout the state. Through their efforts and regulations, hundreds of these sites have been successfully remediated, leaving only 200 sites left today.

A significant program that MassDEP is responsible for monitoring is the Licensed Site Professional (LSP) Program. LSPs are the individuals who oversee waste site assessments and cleanup processes at specific sites (Sellers, 1998). The LSPs' role is to direct the assessment, characterization, and, to the extent necessary, the cleanup process along with relevant regulations and laws.

Waste site cleanup programs in MA utilize a variety of different remedial technologies in order to reduce or eliminate contamination. One of the most common types is the Pump & Treat process, which is used to hydraulically remove pollutants to restore aquifers (MassDEP, 2009). The Groundwater Remediation (GWR) cleaning method, a specific type of P&T, is commonly used to reduce the amount of pollution and environmental damage by cleaning contaminated underground water (MassDEP, 2009). GWR systems often implement various approaches to treatment, the most common being carbon activation, air stripping, and metals removal (Pump and treat technology, 2007).

The current operation of GWR systems present two key problems that cause an environmental paradox. First, GWR systems require electricity, often generated from fossil fuel-based sources (Massachusetts Department of Environmental Protection, 2012). Significant usage of non-renewable energy directly leads to high material consumption and pollution to the contaminated sites, such as greenhouse gas emission (Sustainable Materials Management, 2013).

Secondly, certain GWR systems are vulnerable to power outages caused by severe weather that is exacerbated by climate change (Massachusetts Department of Environmental Protection, 2012).

In order to reduce the environmental footprint and vulnerability of these sites, MassDEP aims to convince LSPs and Site Managers to consider the usage of energy efficient and renewable practices in GWR processes.

Project Goal

Assist MassDEP in promoting greener practices through solar power and energy efficient waste site remediation techniques to LSPs and Project Managers in charge of currently contaminated locations that utilize GWR systems.

We accomplish this goal by fulfilling the following objectives:

1) Identified waste sites in MA actively utilizing Groundwater Remediation (GWR) Systems, and the sites vulnerable to flooding and storm surge.
2) Investigated how the GWR systems in the selected sites can be more energy efficient.
3) Examined the plausibility of using solar power as a renewable energy source for each type of GWR system that is investigated in regards to energy efficiency.

Methodology

We focused on a set of 23 waste sites and determined which sites utilizing GWR systems were vulnerable to flooding or storm surge. We cross searched these waste sites with the vulnerability and waste site activity data sets by utilizing the Route Tracking Number (RTN) of each waste site. Using the Energy & Environmental Affairs Data Portal, we obtained remedial monitoring reports which contained information about each bi-yearly checkup for the 23 waste sites. From these forms we found out when certain unscheduled shutdowns occurred in waste sites due to flooding or storm surge.

To investigate how the current GWR systems can be more energy efficient, we first identified the components that are used in these systems. This was done by collecting and analyzing Phase IV Remediation Implementation Plans (RIPs), Release Abatement Measure (RAM) forms, and Immediate Response Action (IRA) forms for each of the 23 these sites. These forms are LSP-provided documents that provide specifications for the engineering designs of GWR systems, and the manner in which they were implemented. For sites providing detailed component specifications (type, model, make, etc) of system components, we used manufacturer websites and other literature to identify newer or more energy efficient models. To further investigate energy efficiency, we analyzed various suggestions from the Best Management Practices (BMPs) in Standard Guidance of Greener Cleanups (ASTM) provided by MassDEP. We identify energy efficiency practices that can potentially be applied to GWR systems, as well as practices that can be applied to the remediation process as a whole.

To investigate solar power feasibility, we utilized LSP interviews, the B&M Solar PV Feasibility Study, and other online research to identify important considerations for determining if solar energy is an appropriate option to power GWR system operations. The interviews allowed us to focus on understanding the limitations and constraints that LSPs face with regards to energy usage. The B&M study was used to highlight that solar power was a feasible and financially beneficial option for that particular Superfund site. Additionally, we conducted research through government sources to identify various incentive programs or state funding that can be provided to LSPs who decide to adapt their system to a solar-driven power source. The programs we identified exemplify the types of financial incentives and benefits that are available in the solar power implementation process.

Findings

From the data analysis and research, we generated the following conclusions:

1. *BMPs can help to identify opportunities for potential improvements on GWR systems in order to improve energy efficiency, as well as more general opportunities that can be applied to the remedial process as a whole.*

   We identified the most applicable BMPs to energy efficiency, listed in Table ES.1.

Table ES.1: List of applicable Best Management Practices for LSPs (*United States Environmental Protection Agency, 2017)*

Type of BMP:	***BMP Description:***
Buildings	Install demand-response mechanisms to reduce power usage while up-keeping with the systems' needs.
Materials	Introduce a network of piping into the system which would allow for increases or decreases in the extraction and injection rates for treatment.
Power and Fuel	Utilize solar power packs for low-power usage devices such as heating and lighting.
Power and Fuel	Install modular renewable energy system for small scale systems.
Power and Fuel	Utilize a Combined Heat and Power (CHP) system to generate electricity while capturing waste heat.
Power and Fuel	Install variable frequency drive motors to automatically adjust energy usage in blowers, vacuum pumps and aerators.
Power and Fuel	Install amp meters to evaluate energy usage options based on consumption rates.
Power and Fuel	Insulate system pipes and equipment to increase energy efficiency.
Power and Fuel	Install energy efficient lighting fixtures.

In further research, we specifically highlighted the BMP regarding variable frequency drives (VFDs) to exemplify how BMPs can help to improve the energy efficiency in GWR systems. A VFD is a device that is used to control the speed of a motor by means of varying the frequency and voltage of its power source (Danfoss, n.d.). Installation of VFDs in GWR systems can optimize specific components, particularly pumps, to match the energy demand of the system at any time during operation.

We also highlighted the BMP regarding energy efficient lighting, as a way to show that BMPs are available for increasing efficiency in the overall remedial process. From the B&M site visit we identified fluorescent and LED lighting as potential alternatives in order to optimize lighting electricity consumption in remediation site facilities.

2. *Energy efficient pumps and other components are available. Various component manufacturers may also provide incentives for energy efficient products.*

From the B&M site visit we learned that information about new models of system components can be acquired by calling system part manufacturers. Furthermore, these manufacturers may offer various incentives, such as rebates and discounts, for switching to more energy efficient equipment. In addition, new or energy efficient models can be found from manufacturer websites and other supporting literature.

3. *GWR system components are specific to each waste site so it may be hard for MassDEP to identify and recommend which parts to upgrade.*

Each site utilizes different types, models, and arrangements of components. With such variation in the systems and conditions of each site, MassDEP cannot simply recommend all sites to switch to a specific component. Recommending component upgrades or replacements is not a simple task to accomplish; it involves detailed analysis of the specific requirements and needs of each site, as well as the consideration of factors like cost and space. We found that it was difficult for our team to evaluate and compare different component models because we did not have the technical knowledge and expertise needed to assess how energy efficient these parts were.

4. *GWR system component data is incomplete due to the fact that some LSPs are inconsistent in submitting the engineering data that is required by DEP regulations.*

In our research from the Energy & Environmental Affairs Data Portal, we learned that LSPs are either filling out and submitting a Phase IV Report, a Release Abatement Measure (RAM) form, or an Immediate Response Action (IRA) form, all of which are used by these LSPs to report data and specifications about their respective remedial systems. However, from site to site, the data provided was very inconsistent. About half of the sites we analyzed included very detailed and exact specifications for various pumps, blowers, aerators, and other equipment. However, reports from other sites were missing specific data; rather there were only general descriptions of what types of components were installed, or merely statements that a certain part was used. We do not know the reasons why some of these reports seemed incomplete. For future MassDEP work with these sites, it could be difficult to conduct energy efficiency evaluations with only the existing data in the current database.

5. *Renewable energy is applicable to waste sites through state-funded programs that grant rebates on solar installations and for upgrading to more energy efficient components.*

We identified 3 programs:

- Solar Massachusetts Renewable Target (SMART) Program- analytical program created to support solar development in MA; sites can apply to get an analysis of solar panel feasibility at their location.
- DSIRE Program- free and open-source platform that has a collection of existing incentives and policies involved with using renewable energy in different states
- RPS Solar Carve-Out Program v1.0 (DOER financial model)- a tool developed by Massachusetts Department of Energy Resources (DOER), that calculates the savings and costs and can help the user to estimate returns from a "optimal" solar project

6. *Solar energy may not be applicable to certain waste sites due to location, time or funding restrictions.*

Solar panel installations may not be an ideal investment for waste sites in smaller areas, where the amount of available space to install a viable amount of solar panels is limited. One of the main concerns with solar power installations for GWR systems is if the investment cost will equal to or less than the energy generated from the panels. Another factor is the return on investment. The amount of time a waste site will remain active is unknown and dependent on each waste sites' contamination level so it would not seem viable to invest in solar energy if the payback amount is unknown.

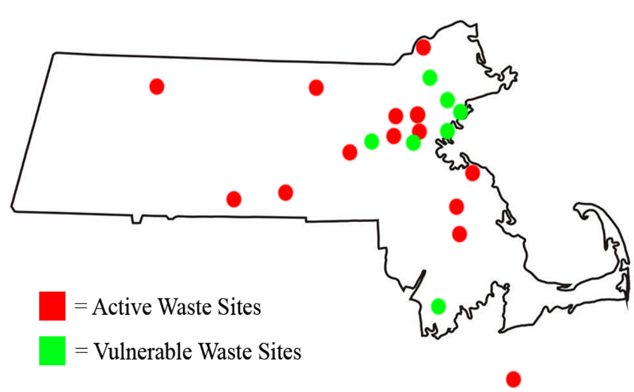

Figure i: Map of the Commonwealth showing the locations Of all active and vulnerable waste sites (*Adobe Photoshop,* 2018)

7. *Of the 23 waste sites in the dataset, 7 of them are vulnerable to flooding or storm surge.*

The waste sites identified as vulnerable to storm surge or flooding were determined to be closer to bodies of water. This relates to waste sites relying on the power grid to operate even during the event of a storm surge or flood which can cause systems to remain offline. We cannot conclude that all waste sites near bodies of water are vulnerable or if current waste sites will be considered vulnerable in the future.

Recommendations

1. *MassDEP should utilize available LSP-submitted reports and data from this project to further investigate challenges LSPs may encounter with GWR. MassDEP should promote BMPs to sites, for both GWR systems specifically as well as the overall remediation process to reduce energy use and costs. MassDEP can use the 7 sites we identified to be vulnerable as a starting point.*

2. *MassDEP should utilize available resources and promote existing programs to encourage LSPs to adopt renewable energy and energy efficient methods to LSPs and site managers.*

3. *MassDEP should consider promoting other renewable energy options for particular waste sites with different locations and available spaces.*

By utilizing the recommendations and deliverables we have provided, MassDEP can gain a better understanding of the considerations that are involved in making GWR systems greener. Ultimately, our findings can help MassDEP to achieve the goal of reducing the environmental footprints that GWR processes currently are leaving behind.

Acknowledgements

We would like to thank those who assisted our group in completing this project. We would like to especially thank Mr. Thomas Potter and the Massachusetts Department of Environmental Protection (MassDEP) for providing us with the resources necessary for this project including the MassDEP database, the Baird & McGuire site visit, and interview with site managers. We would like to thank Pat Hurley for allowing us to visit the Baird & McGuire Superfund site and showing us the process behind groundwater remediation systems. We would also like to thank Dorothy Allen for allowing us to interview her about LSPs roles on waste sites and the decision-making factors tied into renewable energy applications. Finally, we would like to thank our advisor Professor Seth Tuler for providing us with guidance, feedback and support throughout the span of this project.

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B&M - Baird & McGuire
BMP - Best Management Practice
CERP - Clean Energy Results Program
DOER - Department of Energy Resources
DSIRE - Database of State Incentives for Renewables & Efficiency
EPA - Environmental Protection Agency
GWR - Groundwater Remediation
IQP - Interactive Qualifying Project
LSP - Licensed Site Professional
MassDEP - Massachusetts Department of Environmental Protection
P&T - Pump & Treat
RAM - Release Abatement Measure
RIP - Remediation Implementation Plan
ROI - Return on Investment
RTN - Route Tracking Number
SMART - Solar Massachusetts Renewable Target
VFD - Variable Frequency Drive

1.0 An Introduction to Waste Site Remediation

Thousands of contaminated properties and industrial waste sites in the United States cause air, water and soil pollution. Waste sites can negatively impact public health through pollution of groundwater, the main source of drinking water for people (Maibach, 2015). Since its establishment in 1970, the Environmental Protection Agency (EPA) has emphasized the need to identifying waste sites and design remediation methods and plans for the identified sites. In 1983, in conjunction with the EPA federal program, the Commonwealth of Massachusetts passed the State Superfund Law (SSL) which requires landowners to remediate or cleanup hazardous waste and toxic materials contaminating their property (Massachusetts Legislature, 2016). Furthermore, the Massachusetts Department of Environmental Protection (MassDEP) went on to establish waste site remediation techniques to fulfill the requirements set by the SSL (Baruffi, 2013). This has successfully resulted in the remediation of over 40,000 waste sites in the Commonwealth (Mass.gov, 2018).

As the Commonwealth continues to develop and improve remediation processes on waste sites, one of the largest focuses has been on the Pump & Treatment (P&T) systems. The current operation of groundwater remediation (GWR) systems, a common form of P&T, present two key problems that cause an environmental paradox.

The first issue is that GWR systems require electricity generated from consuming non-renewable energy, namely burning fossil fuel (Massachusetts Department of Environmental Protection, 2012). Significant usage of non-renewable energy directly leads to high material consumption and pollution to the contaminated sites, such as greenhouse gas emission (Sustainable Materials Management, 2013).

