Comparative Analysis of Corrective Action Options: North Bennington, Vermont

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Acronyms

Acronym	Description
DWHA	Drinking Water Health Advisory
gpm	Gallons per minute
PFCs	Perfluorinated compounds
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
POET	Point of Entry Treatment
ppt	Parts per trillion
VTDEC	Vermont Department of Environmental Conservation

Executive Summary

This report describes the results of a comparison of corrective action alternatives for PFCs regionally present in groundwater in the Bennington area. The alternatives analysis is intended to address groundwater in areas potentially affected by PFOA that originated as air emissions from the two former Chemfab facilities in the Bennington area: the Northside Drive facility (operated between 1968 and 1978) and the Water Street facility (operated between 1979 and 2002).

Eight different potential corrective action options were considered in detail as part of this evaluation including:

1. Installation and Operation of POET Systems;
2. Installation of Municipal Water Lines;
3. Operation of Existing Wells at Full Capacity with POET Systems;
4. Dedicated Pump-and-Treat Well System with Reinjection;
5. Operation of Existing Wells and Dedicated Pump-and-Treat Well System with Reinjection;
6. Well Replacement;
7. Surficial Soil Excavation; and
8. Monitored Natural Attenuation.

Each of these options were evaluated against the following evaluation criteria:

- Overall Protectiveness of Human Health and the Environment
- Compliance with Applicable and Relevant Requirements
- Short-Term Effectiveness
- Long-Term Effectiveness and Permanence
- Reduction of Contaminant Mass, Mobility, and Toxicity
- Implementability
- Cost
- Community Acceptance

The comparison led to the following conclusions and recommendations for corrective action:

- POETs using granular activated carbon filtration are a proven effective means of treating PFOA in drinking water supply wells and, therefore, the continued operation and maintenance of POETs that have already been installed on impacted private water supply wells provides a readily implementable long-term corrective action option for drinking water that is fully protective of human health and the environment.

- Long-term operation and maintenance of POETs for some private supply wells at certain residences may be more expensive than hooking up such homes to the municipal water system. For such locations, extending municipal waterlines may be a more cost-effective, long-term corrective action to address PFOA in drinking water.

- Natural groundwater flow processes are effectively removing PFOA from the groundwater system and, therefore, MNA and institutional controls are a viable long-term corrective action option for groundwater.

- Corrective action options with active pump-and-treat systems or surficial soil excavation incur significant expense but do not substantially reduce PFOA mass or increase overall protectiveness of human health and the environment. Moreover, there are a number of technical or engineering difficulties associated with each of these alternatives, which make them technically infeasible. Due to the likely public disruption that would occur from wide-scale groundwater pumping or soil excavation, these alternatives would also probably not be accepted by the community.

1.0 Introduction

This report describes the results of a comparison of corrective action alternatives for perfluorinated compounds (PFCs) regionally present in groundwater in the Bennington area. The alternatives analysis is intended to address groundwater in areas potentially affected by perfluorooctanoic acid (PFOA) that originated as air emissions from the two former Chemfab facilities in the Bennington area: the Northside Drive facility (operated between 1968 and 1978) and the Water Street facility (operated between 1979 and 2002).

1.1 Corrective Action Goals

The goals of corrective action are to achieve target outcomes within the corrective action area.

1.2 Corrective Action Area

The corrective action area for this evaluation is shown on Figure 1, and is defined as the area in which the combined air deposition-groundwater models yield concentrations of PFOA in groundwater above 20 parts per trillion (ppt) in 2016 due to past air emissions of PFOA from the former Chemfab facilities, as described in the CSM Report (*Barr, 2017. Conceptual Modeling of PFOA Fate and Transport: North Bennington, Vermont, February 2017*). For purposes of this evaluation, any localized sources and resulting PFOA concentrations in close proximity to the former Chemfab facilities that are not the result of air emissions are not considered. Localized PFOA concentrations in close proximity to the former facilities are more appropriately addressed in site-specific evaluations. PFCs in groundwater beyond the limits of the predicted air deposition area are also not a part of this evaluation.

1.3 Target Outcomes

Corrective action alternatives are intended to meet the overall outcome of protecting human health and the environment. The primary target outcome is to reduce the concentration of PFOA in drinking water below levels of concern. For purposes of this analysis, the level of concern is the Vermont Department of