The second issue is that certain GWR systems are vulnerable to severe weather that is exacerbated by climate change (Massachusetts Department of Environmental Protection, 2012). For example, increasing saturation of water (flooding and storming) in soil will flush heavy metals collected from site remediation and expose them to the surrounding ecosystem (Wuana, 2007). These systems are currently highly reliant on the national grid in order to function, which causes them to be less stable during power outages caused by flooding and storm surge (Sørensen, 2012). Consequently, contamination breach may occur under such hazardous conditions, thus further polluting the surrounding environment.

To resolve this paradox, various waste site operations across the U.S. are currently attempting to apply greener practices. MassDEP is promoting the use of more energy-efficient techniques and the implementation of renewable energy into waste site remediation. An onsite renewable energy system also has the potential part to protect the remedial systems from power outages caused by climate change (Ericson, 2014). The attempts have reached different levels of success. For example, one site that has successfully applied more energy-efficient techniques is Busy Bee's Laundry in Missouri, where new energy storage devices maximize energy flow (United States Environmental Protection Agency, 2016). In Frontier Fertilizer Superfund Site, California, the solar arrays had offset 100% of the P&T system's electricity demand (United States Environmental Protection Agency, 2016).

Many sites, however, have yet to implement greener practices in their remediation methods due to location or funding, which can be seen with sites such as the Baird & McGuire Superfund site in Holbrook, MA. A solar power feasibility study was developed for site in 2012, but the plan for installing PV arrays has not yet been executed (ICF Incorporated, 2012).

The goal of our project was to assist MassDEP in promoting renewable energy through solar power and energy efficient waste site remediation techniques to Licensed site professionals (LSPs) and site managers in charge of currently contaminated locations that utilize Groundwater Remediation Systems. LSPs are the individuals who conduct waste site assessments and cleanup processes at specific sites (Sellers, 1998). The LSPs' role is to direct the assessment, characterization, and, to the extent necessary, the cleanup process in accordance with relevant regulations and laws.

Based on previous interactions with LSPs, MassDEP had developed the theory that LSPs and site managers may be reluctant to invest time and money on solar implementation, especially if they do not think that the process will take long enough for the solar panel investment to pay itself off (Massachusetts Department of Environmental Protection, 2018). Furthermore, LSPs may not be aware of the various options that are available to them in regards to energy efficient and renewable solutions for their GWR systems.

Solar panels have a simple installation process and various financial benefits on for long-term remediation processes (Sørensen, 2010). Because of this, MassDEP has been pushing for LSPs and site managers to utilize solar energy as a means of reducing energy costs and raw energy usage on their waste sites. MassDEP aims to identify benefits or incentives that can help to convince these LSPs to invest in solar energy. With regards to renewable energy, it also needs to be understood which waste sites are capable of utilizing solar panels and solar energy to the fullest extent. We achieved the project goal, on the behalf of MassDEP, by drafting case studies and recommendations which MassDEP can utilize in their goal of green and efficient waste site remediation.

2.0 Identification and Remediation of Contaminated Sites

Waste Sites are locations that contain a significant amount of hazardous substances in the soil, water or air that pose threats to the environment or public health (Massachusetts Legislature, 2018). Waste Sites can range from toxin-ridden soil near abandoned chemical facilities to small oil spills at gas stations. Most potential groundwater contamination sources include gasoline storage tanks, septic systems, landfills, chemicals such as pesticides and fertilizers and other uncontrolled hazardous wastes (The Groundwater Foundation, 2018). With 50% of people's drinking water coming from groundwater, it can be problematic when soil becomes polluted near a water well (The Groundwater Foundation, 2018). The result of drinking contaminated or polluted groundwater can result in contracting diseases such as dysentery and hepatitis A (The Groundwater Foundation, 2018).

Since 1984, there have been 47,759 identified waste sites that must be assessed and cleaned up in Massachusetts (Mass.gov, 2018). Over the past few decades, MassDEP efforts and regulations have helped to successfully remediate hundreds of identified waste sites across the state, narrowing down to about 200 waste sites left today. MassDEP has worked with the EPA to create these regulations and rules in the waste site remediation process in hopes of achieving their goal to remediate these contaminated waste sites as soon as possible.

2.1 Current Efforts Towards Environmental Remediation in MA

The EPA identified hazardous waste sites as a large contributor to air and water pollution, and in 1980 they established the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the federal superfund program (United States Environmental Protection Agency, n.d.). Using this legislation, the EPA is able to classify the most hazardous waste sites throughout the nation, identify the parties responsible for the contamination, and ensure that they are held accountable for aiding in the cleanup process (United States Environmental Protection Agency, n.d.).

The Commonwealth of Massachusetts utilized the federal superfund program as a framework for its own waste site remediation regulations. The State Superfund Law, also known as Chapter 21E, was created to allow the Massachusetts government to take designated actions (described in the Massachusetts contingency plan) in response to any site containing a risk of oil or hazardous material release (The General Court of the Commonwealth of Massachusetts, 2018). An amendment to Chapter 21E was created in 1998 with the intention of ensuring cleanup effort progress, preserving green spaces, and encouraging land or facility redevelopment (Massachusetts Department of Environmental Protection, 2016). The amendment was passed as a means of offering both financial incentives and liability relief to landowners of identified sites.

In addition to the establishment of Chapter 21E, the Massachusetts government had also created a handful of programs focused on the development of waste site remediation efforts. One of these programs was the Brownfields Act, or Brownfields Liability Relief (Massachusetts Department of Environmental Protection, 2017). Put simply, it provides eligible parties with limited liability for the contamination if the party meets the clean-up standards specified in the State Superfund Law. The program further specifies how to be considered eligible for liability relief, particularly for down gradient property owners and tenants Furthermore, it states that redevelopment authorities and community development corporations are exempt from this accountability measure (Massachusetts Department of Environmental Protection, 2017).

Additionally, there are various programs created for specific contaminant types. For instance, the Oil Spill Prevention & Response program allows the public to view information about various oil spills identified throughout the state, as well as procedures for cleaning them up (Mass.gov, n.d.). The USEPA Land Disposal Restrictions program regulates how certain wastes are treated and provides guidelines on how to handle contaminated soil (Mass.gov, n.d.).

Another significant program is the Licensed Site Professional (LSP) Program. LSPs are the individuals who regulate waste site assessments and cleanup processes at specific sites (Sellers, 1998). The LSPs' role is to direct the assessment, characterization, and, to the extent necessary, the cleanup process along with relevant regulations and laws. Furthermore, LSPs work with property owners, operators, and other third parties to foresee and assess waste site environmental damage, and are responsible for managing the remediation equipment used at their respective sites (Sellers, 1998). Most LSPs are scientists, engineers, or public health specialists; each of which brings a unique background and type of expertise to waste site remediation management. (What is a Licensed Site Professional, 2018). The LSP program also offers significant financial incentives to environmental professionals who have demonstrated rapid response to waste site cleanup (Hughto, 1997). Yearly monetary investments are provided to LSPs in order to encourage them to optimize current practices in a timely and effective manner.

In many sites, one or more remediation technologies are evaluated and implemented by LSPs to determine the effectiveness of treating the contaminated groundwater. According to MassDEP requirements for data submission, LSPs are required to submit various reports identifying the methods of remediation and relevant system data used in their respective sites. Therefore, LSPs play important roles in determining the success of waste remediation.

2.2 The Pump & Treatment Remedial Process

Waste site cleanup programs in Massachusetts utilize a variety of different remedial technologies in order to reduce or eliminate contamination. One of the most common types of remedial technologies is the Pump & Treat (P&T) process. P&T remediation methods are typically selected to hydraulically remove contamination in order to restore aquifers (MassDEP, 2009). Once the contaminant is pumped to the surface, it can then be treated above ground. The Groundwater Remediation (GWR) method, a specific type of Pump and Treat (P&T) remediation technology, is commonly used to reduce the amount of pollution and environmental damage by cleaning contaminated underground water (MassDEP, 2009).

2.2.1 Groundwater Remediation (GRW) System Specifications

Modern remediation technologies for cleaning up contaminated groundwater fall into two categories: ex situ or in situ. Ex situ refers to processes that can be applied above ground. Likewise, in situ refers to the processes that operate below ground, typically in soil (Massachusetts Department of Environmental Protection, 2013). This project focuses mainly on ex situ GWR processes, particularly on systems that rely on groundwater P&T. There are typically three different phases involved in the GWR process (Figure 1):

1. Extracting the contaminated water from the underground aquifer
2. Treating the groundwater by removing the pollutants

3. Converting the pollutants into carbon-like products (Sørensen, 2010).

Groundwater remediation systems often implement various approaches to treatment, the most common approaches being carbon activation, air stripping, and metals removal (Pump and treat technology, 2007).

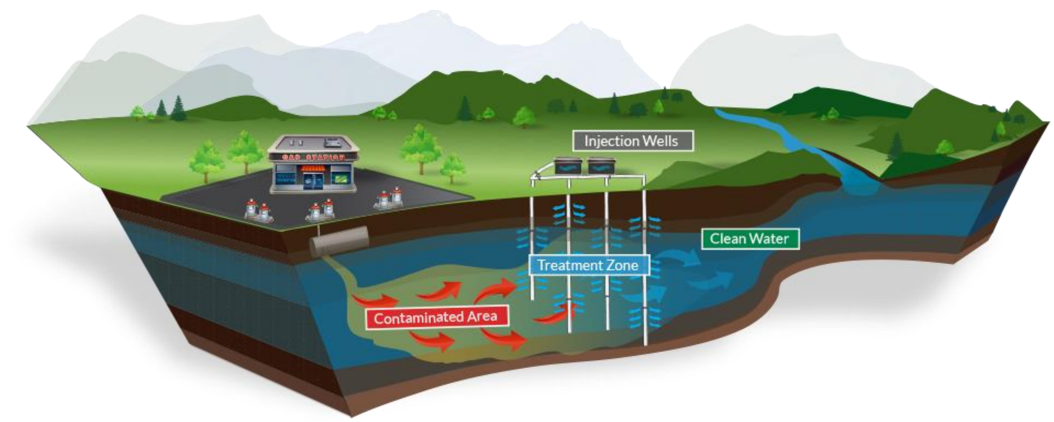


Figure 1. Groundwater Remediation System Sample (retrieved from: envirosouth.com)

2.3 Drawbacks in Current Groundwater Remediation Systems

There are two major drawbacks to current GWR systems. The first is that they typically have high energy consumption rates. Secondly, they produce large amounts of carbon emission, resulting in large environmental footprints.

Operating a GWR system requires a significant amount of energy, mainly electricity, in order to power the whole system and keep it running throughout the remediation process. This can be seen particularly with GWR (P&T) systems at Superfund sites, which are federal, large-scale hazardous waste sites located all across the country (United States Environmental Protection Agency, n.d.). The EPA estimates that, from 2008 to 2023, the operation of GWR (P&T) systems could consume an average of 490,000 MWh annually at these sites (Sørensen, 2010). Currently there are 1338 Superfund sites in the United States (United States Environmental Protection Agency, 2018), so each site uses approximately 366 MWh per year. A direct consequence of this high energy consumption is high cost from operating the GWR systems. As shown in *Figure 2*, the operation of GWR (P&T) systems are estimated to cost of $52,381,000 annually at all the Superfund sites (Sørensen, 2010). *Figure 2* also portrays other common types of remedial technologies regarding estimated annual energy consumption rates and the corresponding estimated cost to run each system.

Technology	Average Annual Electricity Consumption (MWh)	Average Annual Cost ($)*
Pump and treat	490,000	52,381,000
Thermal desorption	93,000	9,941,700
Multi-phase extraction	18,700	1,999,030
In situ thermal treatment	13,000	1,389,700
Air sparging	10,000	1,069,000
Soil vapor extraction	6,700	716,230
Ex situ stabilization	22	2,352
Other**	6	641
Total	631,428 MWh	$67,499,653

* Using the August 2010 national average of $106.90/MWh for commercial use

**Including ex situ bioremediation of soil, in situ bioremediation (source), in situ chemical oxidation (source), in situ bioremediation of groundwater, and in situ chemical oxidation of groundwater

Figure 2. Common Cleanup Technologies [retrieved from (Sørensen, 2010)]

High carbon emissions resulting from GWR system operation is a consequence of the system's reliance on grid power. According to the U.S Energy Information Administration, natural gas and coal were the largest and the second largest sources for U.S. electricity grid power in 2017 (United States Energy Information Administration, 2018). Burning fossil fuels such as natural gas or coal to supply national power grids will emit various air pollutants, primarily carbon, that are harmful to both the environment and public health (United States Environmental Protection Agency, 2018). As most of GWR systems are currently electrically-based, they depend heavily on the grid as a continuous source of electricity (Sørensen, 2010). Ultimately, the high energy demand of GWR systems correspondingly consumes a mass of fossil fuel, and consequently creates large environmental footprints that these sites leave.

Other environmental impacts have possibly resulted from system failures due to unexpected climate change. Severe weather-related events, such as flooding and storm surges, can crucially impact the operation of power grids, and can potentially cause power loss in associated GWR systems (Environmental and Energy Study Institute, 2017). Furthermore, this can affect the functionality of various components within these systems that are used to maintain effective water control (Sørensen, 2010). If these parts become disrupted or inactivate due to power shutdowns, contaminated water may be inadequately captured or insufficiently treated (Baruffi, 2013). Consequently, the processes of the remediation can be interrupted during extreme weather events, potentially leading to remediation failures (Baruffi, 2013). Ultimately, the higher vulnerability of these systems during climate changes downgrades system reliability and presents risk to the surrounding communities that utilize the groundwater sources.

2.4 Approaches of Overcoming Drawbacks in Current GWR Systems

MassDEP has proposed two possible approaches to eliminate these drawbacks, the first is to improve energy efficiency of certain components of the system so that GWR systems consume less energy overall. The second is to promote the usage of renewable energy, namely solar power, to reduce the carbon pollution from burning fossil fuel and to minimize potential system vulnerability resulting from climate change.

2.4.1 Improving Energy Efficiency in GWR Systems

Various sites across the country have attempted to optimize overall GWR energy usage by upgrading specific system components, particularly for pumping systems (McKinney, 1996). For example, in 2004, the Frontier Fertilizer Superfund site in Davis, California had replaced their conventional 10-horsepower pump with a pumping system model that was nine-years newer (United States Environmental Protection Agency, 2016). This upgrade helped to successfully reduced the energy demand of the GWR system by 25%, which ultimately saved Frontier Fertilizer $7,000 annually in electricity-related operating costs (United States Environmental Protection Agency, 2016). As seen, optimizing the power-consuming parts in GWR systems is a potential opportunity for improving overall efficiency.

2.4.2 Using Solar Energy as a Power Alternative

The principle of waste site remediation is to remove pollutants from the land and to avoid secondary pollution emissions and costs (McKinney, 1996). Compared with traditional remediation, green remediation considers all environmental effects and attempts to minimize the environmental footprints during remedial processes (United States Environmental Protection Agency, 2018). With this in mind, implementing renewable energy as a power source is a potential option for making remedial systems greener.

By definition, renewable sources are able to be replenished by naturally occurring processes (Renewable sources, n.d.). In contrast, non-renewable sources such as fossil fuels require a constant provision of the source, resulting in the emission of pollutants to the surrounding environment (Sørensen, 2010). In terms of energy expenditure, renewables may potentially be able to reduce the total amount and cost of energy needed to keep GWR systems functional.

Renewable systems can be of various types, such as solar, wind, thermal, hydroelectric, etc. Among them, solar energy is expected to be a potential alternative energy source for GWR systems for several reasons. First, solar power can be installed on site (MassDEP, 2018). The on-site installations can eliminate the reliance on power grids, and can furthermore reduce the risk of expected power outages caused by climate change (MassDEP, 2018). Second, solar power installations can also be incentivized by the state government rebate programs or policies, as evident in California government programs (Sørensen, 2010). Consideration of solar power as an energy alternative has proven to be successful in past waste site analyses. For instance, a photovoltaic (PV) array was installed on the roof of a building used for ex situ groundwater treatment in the Frontier Fertilizer Superfund Site in Davis, California (United States Environmental Protection Agency, 2016). With the recent expansion of PV array funding provided by the government, one hundred percent of the Frontier Fertilizer system energy demand was covered by the solar power in a time span of three years (United States

Environmental Protection Agency, 2016). With no electricity usage from traditional national power grid, solar power proved to be a viable and sustainable replacement at this particular site.

2.5 Promotion of Greener Cleanup

Currently, MassDEP aims to promote the optimization of remediation techniques, with a specific focus on reducing the environmental footprint that such processes leave behind. To improve the sustainability of GWR systems and to minimize overall carbon emissions, MassDEP wants to convince LSPs of replacing fossil fuel with alternative energy, specifically solar power. In addition, MassDEP is prioritizing the waste sites that are most susceptible to flooding and storm surges, which helps to identify which sites may be more vulnerable to system shutdowns. The hope is that LSPs will be convinced to increase the resiliency of their current remediation processes during more extreme, naturally-occurring events.

However, MassDEP has theorized that there is a major barrier to the move towards greener remediation: LSPs have may be reluctant to adopt newer methods because of the cost, time, and space that the processes would entail. Also, some LSPs may not be fully aware of the various options that exist for effectively making their systems energy efficient or renewable. Currently MassDEP cannot force these individuals to make these changes, because the existing legislation does not require all sites to adopt the most energy efficient systems, nor does it state that solar power or other forms of renewable energy should be implemented (The General Court of the Commonwealth of Massachusetts, 2018).

So to solve this issue, MassDEP has expressed the need to find effective ways of convincing LSPs to use more efficient practices for waste site remediation. The first step in doing so is to ensure that LSPs are informed of all of greener options that are available and applicable for their sites. Since these LSPs are the people actively developing and operating the remediative equipment used in cleanup processes, it is vital that they understand how to optimize these systems to achieve a more positive environmental impact. Secondly, MassDEP hopes to identify incentives that can be offered to these LSPs so they'd be more willing to consider more energy efficient modifications.

MassDEP currently has an extensive collection of LSP-submitted reports that provide designs and specifications of many remedial systems all across the state. According to our sponsor, however, a lot of this data is not currently being reviewed by MassDEP for investigations on site energy usage. Furthermore, they do not have a structured deliverable that can be used to inform LSPs of the options available for changing their remediative practices.

3.0 Methods for Identifying Renewable Energy & Energy Efficient Applications in Waste Site Remediation

The goal of this project was to assist MassDEP in promoting renewable energy through solar power and energy efficient waste site remediation techniques to LSPs and Project Managers in charge of currently contaminated locations that utilize Groundwater Remediation Systems. We accomplished this fulfilling the following objectives:

1) Identified waste sites in MA actively utilizing Groundwater Remediation (GWR) Systems, and the sites that are vulnerable to flooding and storm surge.
2) Investigated how the GWR systems in the selected sites can be more energy efficient.
3) Examined the plausibility of using solar power as a renewable energy source for each type of GWR system that is investigated in regards to energy efficiency.

3.1 Identified Waste Sites Vulnerable to Flooding & Storm Surge

MassDEP supplied us with datasets about waste site vulnerability and active GWR systems on waste sites. These datasets highlighted which waste sites active in Massachusetts were actively running GWR systems or were vulnerable to flooding or storm surge. We were then suggested to focus on a specific list of 23 waste sites and determine which sites that utilized GWR systems were vulnerable to flooding or storm surge. We cross searched these waste sites with the vulnerability and waste site activity datasets by utilizing the Route Tracking Number (RTN) labeled with each waste site. When the RTNs matched up on the datasets, we were able to conclude which sites are vulnerable to flooding and storm surge. With accessibility to the RTN of each waste site and the Energy & Environmental Affairs Data Portal, we were able to obtain remedial monitoring reports which contained information about each bi-yearly checkup on waste sites. We then utilized these forms to find out when certain unscheduled shutdowns occurred on waste sites due to flooding or storm surge. We were then able to prioritize which vulnerable waste sites based on the number of unscheduled shutdowns due to flooding or storm surge recorded in the remedial monitoring reports (see Appendix E). This allowed us to decide which of these sites could be used as case studies for the final deliverable or could benefit the most from renewable energy and energy efficient applications.

3.2 Investigated Energy Efficient Applications

Adopting more energy-efficient approaches in current GWR systems is the key to reducing energy consumption and secondary pollutant in each waste site. From background research, we learned that GWR systems are composed of multiple components; mainly pumps, blowers, aerators, and energy regulators. To investigate how the current GWR systems can be more energy efficient, we first collected and studied relevant materials that elaborate what the components of the systems are and how they work. Based on technical information, we then investigated better optimizations or substitutes for system parts.

To have a better understanding of current active remedial systems from the waste sites that are narrowed down from the previous object, we collected the Phase IV reports along with the Remediation Implementation Plans (RIPs) of these sites. In each RIP, MassDEP requires all sites that are in Phase IV remediation to record their engineering designs and construction plans. We accessed the documents from the Energy & Environmental Affairs Data Portal, and organized the documents in google drive for future use.

The next step was to identify the different components in the given GWR system from each RIP. In some reports we found either a list of components or schematics of the systems, which we recorded on our GWR system component spreadsheet (see Appendix G). With the system components information available, we searched for possible substitutes that are more energy-efficient than these components. We utilized the manufacturers` website, the authority of information about all similar components specs, to identify whether there is a more up-to-date model and components that adopts more efficient techniques.

However, a part of the RIPs we were investigating did not give specific information about some of the components in the GWR systems. For these situations, we looked into the suggestions from Best Management Practices (BMPs) in Standard Guidance of Greener Cleanups provided by MassDEP. The BMPs are the official suggestions from MassDEP that help LSP better improve different types of remedial systems. We utilized the BMPs that are related to improving energy-efficient as general suggestions to these GWR systems.

3.3 Identified Renewable Energy Applications through Solar Energy

Through the completion of this research, we demonstrated that solar-driven power sources can be used to reduce non-renewable energy consumption and potentially improve the stability of GWR systems during climate change. To accomplish this task, we identified the incentives of using solar power to run these systems and possible concerns involved in solar power implementation.

We first conducted a case study analysis on using solar power in GWR processes. Solar energy has already proven to be a viable alternative for a handful of other waste sites in the past. In particular, we examined the Baird & McGuire Solar PV Feasibility Study. Baird & McGuire is a MA superfund site utilizing a very large scale GWR system to remove groundwater contaminants such as arsenic. By reviewing this study, our team identified specific, methods, incentives, and concerns used for B&M that can be useful for other LSPs looking to incorporate renewable energy into their own sites.

We utilized LSP interviews, the B&M Solar PV Feasibility Study to identify important considerations for determining if solar energy is an appropriate option to power GWR system operations. We conducted research through government sources to identify any incentive programs or assistive tools that could be provided to LSPs who decide to adapt their system to a solar-driven power source. Furthermore, we collected materials that support or promote solar energy usage within site remediation processes, specifically in GWR systems.

Initially we had planned to utilize LSP interviews to gain additional understanding of the incentives or barriers that these individuals have with regard to adopting greener GWR methods. Furthermore, we intended to understand the level of interest LSPs may have with regards to the various energy efficient and renewable opportunities identified in our project. However, due to the limited availability of LSPs, we were not able to conduct any interview that could do this. We were only able to conduct one interview with an LSP, through which we discovered that the individual's site did not even have an active GWR system.

4.0 Renewable Energy and Energy Efficiency Application Opportunities

MassDEP provided us with information about 23 waste sites in Massachusetts that have active GWR systems. Through research, we investigated the GWR systems to identify more energy-efficient solutions. From analyzing online sources, we reviewed available resources that could potentially help LSPs to adopt renewable or more efficient solutions. After gathering the information collected from the remedy implementation plan reports, remedial monitoring reports, and the Baird & McGuire Superfund site visit, we developed the following findings with regards to the possibility of promoting renewable energy and energy efficient changes to GWR processes.

4.1 Potential Opportunities to Increase Energy Efficiency in Current GWR Systems

Finding 1: BMPs can help to identify opportunities for potential energy efficient improvements in GWR systems specifically, as well as opportunities to improve overall efficiency in the remediation process as a whole.

<u>Best Management Practices for LSPs and Site Managers</u>

MassDEP supplied us with a spreadsheet of Best Management Practices (BMPs) created by the EPA to help site managers and LSPs make energy efficient and financially beneficial changes to their assigned waste site. From this spreadsheet, our team selected specific BMPs based on the applicability to small-scale waste sites and the financial benefits that resulting from GWR system changes. The BMPs we identified are listed in *Table 1*.

Table 1: List of applicable Best Management Practices for LSPs (*United States Environmental Protection Agency, 2017)*

Type of BMP:	***BMP Description:***
Buildings	Install demand-response mechanisms to reduce power usage while up keeping with the systems' needs.
Materials	Introduce a network of piping into the system which would allow for increases or decreases in the extraction and injection rates for treatment.
Power and Fuel	Utilize solar power packs for low-power usage devices such as heating and lighting.
Power and Fuel	Install modular renewable energy system for small scale systems.
Power and Fuel	Utilize a Combined Heat and Power (CHP) system to generate electricity while capturing waste heat.
Power and Fuel	Install variable frequency drive motors to automatically adjust energy usage in blowers, vacuum pumps and aerators.
Power and Fuel	Install amp meters to evaluate energy usage options based on consumption rates.
Power and Fuel	Insulate system pipes and equipment to increase energy efficiency.
Power and Fuel	Install energy efficient lighting fixtures.

These BMPs are general yet possible methods for LSPs to apply at their own sites in order to reduce the potential amount of time and energy involved in the remediation process. Even though some of these BMPs may only be applicable to certain waste sites, MassDEP can utilize these to incentivize LSPs and site managers to adapt their remediation systems to be more energy efficient.

Installing Variable Frequency Drives

In further research conducted, we specifically highlighted the BMP regarding variable frequency drives to show that there are certain BMPs that LSPs can potentially utilize in order to make their GWR systems more efficient.

A variable frequency drive (VFD) is a device that is used to control the speed of a motor by means of varying the frequency and voltage of its power source (Danfoss, n.d.). When VFDs are wired to a motor, they are automatically able to adjust the speed at which the motor is running, dependent upon the fluctuation of the equipment's energy requirement. This means that VFDs can manipulate the frequency coming from the power source so that it can match the minimum energy requirement needed for the given system to run. In contrast, typical motors without a VFD run at a constant, full speed for the whole time of operation (Danfoss, n.d.). This results in a lot of wasted energy, as these motors cannot accommodate for a changing energy demand of a system. In this way, using a VFD optimizes the rate at which energy in the motor is used.

As seen in the data collected from waste site Phase IV reports (Appendix G), a lot of the equipment components utilized in groundwater remediation systems are electrically driven, involving the usage of motors to run various pumps, blowers, fans, etc. Through the installation of VFDs in GWR systems, these components can be optimized to consume the minimum amount of energy needed at any time during operation. An example of this energy efficient tactic can be observed in the Baird & McGuire (B&M) Superfund Site in Holbrook, MA. On September 20, 2018, our team attended a site visit at B&M where we were shown how the B&M GWR system functioned and the various components that contributed to the remediation process. One of their most effective efficiency tactics was the implementation of VFDs in throughout the GWR system. In 2008, VFDs were installed for the system's extraction well pumps, bio-clarifier pumps, influent pumps, and filter press feed pumps used in the groundwater remediation system at the site (ICF Incorporated, 2012). During the B&M site visit, we learned that the site operators were able significantly reduce energy consumption in these pumps by installing VFDs. Initially, all of these pumps were fed directly by the national grid. The grid uses the United States utility frequency standard, which is 60 hz. However, B&M was successfully able to use VFDs to reduce pump energy consumption to an average of around 40 hz, which was the minimum required frequency these pumps were able to operate on.

Adopting More Energy-Efficient Lighting

We conducted additional research on the BMP regarding energy efficient lighting fixtures to demonstrate that BMPs are not limited to the optimization of just the GWR systems themselves; rather, there are BMPs available that can potentially optimize overall energy usage in the remediation processes as a whole.

Lighting fixtures are not components of GWR systems themselves. Instead, they are most often used in site remediation facilities as a basic utility. So lighting plays no role in the amount of energy that a GWR system consumes, but it does contribute to a given facility's total energy usage. Therefore, adopting more efficient lighting is a possible way for LSPs to reduce energy consumption in their process as a whole.

Our team was able to identify this BMP in action during the B&M site visit. In 2008, more efficient fluorescent lighting fixtures were installed for the whole GWR facility (ICF Incorporated, 2012). According to Mr. Hurley, a MassDEP employee responsible for overseeing plant operation and maintenance, the new lighting installed was the most efficient form of lighting at the time, as fluorescents produce a lot less heat than the incandescent light bulbs used previously. Since 2008, LED lighting has currently proven to be the most efficient source, and B&M plans to upgrade to LEDs if they do not notice any significant further savings from their current lighting installation. He further went on to explain that lighting is generally the first step site managers and LSPs should take when considering total optimization of the plant.

With these benefits in mind, our team conducted research on the kinds of programs that exist through which LSPs can potentially utilize for efficient lighting installation. We identified Mass Save as one such program. MassSave is a Massachusetts government agency that collaborates with utility service providers such as electric utilities to install energy efficient system upgrades with the aid of different rebates and incentives (Masssave.com, 2018) A particular service that Mass Save provides is the Performance Lighting Program, Mass Save partnered with the National Grid and Eversource to offer both technical and financial guidance with installation of efficient lighting. This can include examining the feasibility of upgrading existing lighting and suggesting new lighting designs, and analysis of the returns from replacing the less energy-efficient lighting equipment (Masssave.com, 2018). The Performance Lighting Program offers potential monetary incentives, such as rebates, to those LSPs that do consider upgrading to more energy efficient lighting. (Mass Save, n.d.).

Finding 2: Energy efficient pumps and other components are available. Various component manufacturers may also provide incentives for energy efficient products.

Before we conducted research of efficient pump availability, we first had to get an understanding of the age of the components utilized at the 23 sites in our universe. We found that, due to incomplete data in the Remedy Implementation Plan reports (described in Finding 4), it was difficult for our team to determine exactly how old each component was, and whether or not a newer model was actually available.

Therefore, we were only able to make the assumption that these components were older models based on Phase IV submission dates. From the LSP report analysis, we observed that all 23 of the Phase IV reports were submitted in 2008 or earlier. Furthermore, 16 of those 23 were submitted in the early 2000’s. Since these reports are submitted by LSPs following the completion of the GWR system installation, our team assumed that the components in these sites were installed around the same time frame, which meant that all of these components for each site are at least 10 years old or older. We used this assumption to establish a reference point for understanding the age of more energy efficient components found from our online research.

From the analysis of the LSP reports, we found only one case where a newer model was able to be identified. A particular example from our findings is the model NPE centrifugal pump manufactured by Gould’s Pumps, Inc., which was implemented in the site of RTN 3-001331. From research collected online, our team found out that the NPE is an older model of centrifugal pump. However, Goulds had since then released a newer model of the NPE (Goulds Water Technology, n.d.). The newer model was similar to the one used in 3-001331, but upgrading to a newer pump could allow the site to improve overall pump efficiency, as an older pump has a decreased efficiency rating particularly noticeable in pumps over 10 years old (NSW Farmers Association, n.d.). However, because every site is different (refer to Finding 3), it cannot be concluded that upgrading to a newer model will have a beneficial payback period for every site.

Contacting Manufacturers

According to Mr. Hurley, information about new models of a system components can be acquired by calling system part manufacturers, who are responsible for offering new models of their products if applicable. So LSPs can also possibly learn about the more efficient models by communicating with the producers. Communication with these manufacturers can aid in helping LSPs to replace older model pumps with the newest model, as to renew the efficiency of a given machine. The B&M team explained to us that not only were they informed of newer model pumps, they were also given incentives by the manufacturers themselves for upgrading. In particular, there was a set of centrifugal pumps in the B&M treatment facility that were recently upgraded to a more efficient model, which would incorporate the use of VFDs. Mr. Hurley explained that because the B&M team had planned to reduce energy usage with VFDs, the pump manufacturer actually offered a discount of about $6,000 for these pumps (originally about $10,000).

Case Study: Redi-Flo Submersible Pumps

From our research, we determined that an example of a highly energy efficient component is the Grundfos Redi-Flo Series. Redi-Flo is a collection of various different models of submersible pumps produced by Grundfos, a popular pump manufacturer recognized for advanced and sustainable pump solutions (Grundfos, n.d.). Several sites in our database have already utilized Grundfos pumps for their respective subversive applications, such as RTN 2-0000815. As evident in this sites' Phase IV report, the Grundfos Redi-Flo 2" submersible pump was implemented in the sites' GWR system. The Redi-Flo 2" model is designed specifically for monitoring groundwater; It's built for a 2" diameter well, meaning that it's used primarily for pumping smaller samples of groundwater (Cuvo Pumping Solutions, Inc., n.d.). What makes the Redi-Flo 2" so efficient is that it incorporates a variable frequency drive (VFD), which allows the pump to adapt to different pumping rates. This makes this pump model flexible for various pumping applications, but also it is able to conserve energy usage based on groundwater flow demand. Other sites we analyzed, such as RTN 3-0026407 and RTN 3-001331, are utilizing the Grundfos Redi-Flo 4" submersible pump. Similar to Redi-Flo 2", this model also incorporates a VFD to increase energy usage efficiency (Geotech, 2014). However, for the sites mentioned above, it was unclear of how old these pumping systems were. This is due to the fact that the Phase IV reports provided for the respective sites did not provide adequate information in regards to how long ago the pump had been installed in the GWR system. Overall, the successful implementation of VFDs in Grundfos Redi-Flo pumps is a one of the examples of adopting more energy-efficient solutions to the GWR systems components.

4.2 Barriers to Energy Efficiency Optimization

Finding 3: GWR system components are specific to each waste site so it may be hard for MassDEP to identify and recommend which parts to upgrade.

Due to each site having a different design for its GWR system, it is difficult for MassDEP to make generalized recommendations to replace specific components or upgrade to newer models. Each site utilizes different types, models, and arrangements of components, so it is not logical to conclude that all sites are using older and less-efficient parts in their systems. In fact, our team had found several instances where a handful among the 23 sites already had efficient pumps installed.

Recommending component upgrades or replacements is not a simple task to accomplish; it involves detailed analysis of the specific requirements and needs of each site, as well as the consideration of factors like cost and space. It was difficult for our team to evaluate and compare different component models because we did not have the technical knowledge and expertise needed to assess how energy efficient these parts were.

Finding 4: GWR system component data is incomplete due to the fact that some LSPs are inconsistent in submitting the engineering data that is required by DEP regulations.

A limitation that our team encountered in regards to GWR system component analysis was the inconsistency of the data provided in the Massachusetts database. In our research from the Energy & Environmental Affairs Data Portal, we learned that LSPs are either filling out and submitting a Phase IV Report, a Release Abatement Measure (RAM) form, or an Immediate Response Action (IRA) form. According to our sponsor, all three forms are supposed to cover similar information in regards to the layout of the remediation system and the process of implementing it; the information provided should adhere to the guidelines set forth for LSPs by MassDEP. However, from looking at the LSP remediation reports collected, we found that 3 out of the total 23 sites included no information of any kind for the components used. Furthermore, 6 of the 23 sites included very general or minimal information, only stating the kind of component that was used (ex: "submersible pump", "air stripper blower", etc.). Additionally, 11 of the sites had mixed specifications, where they would provide the models or manufacturers of only some components and for the rest would only state the kind of component. Only 3 of the 23 sites included specific component models and manufacturers of every component that was provided (To see the specifics of this data, refer to Appendix G). In our analysis, we considered "good data" to be any type of schematic or list of manufacturer specifications that identified the model and manufacturer of each system component. It is evident that most reports had incomplete component specifications, or were inconsistent in which components were identified. We do not know the reasons why some of these reports seemed incomplete.

For future MassDEP work with these sites, it could be difficult to conduct energy efficiency evaluations with only the existing data in the current database.

4.3 Opportunities for Solar Energy Applications

Due to the problems involved with data consistency and varying GWR system designs, the promotion and identification of energy usage optimizations was limited. Therefore, we also consider renewable energy usage in GWR processes as an option for further reducing energy consumption and cost, and ultimately minimizing overall greenhouse gas emissions. We focused on identifying various incentives that will convince LSPs to consider adapting a system to a renewable energy source.

Finding 5: Renewable energy is available to waste sites through state-funded programs that grant rebates on solar installations and for upgrading to more energy efficient components.

We determined that there are existing state-funded programs that provide incentives and rebates for businesses to utilize renewable energy installations and upgrade any system components to more energy efficient models.

Solar Massachusetts Renewable Target (SMART) Program

Not only is it possible to utilize renewables through solar power to reduce energy usage, there are also potential ways to estimate or reduce overall installation cost. We determined that there are multiple in-state programs set up to financially assist in applying renewable energy and energy efficient changes to businesses utilizing a large amount of energy. One such program is the Solar Massachusetts Renewable Target (SMART) Program, which is a program in affiliation with Eversource, National Grid, and Unitil that was created to support solar development in Massachusetts (Mass.gov, 2018). Businesses can apply to have their location analyzed to determine if solar panel installation is viable for their own sites. These analyses can also provide site managers with estimations of the money saved based on accumulated solar energy from the panels and the site-specific parameters (masmartsolar.com, 2018). This can be beneficial for waste sites that currently are reliant on the power grid and meet the requirements for solar installation. Figure 3 shows the application process for the SMART program and which options are available for businesses looking to reduce energy consumption and corresponding costs.

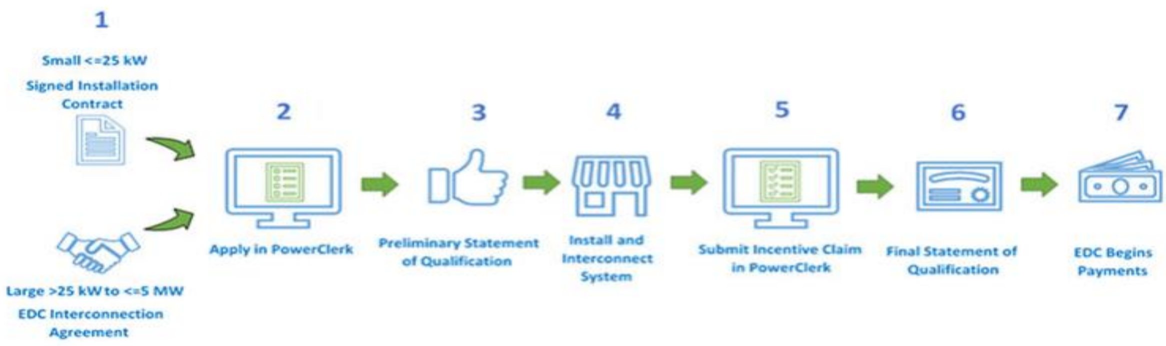


Figure 3: How to participate in the SMART solar program (Retrieved from *masmartsolar.com*, 2018).

Financial Models for Solar Feasibility Studies

According to MassDEP, the financial uncertainties in investing onsite solar panels is a barrier to the implementation of on-site solar power systems in waste sites. Under this situation, financial models for estimating the return of investment (ROI) can potential vary LSPs minds to use solar energy as the power source. A solar feasibility study had been successfully conducted on Baird & McGuire Superfund Site. In the study, Solar Photovoltaic Project Simple Financial Model (RPS Solar Carve-Out Program v1.0) is used as a tool that calculate the saves and costs. RPS Solar Carve-Out Program, designed and released by Massachusetts Department of Energy Resources (DOER), is a free online program that can help the user to estimate returns from a "optimal" solar project (Baird & McGuire). As shown in the *Figure 4*, the model shows the assumptions on financial incentives, including the cost, tax, rebate, savings, and financing. The *Figure 4* is a screenshot of the software user interface that includes the entries in the model and some sample results. LSPs can use this financial model to calculate the saves and costs, similar to the the B&M solar feasibility study, to assess the benefits of adopting solar power in the GWR systems.

Solar Photovoltaic Project Simple Financial Model
RPS Solar Carve-Out Program v1.0
DATA ENTRY AND FINANCIAL SUMMARY

Key	
Entry Cells	
Calculation Cells (Not for Entry)	
Select Taxable or Non-Taxable Entity	Taxable
Project and Customer Cost Assumptions	
Solar Photovoltaic System Size	200000
Total System Cost/Watt	$ 5.500
Total System Cost	$ 1,100,000.00
CEC Rebate Assumptions	
Rebate$ per/Watt	$ -
Total Rebate	
Project Performance and Savings/ Cost Assumptions	
Annual Net Capacity Factor	13.0%
Annual Production Degradation	0.50%
Project Life	25
Depreciation Life	20
Electricity Revenue (Avoided Costs)	$ 0.16
Electricity Revenue (Avoided Costs) Annual Adjustor	3.0%
Solar Renewable Energy Certificate (SREC) Auction Price	$ 0.285
SREC Auction Opt-In Term	10
SREC Revenue Annual Adjustor	0.0%
SREC Contract Price	
SREC Contract Term	
Annual Operations and Maintenance Cost Factor	$ 17.59
Annual Operations and Maintenance Cost	$ 3,518
Annual Operations and Maintenance Adjustor	3.0%
Future Inverter Replacement Cost	$ 0.30
Inverter Life, Replace Every X Years	10

Tax Assumptions	
Federal Tax Rate	35%
State Tax Rate	10%
Effective Tax Rate	42%
Federal Tax Credit	30%
State Tax Deduction	100%
5 Year Accelerated Depreciation Schedule (MACRS)	20.00%
Depreciation	20.00%
Asset Basis	
Gross Cost	$ 1,100,000
Rebate	$ -
Less 50% of Federal Tax Credit	$ (165,000)
Asset Basis	$ 935,000
Financing Assumptions	
% Financed w/ Cash	100%
% Financed w/ Loan	0%
Loan Interest Rate	9.00%
Loan Period	20
Net Cost	$ 1,100,000
Customer Discount Rate	8.00%
Loan	$ -

Solar Project Financial Analysis Summary	
Net Present Value	$ 52,425
Simple Payback (100% Cash only)	Year 7
Estimated Return on Equity	9.4%

Figure 4: Example outcome generated from the DOER financial model (Retrieved from *scribd.com*)

From online research, we found that there are other models that can also be used to do financial estimations for LSPs. Specifically, we identified the Simple Project Viability Evaluation Model, and the Solar Energy Financial Model. These two financial models are similar to the DOER financial model and provide entry-level analysis and assumptions of the financial feasibility at the given constraints. This can be helpful for people who do not have the technical knowledge or expertise needed to do their own feasibility analyses.

DSIRE Program

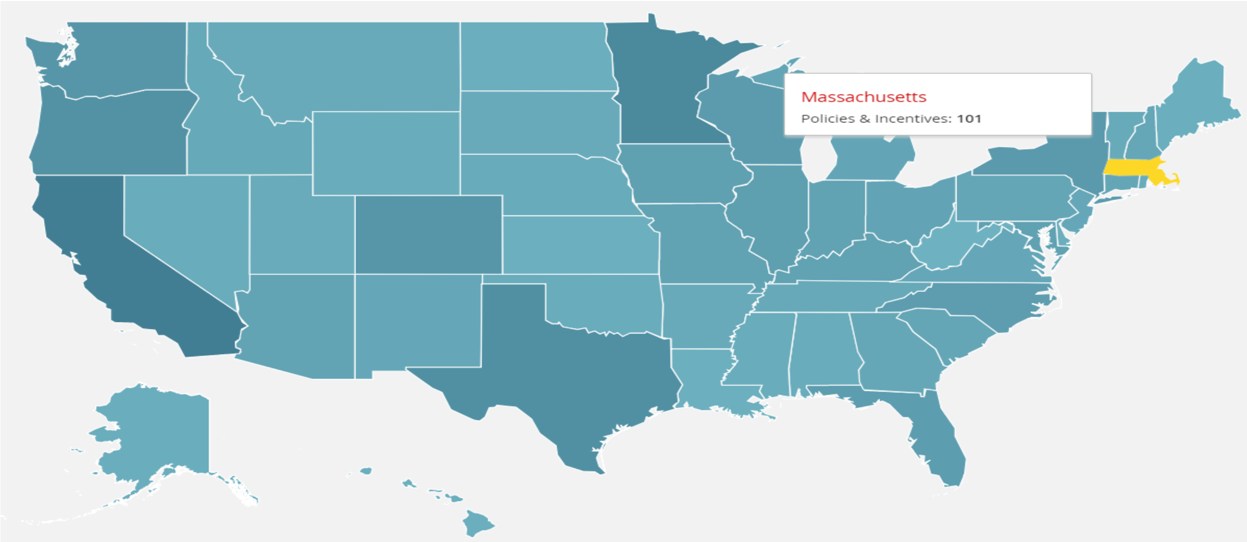


Figure 5: DSIRE Map that shows renewable energy programs by states (Retrieved from *dsireusa.org*)

The DSIRE program is a free and open-source platform that has a collection of existing incentives and policies involved with using renewable energy in different states (North Carolina Clean Energy Technology Center, 1995). Currently, there are 101 different policies and incentives in Massachusetts, as shown in *Figure 5*.

The program continually maintains its collection so that the policies and incentives are updated, informative, and organized. The latest profile of the program was created in 2018. For each program or policy profile, the platform records basic information about policies, specifications of incentives, and summaries. All programs or policies are documented by type, and the built-in search engine allows users to apply filters to search results.

These policies and incentive programs can potentially be useful references for LSPs. By using the platform to get relevant program information, LSPs can become more knowledgeable of the current benefits of using renewable energy, such as solar power.

4.4 Barriers to Using Solar Power

Finding 6: Solar energy may not be applicable to certain waste sites due to location, return on investment, or time till remediation.

Due to different characteristics of the sites, we determined that solar panel installations would not be an ideal investment for waste sites in smaller areas. One of the main concerns with solar power installations for GWR systems is if the investment cost will equal to or less than the energy generated from the panels. With most of the 23 waste sites we analyzed being located near gas stations or convenience stores, the amount of available space to install a viable amount of solar panels is limited.

Figure 6 showcases an active waste site at a Global Petroleum gas station in Massachusetts. Although it is possible to install solar panels on the roof of the gas station, the amount of energy the panels would produce in that amount of space is insignificant compared to the amount required to run the site remediation systems. There would need to be a greater amount of space available for a solar panel installation to have a viable impact on the raw energy usage.

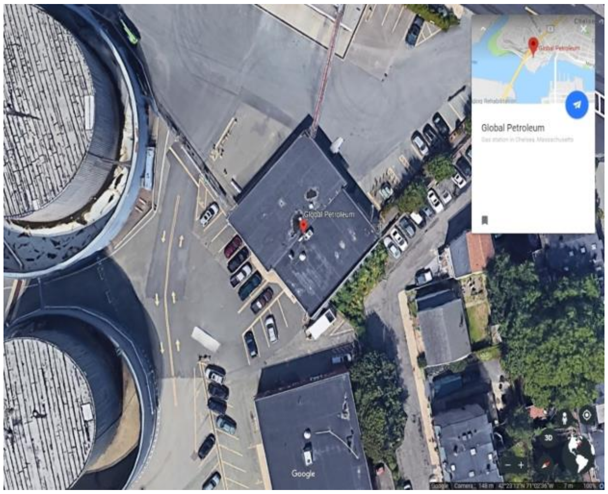


Figure 6: Sky-view of an active waste site at a Global Petroleum gas station in Chelsea MA (*Google Earth*, 2018)

Despite a shortage of available space, there are other concerns with solar energy being applied to waste sites. One prominent issue is the amount of time that is required to obtain an ideal return of investment (ROI) in a solar panel installation. The amount of time a waste site will remain active is unknown and dependent on each waste sites' contamination level so it would not seem viable to invest in solar energy if the payback amount is unknown. In an interview with Dorothy Allen, a MassDEP agency member who was responsible for the remediation management at the Baird & McGuire Superfund Site, we learned that the short time period of the site remediation process is one of the major barriers in adopting solar energy systems on waste sites for LSPs. If the pay back from the investment of a solar panel installation is within a 7 to 10-year period, then the return of investment (ROI) will gradually increase as the time gets longer. This idea is supported by the case study from the Baird & McGuire Financial Model (B&M Feasibility Study).

4.5 Waste Site Vulnerability

Finding 7: 7 of the 23 waste sites are vulnerable to flooding or storm surge.

MassDEP supplied a dataset of 23 waste sites containing different remedial monitoring reports (BWSC108 forms) with key submission dates for us to focus on. After gathering and analyzing the forms for the 23 waste sites, along with cross referencing the route tracking numbers (RTNs) between the datasets, we found that 7 of the 23 waste sites are vulnerable to flooding or storm surge. Figure 7 showcases the 23 waste sites and 7 vulnerable waste sites identified on a map of the Commonwealth of Massachusetts. The waste sites identified as vulnerable to storm surge or flooding were determined to be closer to bodies of water. This relates to waste sites relying on the power grid to operate even during the event of a storm surge or flood which can cause systems to remain offline. We cannot agree that all waste sites near bodies of water are vulnerable or if current waste sites will be considered vulnerable in the future.

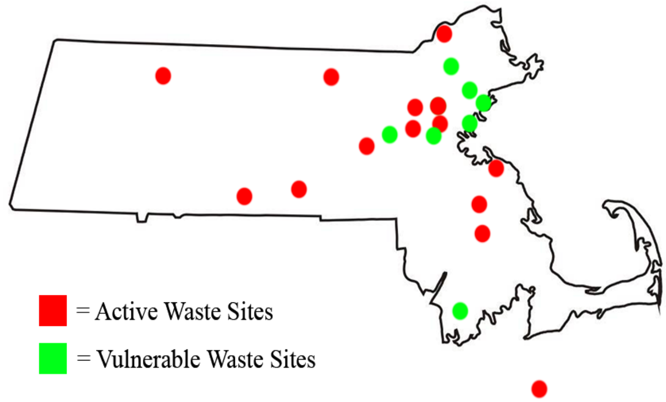
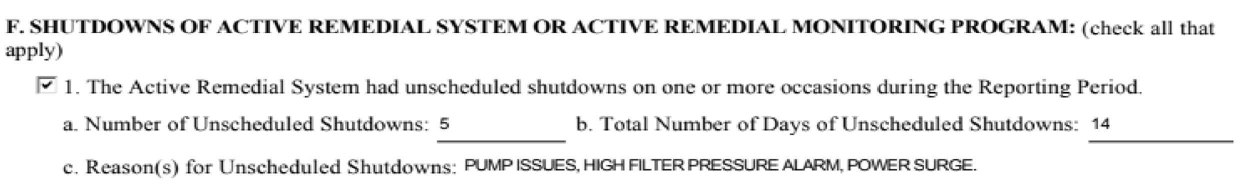


Figure 7. Map of the Commonwealth showing the locations of all active and vulnerable waste sites (*Adobe Photoshop, 2018*)

The remedial monitoring reports showcased information about unscheduled shutdowns that occurred and how long they lasted. From this information, we determined that vulnerable waste sites experience more unscheduled shutdowns due to flooding or storm surge than waste sites that are not considered viable. It was determined that waste sites that experienced a certain threshold of unscheduled shutdowns, due to flooding and storm surge, for a certain amount of days were deemed vulnerable. Figures 8 and 9 showcase two different waste sites that experienced unscheduled shutdowns due to storm surge. According to the MassDEP database, Figure 8 is not considered a vulnerable waste site which can be evident due to experiencing less unscheduled in general.



F. SHUTDOWNS OF ACTIVE REMEDIAL SYSTEM OR ACTIVE REMEDIAL MONITORING PROGRAM: (check all that apply)

☑ 1. The Active Remedial System had unscheduled shutdowns on one or more occasions during the Reporting Period.

a. Number of Unscheduled Shutdowns: 5 b. Total Number of Days of Unscheduled Shutdowns: 14

c. Reason(s) for Unscheduled Shutdowns: PUMP ISSUES, HIGH FILTER PRESSURE ALARM, POWER SURGE.

Figure 8: Remedial monitoring report for waste site RTN 3-0002060 (*MassDEP*, 2018)

F. SHUTDOWNS OF ACTIVE REMEDIAL SYSTEM OR ACTIVE REMEDIAL MONITORING PROGRAM: (check all that apply)

☒ 1. The Active Remedial System had unscheduled shutdowns on one or more occasions during the Reporting Period.

a. Number of Unscheduled Shutdowns: 3 b. Total Number of Days of Unscheduled Shutdowns: 1

c. Reason(s) for Unscheduled Shutdowns: POWER SURGES AND DAMAGE TO WATER TRANSFER PIPE

Figure 9: Remedial monitoring report for waste site RTN 4-0012087 (*MassDEP*, 2018)

5.0 Recommendations for Promoting Clean Environmental Remediation

We propose a series of recommendations to assist MassDEP in promoting renewable and more energy efficient systems to LSPs in charge of GWR systems. The recommendations and brief explanations for each recommendation follows.

Recommendation 1: MassDEP should utilize collected material and data from this project to further investigate challenges LSPs may encounter with GWR

<u>Use our spreadsheet of component data and our collection of LSP-submitted reports to conduct more in-depth studies on GWR energy usage of individual sites</u>

Through the studies of the components of the systems, we learned that there are opportunities for LSPs to upgrade the less energy efficient models of the components. From our investigations of the phase IV reports and review of manufacturers` websites, we realized the possibility that the components of the current GWR systems were older, more energy-consuming, and consequently more expensive to operate than the latest models available from the manufacturers. We also learned that manufacturers could help LSPs to upgrade the old parts of the systems. Therefore, we recommend MassDEP to inform LSPs that component manufacturers can potentially provide financial incentives and equipment upgrades. The limitation of this recommendation, however, is that the detailed information of the current remedial systems is not available to MassDEP. As a result, MassDEP is unlikely to identify the actual new models of the current system components

<u>Use the narrowed down BMPs as guidance to help LSPs make GWR systems greener</u>

According to various successful energy-efficient applications of BMPs, we observed that BMPs are not only applicable to current GWR systems, but may also be used as potential guidance for LSPs that will ultimately help them think of different approaches of reducing energy usage and cost. We recommend that MassDEP use existing BMPs to inform LSPs of the greener cleanup practices. Specifically, MassDEP can recommend the use of VFDs as a possible method for GWR system optimization. In addition, the BMP regarding efficient lighting exemplifies how BMPs can also help to reduce energy consumption in the whole remedial process. Both examples can be shown and promoted to LSPs, based on the research highlighted in our study. We provided evidence that VFDs can be effective tools for reducing overall energy consumption for the given system more efficiently by means of adjusting motor speed. Also, our research supports the usage of efficient lighting and several options available for optimizing energy usage in lighting fixtures to help reduce overall energy usage in remediation facilities. To help LSPs realize the value of BMPs to their remedial projects, MassDEP can use the B&M discussion from our study to demonstrate that BMPs are widely applicable and very possible for improving energy efficiency.

<u>The 7 vulnerable waste sites identified can be used as a starting point</u>

If MassDEP decides to complete site-specific analyses within the 23-site universe, then we recommend that they start with the 7 sites we identified as vulnerable. Not only will it allow them to identify the risks that are involved in these specific GWR systems, it will also enable them to promote renewables as a way to reduce system vulnerability and ultimately improve site resilience to climate change.

Recommendation 2: MassDEP should utilize the available resources to promote renewable energy and energy efficient methods to LSPs and site managers.

LSPs and site managers can utilize the programs or the assistive tools to apply for rebates or cost deductions when upgrading to more energy efficient systems and completing solar panel installations. MassDEP should distribute information about these programs and applications to LSPs and site managers as a means of incentivizing or convincing them to utilize clean and efficient energy. Through investigation of these programs, LSPs and site managers can be more aware of greener remedy options and to be more knowledgeable on the financial benefits of adopting renewable energy. The programs we identified are:

- The Solar Massachusetts Renewable Target (SMART) program
- DOER Financial models (RPS Solar Carve-Out Program v1.0), and other models such as the Simple Project Viability Evaluation Model and Solar Energy Financial Model
- The Database of State Incentives for Renewables & Efficiency (DSIRE) program
- The MassSave: Performance Lighting Program and others

Recommendation 3: MassDEP should consider promoting other renewable energy options for particular waste sites with different locations and available spaces.

MassDEP has considered promoting renewable energy applications specifically through solar panel installations on waste sites utilizing GWR systems. Because the scope of active waste sites has variations in available space and location, solar energy would not be viable for most waste sites. Though this is the case, other renewable energy applications are available for use on waste sites, such as wind power through turbines, and wind power can be utilized as an on or off-site source of renewable energy (Sørensen, 2010). Because certain waste sites have small amounts of available space and are located near rivers or shorelines, it could be beneficial to install wind turbines as a renewable energy source. EPA factsheets showcase financial benefits and potential savings from utilizing different forms of renewable energy (Sørensen, 2010). We recommend that MassDEP investigate other forms of renewable energy and consider utilizing them based on a waste site's available space, location, and other factors.

6.0 Conclusion

We identified several key findings regarding the promotion of energy efficient and renewable methods for GWR systems. First, we identified various Best Management Practices (BMPs) and highlighted the potential opportunities for energy usage optimization that they offer. MassDEP can use these BMPs as a guide for LSPs to identify opportunities to make changes in their own sites. Furthermore, we found that the BMPs available are not limited strictly for improving GWR energy efficiency; rather, LSPs can also utilize the more general BMPs that address energy usage in overall site facility operations. We also concluded that there are energy efficient GWR components available through various manufacturers, who may also be able to provide incentives and recommendations for installing these components. However, each site has its own specific system design, utilizing various types, models, and configurations of components, with a varying range of efficiencies; so proposing recommendations to LSPs is a complex process. In regards to solar power consideration, we found that the promotion of renewable energy can be achieved through state-funded programs that grant rebates and aid for solar installations. However, solar energy may not be applicable to certain waste sites due to a wide range of considerations, such as time, cost, or space.

The goal of promoting energy efficient and renewable solutions in GWR systems has proven to be complex and difficult, and there is still a lot of uncertainty to what LSPs will actually consider. However, the findings of this project provide MassDEP with a general idea of how LSP-provided data can be collected and analyzed so that opportunities for energy efficient or renewable solutions can be identified. Furthermore, this project has helped to reveal several issues that currently inhibit MassDEP from gaining a full understanding of GWR operations. Incomplete data and inconsistency in the reports submitted by LSPs in the MassDEP database limit how much MassDEP can actually discover about the remediation processes at these sites. From the data we analyzed, MassDEP can better understand what information is useful for energy efficiency and renewable energy analyses, and may aid in making data submission more consistent for future site assessments.

By utilizing the recommendations and deliverables we have provided, MassDEP can gain a better understanding of the considerations that are involved in making GWR systems greener. Ultimately, our findings can help MassDEP to achieve the goal of reducing the environmental footprints that GWR processes currently are leaving behind.

7.0 Deliverables

Upon the completion of our project, we sent our sponsor MassDEP a zipped file of deliverables containing our findings and recommendations. The highlighted deliverables include the following:

- Remedial monitoring reports of each waste site (Appendix D): This includes the BWSC108 forms and Phase IV reports for the 23 identified waste sites

- EPA factsheets that highlight different applications and financial benefits for renewable energy (Appendix B)

- Spreadsheets that highlight which sites are vulnerable to flooding or storm surge (Appendix C)

- Table of most applicable BMPs to waste sites utilizing GWR systems (Table in Findings Chapter)

- Spreadsheet containing which components and models are utilized by each waste site's GWR systems (Appendix E)

- A spreadsheet that summarizes all the useful information of each waste site, including our vulnerability analysis, specifications of system components, and related model information of the components.

These deliverables are collection of materials including information about current GWR systems in the 23 sites, and opportunities that can then be utilized by MassDEP to promote the use of clean and efficient energy applications in the waste site remediation process.

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Appendices

Appendix A: Interview Questions

Introduction:

Hello ______,

We are a group of students from Worcester Polytechnic Institute in Massachusetts (and we are working with the Massachusetts Department of Environmental Protection). Our project is intended to help MassDEP promote Greener Cleanups at sites with a specific focus on energy efficiency and renewable energy applications for groundwater recovery and treatment remediation systems.

You are currently listed as the LSP-of-Record associated with Release Tracking Number _________. Would you be willing to answer a few questions about the Groundwater Recovery and Treatment System (GRTS) or Pump & Treat system currently operating in your site?

This will take about 5~10 minutes and the interview is voluntary, your input will be kept confidential.

General Questions:

<u>Objective 2:</u>

1) What is the energy source(s)?
2) Is it **costly** to operate?
3) Over the course of operation, has the system been modified/upgraded? If so, for what reasons?

<u>Objective 3:</u>

4) How long has your system been operating? How long you estimate the system will be operating?
5) Are you familiar with MassDEP's 2014 Greener Cleanup regulatory provisions (310 CMR 40.0191?) If yes, how have you complied with it?
6) Are you familiar with MassDEP's 2014 Greener Cleanup Guidance document? If yes, how have you used it?
7) Are you familiar with ASTM's Standard Guide for Greener Cleanups? If yes, how have you used it?
8) Are you familiar with Best Management Practice (BMP) applications for P&T sites? If yes, how have you used it?

Objective 2 Energy Efficiency

9) <u>Have you tried to do anything to reduce energy use in the P&T systems?</u>
    a) **Yes**:
        i) (Why) What made you to do so? And <u>incentives</u>?
        ii) What did you do?

iii) What tools/materials/models did you use? What tools can we use to help reduce energy use in similar GWR systems as yours? (if they ask us, ask them to inquire a MassDEP agent)

iv) On average, how much energy used to be consumed by the remediation system annually?

v) How much energy use was reduced from the optimizing the system?

b) **No**:

i) (Why not) What are the barriers for you to considering using more energy-efficient components? Cost? Professional knowledge? Performance? Time? Etc?

ii) Do you think there are opportunities to reduce energy consumed by (P&T/GWR) system in your waste site, but you are just unable to do that because of the barriers?

iii) Do you want to reduce the energy consumption by either improving or replacing some components in your system? Any possibilities? Any drawbacks? Why/Why not?

Objective 3 Renewable Energy

1) Do you have any backup power systems? What are they? How is the system designed? (e.g., duration can operate? What can it operate? How much fuel is stored onsite, if needed?)

Based on our research, renewable energy (e.g. solar power) provide possible alternative to support the operation of P&T remediation systems in a handful of other waste sites, which may also be useful if there are power disruptions. We do have a couple of questions specifically on this idea if you would be willing to answer them.

2) Have you considered implementing renewable energy, such as **solar powe**r, in your GWR systems?

a) **Yes:**

i) What were your incentives of considering solar power?

ii) What challenges do you face with integrating or setting up solar panels to implement renewable (clean) energy into waste site remediation at this site? / What are the barriers that stopped you?

(1) (financial) Funding is limited? The Return of Investment is low? The waste site remediation won't take that long? Why/Why not?

(2) (technical) Using solar power is technically infeasible (e.g. space)? Why/Why not?

(3) Regulatory issues?

iii) Have you used any tools/materials/models that help to estimate renewable energy usage on-site?
Are they helpful / What can be more helpful to you (financial model? energy calculator?)
Is there any missing information or key points you might want to know about using renewable energy, i.e. solar power, in your waste site? Any uncertainties?

b) **No**:
   i) Are you interested in using solar power? Why/Why not?
   What challenges do you face with integrating or setting up solar panels to implement renewable (clean) energy into waste site remediation at this site? / What are the barriers that stopped you?
      (1) (financial) Funding is limited? The Return of Investment is low? The waste site remediation won't take that long? Why/Why not?
      (2) (technical) Using solar power is technically infeasible (e.g. space)? Why/Why not?
      (3) Regulatory issues?
   ii) Do you have any information you want to know about using renewable energy, i.e. solar power, in you waste site? Financial model? Energy calculator?

3) What`s your opinion on the social influence of your current methods? Any threats or benefits?

Appendix B: List of 23 Waste Sites and their Locations

RTN	SITE NAME	LOCATION
1-0011931	Convenience Store	Greenfield
1-0012147	Easterly Realty LLC FMR Westview Farms	Monson
1-0013130	Sandri Bulk Plant	Greenfield
2-0000165	Cresticon Sub NGGEC Former Litton	Westminster
2-0000401	Former Mobil Station	Westborough
2-0000760	Mobil Station 6W	Charlton
2-0000815	LA Mountain Exxon	Charlton
2-0011319	PWA Decor - Munksjo Paper Co	Fitchburg
3-0000310	Exxonmobil Petroleum Bulk Storage Terminal	Everett
3-0002060	Petroleum Terminal	Chelsea
3-0002363	YRC INC FMR Roadway Express	North Reading
3-0012266	No Location Aid	Peabody
3-0013302	Raytheon Company	Wayland
3-0013311	UTM 4696698 N 314255 E	Waltham
3-0014835	Global Petro	Revere
3-0023300	Tops Cleaners	Belmont
3-0026407	Draper Laboratory - Hanscom Test FAC	Concord
3-0027153	Kendall Green Energy LLC	Cambridge
4-0000256	Anderson Realty Trust	Abington
4-0000815	Revere Copper Products Inc	New Bedford
4-0012087	Airport RD	West Tisbury
4-0016968	Shell Gas Station	Brockton
4-3003287	Microsonics	Weymouth

Appendix C: EPA Factsheet for Integrating Renewable Energy

United States
Environmental Protection Agency

Office of Solid Waste and
Emergency Response (5102G)

EPA 542-F-11-006
April 2011

Green Remediation Best Management Practices:
Integrating Renewable Energy into Site Cleanup

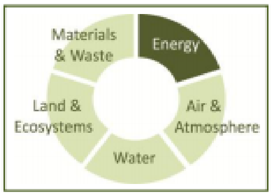
Office of Superfund Remediation and Technology Innovation

Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outline the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) identified in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Use of renewable energy resources provides a significant opportunity to reduce the environmental footprint of activities conducted during investigation, remediation, and monitoring of hazardous waste sites. Substitution of energy from fossil fuel resources with energy from renewable resources is a primary approach for addressing energy as one of the five core elements of green remediation strategies. In turn, lower consumption of fossil fuel will reduce emission of greenhouse gases (GHG) as well as particulate matter and other air pollutants.



EPA estimates that operation of 12 common cleanup technologies at Superfund sites could consume an average of 631,000 MWh annually between 2008 and 2023,[3] a quantity equivalent to the electricity consumption in about 55,000 homes over one year.[4]

Technology	Average Annual Electricity Consumption (MWh)	Average Annual Cost ($)*
Pump and treat	490,000	52,381,000
Thermal desorption	93,000	9,941,700
Multi-phase extraction	18,700	1,999,030
In situ thermal treatment	13,000	1,389,700
Air sparging	10,000	1,069,000
Soil vapor extraction	6,700	716,230
Ex situ stabilization	22	2,352
Other**	6	641
Total	631,428 MWh	$67,499,653

* Using the August 2010 national average of $106.90/MWh for commercial use
**Including ex situ bioremediation of soil, in situ bioremediation (source), in situ chemical oxidation (source), in situ bioremediation of groundwater, and in situ chemical oxidation of groundwater

Renewable sources of energy for production of electricity or direct power needed for site cleanup can include:

- ***Solar*** resources captured by photovoltaic (PV), solar thermal, and concentrating solar power systems
- ***Wind*** resources gathered through windmills to generate mechanical power or turbines of various sizes to generate electricity
- ***Geothermal*** resources, primarily through geoexchange systems such as geothermal heat pumps or by accessing subsurface reservoirs of hot water
- ***Hydrokinetic*** and ***marine*** resources, through the hydropower of rivers and streams or the tidal and thermal influences of oceans, and
- ***Biomass*** such as untreated woody waste, agricultural waste, animal waste, energy crops, landfill gas and wastewater methane, anaerobic digestion, and algae.

Methane captured from decomposing organic materials in landfills or wastewater treatment can also be used for direct heating rather than for electricity generation. Aspects of using this (ultimately finite) source of energy will be described in EPA's upcoming fact sheet on best management practices for addressing landfills at contaminated sites.

Evaluating the potential for integrating renewable energy at a hazardous waste site to achieve a "greener cleanup" typically involves:

- ***Maximizing energy efficiency and monitoring energy demand*** of remediation system(s), auxiliary equipment, buildings or sheds, and the supporting infrastructures for a new or existing project [page 2]
- Exploring potential applications for ***onsite production of energy*** from renewable resources [page 2]
- Conducting a preliminary ***renewable energy assessment*** to obtain site-specific information [page 6]
- Conducting a detailed ***economic and technical feasibility study*** for large or utility-scale renewable energy projects [page 6], and
- Considering ***purchases of clean energy*** from offsite resources through various mechanisms such as renewable energy certificates [page 7].

Lighten the Energy Load First

Use your energy dollar wisely by beginning with an energy audit and consistently using BMPs for energy conservation and efficiency.

1

Appendix D: EPA Factsheet for Pump and Treat Technologies

United States Environmental Protection Agency | Office of Solid Waste and Emergency Response (5102G) | EPA 542-F-09-005 December 2009

Green Remediation Best Management Practices:
Pump and Treat Technologies

Office of Superfund Remediation and Technology Innovation | Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) *Principles for Greener Cleanups* outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Pump and treat (P&T) technology typically is selected in a cleanup remedy to hydraulically contain contamination and/or restore an aquifer to beneficial use. Opportunities to reduce the energy and environmental footprint of a P&T remedy, which are available during site characterization and the remedy selection, design, construction, and operation phases, rely on effective planning and continual re-evaluation of P&T operations. Options for reducing the footprint vary based on the site conditions and cleanup objectives as well as the configuration and components of a planned or existing P&T system. Effective footprint reduction activities will complement the cleanup objectives while aligning with related guidelines such as *Executive Order 13514: Federal Leadership in Environmental, Energy, and Economic Performance.*[3]

P&T remedies often operate for long periods, in some cases decades, due to the nature of the technology and the nature of contaminant transport in the subsurface. As a result, operation of a P&T system, compared to system construction, can contribute significantly to the energy and environmental footprint of a P&T remedy. The best opportunities typically relate to optimizing efficiency of long-term operations, particularly in terms of energy and other natural resource consumption.

Continuous motor operation under load (for pumps, blowers, and other machinery) during a 30-year period of operation uses over 240,000 kWh of electrical energy per motor horsepower or over 2.7 billion BTUs of energy per motor horsepower (hp). This amount of energy is equivalent to the electricity used by more than 22 homes over one year.

Illustration of a P&T system with a fairly complex treatment process indicates how a system relates to each of the five core elements of green remediation. Components in this example can be removed to focus on how a simpler P&T system could affect the environmental footprint during operations.

P&T Component	Examples of Environmental Effects During a Complex P&T Operation
Groundwater Extraction	• **Energy** use (and associated **air** emissions) caused by generating electricity from fossil fuels to power extraction pumps • **Materials** use for well construction, maintenance, and rehabilitation • Removal of contaminated **water** and protection of other groundwater • Potential dewatering of wetlands and disrupting wetland **ecosystems** located near extraction wells
Process Equalization	• **Energy** use (and **air** emissions) for pumps used to adjust pressures among treatment components
Metals Removal (chemical addition, precipitation, settling, filtration, and solids handling)	• **Energy** use (and **air** emissions) for electricity operating mixer motors and filter feed or solids handling pumps • **Materials** use from chemical addition • **Waste** disposal from removed solids, such as metals or biosolids • Infringement on **land** and **ecosystems** from landfill space for waste disposal
Air Stripping	• **Energy** use (and **air** emissions) for electricity to operate a blower • **Materials** use for chemical cleaning of a stripping system
Off-Gas Treatment and ***Granular Activated Carbon Filtration***	• **Energy** (and **air** emissions) for electricity to preheat off-gas prior to vapor treatment • **Materials** and potential **waste** disposal for granular activated carbon
Effluent Tanks	• **Energy** use (and **air** emissions) for electricity to pump water across a multi-step treatment process
Discharge to Surface Water	• Net withdrawal of local groundwater resources when extracted **water** is discharged to surface water
Building Operations	• **Energy** use (and **air** emissions) for electricity to power lights, ventilate a building, and potentially provide heat
Long-Term Operation	• Affects on **land** use and the local community and long-term stewardship of **land** and nearby **ecosystems**

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Appendix E: Vulnerable Waste Sites Spreadsheet

From the list of 23 waste sites and the data set of waste sites considered to be vulnerable, we created a spreadsheet that highlights which of these waste sites is vulnerable to flooding or storm surge. We were also able to use the same data set to determine if certain waste sites are actively running GWR systems. As shown below, we found 7 waste sites to be vulnerable to flooding or storm surge and 14 waste sites currently running GWR systems.

RTN	Vulnerable	Open_sites_flood	ARS_flood	Open_sites_storm_surge	ARS_storm_surge	Open_sites_total	ARS_total	GWR ACTIVE WASTE SITES	MYSTIC RIVER?	LOCATION
1-0011931								1-0011931	NO	Greenfield
1-0012147								1-0012147	NO	Monson
1-0013130								1-0013130	NO	Greenfield
2-0000165								2-0000165	NO	Westminster
2-0000401								2-0000401	NO	Westborough
2-0000760								2-0000760	NO	Charlton
2-0000815								2-0000815	NO	Charlton
2-0011319								2-0011319	NO	Fitchburg
3-0000310	X			X				3-0000310	YES	Everett
3-0002060	X			X	X			3-0002060	YES	Chelsea
3-0002363								3-0002363	YES	North Reading
3-0012266	X			X	X			3-0012266	NO	Peabody
3-0013302	X		X					3-0013302	NO	Wayland
3-0013311								3-0013311	NO	Waltham
3-0014835	X		X		X		X	3-0014835	YES	Revere
3-0023300								3-0023300	YES	Belmont
3-0026407								3-0026407	NO	Concord
3-0027153	X			X	X			3-0027153	YES	Cambridge
4-0000256								4-0000256	NO	Abington
4-0000815	X	X	X	X	X	X	X	4-0000815	NO	New Bedford
4-0012087								4-0012087	NO	West Tisbury
4-0016968								4-0016968	NO	Brockton
4-3003287								4-3003287	NO	Weymouth
TOTAL:										
23	7	1	4	5	5	1	2	15	6	N/A

Appendix F: Remedial Monitoring Report Sample

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup

COMPREHENSIVE RESPONSE ACTION TRANSMITTAL FORM & PHASE I COMPLETION STATEMENT

Pursuant to 310 CMR 40.0484 (Subpart D) and 40.0800 (Subpart H)

BWSC108

Release Tracking Number

☐ - ______

A. SITE LOCATION:

1. Site Name: ______
2. Street Address: ______
3. City/Town: ______ 4. ZIP Code: ______

☐ 5. Check here if the disposal site that is the source of the release is Tier Classified. Check the current Tier Classification Category.

☐ a. Tier I ☐ b. Tier ID ☐ c. Tier II

B. THIS FORM IS BEING USED TO: (check all that apply)

☐ 1. Submit a **Phase I Completion Statement**, pursuant to 310 CMR 40.0484.

☐ 2. Submit a **Revised Phase I Completion Statement**, pursuant to 310 CMR 40.0484.

☐ 3. Submit a **Phase II Scope of Work**, pursuant to 310 CMR 40.0834.

☐ 4. Submit an **interim Phase II Report**. This report does not satisfy the response action deadline requirements in 310 CMR 40.0500.

☐ 5. Submit a **final Phase II Report and Completion Statement**, pursuant to 310 CMR 40.0836.

☐ 6. Submit a **Revised Phase II Report and Completion Statement**, pursuant to 310 CMR 40.0836.

☐ 7. Submit a **Phase III Remedial Action Plan and Completion Statement**, pursuant to 310 CMR 40.0862.

☐ 8. Submit a **Revised Phase III Remedial Action Plan and Completion Statement**, pursuant to 310 CMR 40.0862.

☐ 9. Submit a **Phase IV Remedy Implementation Plan**, pursuant to 310 CMR 40.0874.

☐ 10. Submit a **Modified Phase IV Remedy Implementation Plan**, pursuant to 310 CMR 40.0874.

☐ 11. Submit an **As-Built Construction Report**, pursuant to 310 CMR 40.0875.

☐ 12. Submit a **Phase IV Status Report**, pursuant to 310 CMR 40.0877.

☐ 13. Submit a **Phase IV Completion Statement**, pursuant to 310 CMR 40.0878 and 40.0879.

Specify the outcome of Phase IV activities: (check one)

☐ a. Phase V Operation, Maintenance or Monitoring of the Comprehensive Remedial Action is necessary to achieve a Permanent or Temporary Solution.

☐ b. The requirements of a Permanent Solution have been met. A completed Permanent Solution Statement and Report (BWSC104) will be submitted to DEP.

☐ c. The requirements of a Temporary Solution have been met. A completed Temporary Solution Statement and Report (BWSC104) will be submitted to DEP.

Revised: 11/14/2013 Page 1 of 5

B. THIS FORM IS BEING USED TO (cont.): (check all that apply)

☐ 14. Submit a **Revised Phase IV Completion Statement**, pursuant to 310 CMR 40.0878 and 40.0879.

☐ 15. Submit a **Phase V Status Report**, pursuant to 310 CMR 40.0892.

☐ 16. Submit a **Remedial Monitoring Report.** (This report can only be submitted through eDEP.)

a. Type of Report: (check one) ☐ i. Initial Report ☐ ii. Interim Report ☐ iii. Final Report

b. Frequency of Submittal: (check all that apply)

☐ i. A Remedial Monitoring Report(s) submitted monthly to address an Imminent Hazard.

☐ ii. A Remedial Monitoring Report(s) submitted monthly to address a Condition of Substantial Release Migration.

☐ iii. A Remedial Monitoring Report(s) submitted every six months, concurrent with a Status Report.

☐ iv. A Remedial Monitoring Report(s) submitted annually, concurrent with a Status Report.

c. Status of Site: (check one) ☐ i. Phase IV ☐ ii. Phase V ☐ iii. Remedy Operation Status ☐ iv. Temporary Solution

d. Number of Remedial Systems and/or Monitoring Programs: ____________

A separate BWSC108A, CRA Remedial Monitoring Report, must be filled out for each Remedial System and/or Monitoring Program addressed by this transmittal form.

☐ 17. Submit a **Remedy Operation Status**, pursuant to 310 CMR 40.0893.

☐ 18. Submit a **Status Report to maintain a Remedy Operation Status**, pursuant to 310 CMR 40.0893(2).

☐ 19. Submit a **Transfer and/or a Modification of Persons Maintaining a Remedy Operation Status (ROS)** , pursuant to 310 CMR 40.0893(5) (check one, or both, if applicable).

☐ a. Submit a Transfer of Persons Maintaining an ROS (the transferee should be the person listed in Section D, "Person Undertaking Response Actions").

☐ b. Submit a Modification of Persons Maintaining an ROS (the primary representative should be the person listed in Section D, "Person Undertaking Response Actions").

c. Number of Persons Maintaining an ROS not including the primary representative: ____________

☐ 20. Submit a **Termination of a Remedy Operation Status**, pursuant to 310 CMR 40.0893(6).(check one)

☐ a. Submit a notice indicating ROS performance standards have not been met. A plan and timetable pursuant to 310 CMR 40.0893(6)(b) for resuming the ROS are attached.

☐ b. Submit a notice of Termination of ROS.

☐ 21. Submit a **Phase V Completion Statement**, pursuant to 310 CMR 40.0894.

Specify the outcome of Phase V activities: (check one)

☐ a. The requirements of a Permanent Solution have been met. A completed Permanent Solution Statement and Report (BWSC104) will be submitted to DEP.

☐ b. The requirements for a Temporary Solution have been met. A completed Temporary Solution Statement and Report (BWSC104) will be submitted to DEP.

☐ 22. Submit a **Revised Phase V Completion Statement**, pursuant to 310 CMR 40.0894.

☐ 23. Submit a **Temporary Solution Status Report**, pursuant to 310 CMR 40.0898.

☐ 24. Submit a **Plan for the Application of Remedial Additives** near a sensitive receptor, pursuant to 310 CMR 40.0046(3).

a. Status of Site: (check one)

☐ i. Phase IV ☐ ii. Phase V ☐ iii. Remedy Operation Status ☐ iv. Temporary Solution

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup

BWSC108A

COMPREHENSIVE RESPONSE ACTION REMEDIAL MONITORING REPORT

Pursuant to 310 CMR 40.0800 (Subpart H)

Release Tracking Number ☐ - ☐

Remedial System or Monitoring Program: ________ of: ________

A. DESCRIPTION OF ACTIVE OPERATION AND MAINTENANCE ACTIVITY:

1. Type of Active Operation and Maintenance Activity: (check all that apply)
   - ☐ a. Active Remedial System: (check all that apply)
     - ☐ i. NAPL Recovery ☐ ii. Soil Vapor Extraction/Bioventing ☐ iii. Vapor-phase Carbon Adsorption
     - ☐ iv. Groundwater Recovery ☐ v. Dual/Multi-phase Extraction ☐ vi. Aqueous-phase Carbon Adsorption
     - ☐ vii. Air Stripping ☐ viii. Sparging/Biosparging ☐ ix. Cat/Thermal Oxidation
     - ☐ x. Other Describe: ________
   - ☐ b. Active Exposure Pathway Elimination Measure:
     Active Exposure Pathway Mitigation System to address (check one): ☐ i. Indoor Air ☐ ii. Drinking Water
   - ☐ c. Application of Remedial Additives: (check all that apply)
     - ☐ i. To the Subsurface ☐ ii. To Groundwater (Injection) ☐ iii. To the Surface
   - ☐ d. Active Remedial Monitoring Program Without the Application of Remedial Additives: (check all that apply; Sections C, D and E are not required; attach supporting information, data, maps and/or sketches needed by checking Section G5)
     - ☐ i. Reactive Wall ☐ ii. Natural Attenuation ☐ iii. Other Describe: ________
2. Mode of Operation: (check one)
   ☐ a. Continuous ☐ b. Intermittent ☐ c. Pulsed ☐ d. One-time Event Only ☐ e. Other: ________
3. System Effluent/Discharge: (check all that apply)
   - ☐ a. Sanitary Sewer/POTW
   - ☐ b. Groundwater Re-infiltration/Re-injection: (check one) ☐ i. Downgradient ☐ ii. Upgradient
   - ☐ c. Vapor-phase Discharge to Ambient Air: (check one) ☐ i. Off-gas Controls ☐ ii. No Off-gas Controls
   - ☐ d. Drinking Water Supply
   - ☐ e. Surface Water (including Storm Drains)
   - ☐ f. Other Describe: ________

B. MONITORING FREQUENCY:

1. Reporting period that is the subject of this submittal: From: ________ (mm/dd/yyyy) To: ________ (mm/dd/yyyy)
2. Number of monitoring events during the reporting period: (check one)
   - ☐ a. System Startup: (if applicable)
     - ☐ i. Days 1, 3, 6, and then weekly thereafter, for the first month.
     - ☐ ii. Other Describe: ________
   - ☐ b. Post-system Startup (after first month) or Monitoring Program:
     - ☐ i. Monthly
     - ☐ ii. Quarterly
     - ☐ iii. Annually
     - ☐ iv. Other Describe: ________

☐ 3. Check here to certify that the number of required monitoring events were conducted during the reporting period.

C. EFFLUENT/DISCHARGE REGULATION: (check one to indicate how the effluent/discharge limits were established)

☐ 1. NPDES: (check one) ☐ a. Remediation General Permit ☐ b. Individual Permit
☐ c. Emergency Exclusion Effective Date of Permit: ________ (mm/dd/yyyy)

☐ 2. MCP Performance Standard MCP Citations(s): ________

☐ 3. DEP Approval Letter Date of Letter: ________ (mm/dd/yyyy)

☐ 4. Other Describe: ________

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup

COMPREHENSIVE RESPONSE ACTION REMEDIAL MONITORING REPORT Pursuant to 310 CMR 40.0800 (Subpart H)

Remedial System or Monitoring Program: ________ of: ________

BWSC108A

Release Tracking Number

☐ - ☐

E. STATUS OF ACTIVE REMEDIAL SYSTEM OR ACTIVE REMEDIAL MONITORING PROGRAM DURING REPORTING PERIOD: (cont.)
(check all that apply)

☐ d. Other additives applied: (total quantity applied at the site for the current reporting period)

Name of Additive	Date	Quantity	Units

Name of Additive	Date	Quantity	Units

☐ e. Check here if any additional Remedial Additives were applied. Attach list of additional additives and include Name of Additive, Date Applied, Quantity Applied and Units (in gals. or lbs.)

F. SHUTDOWNS OF ACTIVE REMEDIAL SYSTEM OR ACTIVE REMEDIAL MONITORING PROGRAM: (check all that apply)

☐ 1. The Active Remedial System had unscheduled shutdowns on one or more occasions during the Reporting Period.

a. Number of Unscheduled Shutdowns: ________ b. Total Number of Days of Unscheduled Shutdowns: ________

c. Reason(s) for Unscheduled Shutdowns: ________

☐ 2. The Active Remedial System had scheduled shutdowns on one or more occasions during the Reporting Period.

a. Number of Scheduled Shutdowns: ________ b. Total Number of Days of Scheduled Shutdowns: ________

c. Reason(s) for Scheduled Shutdowns: ________

☐ 3. The Active Remedial System or Active Remedial Monitoring Program was permanently shutdown/discontinued during the Reporting Period.

a. Date of Final System or Monitoring Program Shutdown: ________ (mm/dd/yyyy)

☐ b. No Further Effluent Discharges.

☐ c. No Further Application of Remedial Additives planned; sufficient monitoring completed to demonstrate compliance with 310 CMR 40.0046.

☐ d. No Further Submittals Planned.

☐ e. Other: Describe: ________

G. SUMMARY STATEMENTS: (check all that apply for the current reporting period)

☐ 1. All Active Remedial System checks and effluent analyses required by the approved plan and/or permit were performed when applicable.

☐ 2. There were no significant problems or prolonged (>25% of reporting period) unscheduled shutdowns of the Active Remedial System.

☐ 3. The Active Remedial System or Active Remedial Monitoring Program operated in conformance with the MCP, and all applicable approval conditions and/or permits.

4. Indicate any Operational Problems or Notes:

____

☐ 5. Check here if additional/supporting Information, data, maps, and/or sketches are attached to the form.

Appendix G: Spreadsheet of GWR system components

RTN	Location	Type of Report Used	Types of Components Found	Where Data was Found
1-0011931	Greenfield	Phase IV	Extraction Blower liquid ring pump air stripper bag filter	p14 list p14~17 paragraphs
1-0012147	Monson	Phase IV	-	pg 15 "The selected remedial alternative doe not involve construction specifications or drawings"
1-0013130	Greenfield	Phase IV	liquid ring vacuum pump air compressor vaccum blower OWS Xfer Pump	SVE: p33 schemetics p5: vaper extraction/air sparge
2-0000165	Westminster	Phase IV	-	-
2-0000401	Westborough	Phase IV	Liguid ring pump contrifugal pump rotary vane compressor displacement pump positic dispacment blower centrifugal blower pump piston compressor skimmer pump duaphram pump low profile air stripper air cooled heat exchanger	SVE: p23 general
2-0000760	Charlton	Phase IV	progressive cavity pump liquid ring pump air compressor positive displacement blower transfer pump air strpping blower centrifugal blower pump air cooled heat exchanger	SVE: p103, p114
2-0000815	Charlton	Phase IV	liquid ring pump centrifugal pump rotary vane compressor diaplacement pump blower skimmer pump diaphram pump proportioning pump centrifugal blower pump heater	p24 Grundfos "Redi-Flow 2" submersible pump p60 schemtic
2-0011319	Fitchburg	Phase IV	oil skimmer recovery system: Oil Grabber® Model 4 Oil Skimmer Five soil borings (B-101 through B-105)	p91 ~ 108 Oil Grabber® Model 4 Oil Skimmer p20 oil skimmer recovery system p17 soil borings
3-0000310	Everett	Phase IV	Clean Earth Technology Spill Buster pumps	p36 Clean Earth Technology Spill Buster pumps
3-0002060	Chelsea	Phase IV	GROUNDWATER EXTRACTION SYSTEM: Four (4) CE AP2 Top Loading Pneumatic submersible well pumps Cameron Air Supply compressor - 12 SCFM at 125 PSI WATER TREATMENT SYSTEM: MLE OWS-10 Oil water separator with integral water retention tank Water transfer pump from OWS - 10 GPM QED EZ 2.4P Air Stripper Transfer pump from Air Stripper - 10 GPM Liquid phase Bag filtration - 10 GPM Dual Liquid Phase Carbon filtration - 10 GPM OFF GAS TREATMENT SYSTEM: Vapor Phase carbon filtration- 150 SCFM	p36 tables p37-40 technicla specifications
3-0002363	North Reading	Phase IV	air stripper blower Liquid phase GAC vessel submersible pumps pressure transducers variable frequency drives air stripper blower air stripper sump pump	pg 46 pumps & blowers pg 49 system schematic with model numbers and specific component data
3-0012266	Peabody	IRA	chemical transfer pump	pg 3-6 (1995 IRA form)
3-0013302	Wayland	Phase IV	sump pumps centrifugal pumps high pressure diaphragm pumps manifold pumps	pg 17 pg 36

15	3-0013311	Waltham	Phase IV	Q Mark MUH Series Modular Unit Heaters MUH321 ABS drainage pumps Robusta 300 WTS, 200 WTS, 120 WTS Dayton Utility Shutter-Mounted Exhaust Fans 2C708B Dayton Motorized Dampers Models 4C560, 4C561, 3C315 EZ-Tray Air Stripper American Fan Company SM 844 Pressure Blower Goulds Pumps, Inc. Model NPE / NPE-F centrifugal pump Grundfos Redi-Flo4" Environmental submersible pump 5E Grundfos Redi-Flo4" Environmental submersible pump 10E Grundfos Redi-Flo4" Environmental submersible pump 25E Chromalox	pg 5 pg 11 pg 15 pg 19 pg 25 pg 60 pg 83 pg 98 pg 100 pg 102 pg 116
16	3-0014835	Revere	Phase IV	Grundfos submersible pumps skimmer pumps	p9 skimmer + submersible p23 grundfos
17	3-0023300	Belmont	IRA	exhaust fans sump pumps peristaltic pumps	pg 5 pg 7
18	3-0026407	Concord	RAM	Dual Grundfos Redi-Flo 4" submersible pump Model 5E 1/2 hp 20-gpm model HQI AGM-2SS-73V-1H parallel-corrugated plate coalesc 20-gpm, 3/4 hp transfer pump	pg 8 pg 8 pg 8
19	3-0027153	Cambridge	IRA	polyethylene bailer	pg 4-1
20	4-0000256	Abington	Phase IV	Lift pump Model 3DB-10-E8 biodiffuser (Penney Engineering) Blower Discharge pump wall mounted heater	pg 19 pg 19 pg 21 pg 21 pg 49
21	4-0000815	New Bedford	Phase IV	Clean Earth Technology Magnum Spill Buster portable, automated NAP Diphragm pump Low-flow (1 gal/min) pumping system Passive perstalic skimmer NAPL Recovery System	-
22	4-0012087	West Tisbury	IRA	air injection equipment air extraction blowers groundwater pumping wells	-
23	4-0016968	Brockton	Phase IV	-	-
24	4-3003287	Weymouth	Phase IV	recovery pumps flush-mounted well vaults blower, Fuji Model VFC200P Grundfos submersible pumps transfer pumps (10 gpm, 3 gpm) GAC Vessels	pg 5 general description pg 57 + 58 (Figure 9) schematic of whole GWR system

Appendix H: Authorship Table

Section	Primary Author	Primary Editor
Abstract	Benjamin Duquette	All
Executive Summary	Christian Anderson	All
Acknowledgements	Benjamin Duquette	All
1.0 An Introduction to Waste Site Remediation	All	All
2.0 Identification and Remediation of Contaminated Sites	Benjamin Duquette Zonglin Peng	All
2.1 Current Efforts Towards Environmental Remediation in MA	Christian Anderson	All
2.2 The Pump & Treatment Remedial Process	Zonglin Peng Benjamin Duquette	All
2.2.1 Groundwater Remediation (GWR) System Specifications	Zonglin Peng	All
2.3 Drawbacks in Current Groundwater Remediation Systems	Zonglin Peng	All
2.4 Approaches of Overcoming Drawbacks in GWR Systems	Zonglin Peng	All
2.4.1 Improving Energy Efficiency in GWR Systems	Zonglin Peng	All

2.4.2 Using Solar Energy as a Power Alternative	**Zonglin Peng**	**All**
2.5 Promotion of Greener Cleanup	**Christian Anderson**	**All**
3.0 Methods for Identifying Renewable Energy & Energy Efficient Applications in Waste Site Remediation	**Benjamin Duquette**	**All**
3.1 Identified Waste Sites Vulnerable to Flooding & Storm Surge	**Benjamin Duquette**	**All**
3.2 Investigated Energy Efficient Applications	**Christian Anderson** **Zonglin Peng**	**All**
3.3 Identified Renewable Energy Applications through Solar Energy	**Benjamin Duquette**	**All**
4.0 Renewable Energy and Energy Efficiency Application Opportunities	**Benjamin Duquette**	**All**
4.1 Potential Opportunities to Increase Energy Efficiency in Current GWR Systems	**Christian Anderson** **Zonglin Peng**	**All**
4.2 Barriers to Energy Efficiency Optimization	**All**	**All**
4.3 Opportunities for Solar Energy Applications	**All**	**All**
4.4 Barriers of Using Solar Power	**Benjamin Duquette** **Zonglin Peng**	**All**
4.5 Waste Site Vulnerability	**Benjamin Duquette**	**All**

5.0 Recommendations for Promoting Clean Environmental Remediation	**Benjamin Duquette** **Zonglin Peng**	**All**
Recommendation 1	**Zonglin Peng** **Christian Anderson**	**All**
Recommendation 2	**Benjamin Duquette** **Zonglin Peng**	**All**
Recommendation 3	**Benjamin Duquette**	**All**
6.0 Conclusion	**Christian Anderson**	**All**
7.0 Deliverables	**Benjamin Duquette**	**All**
Bibliography	**All**	**All**
Appendices	**Benjamin Duquette**	**All**
Appendix A	**All**	**All**
Appendix B	**All**	**All**
Appendix C	**All**	**All**
Appendix D	**All**	**All**
Appendix E	**All**	**All**

Appendix F	**All**	**All**
Appendix G	**All**	**All**
Appendix H	**All**	**All**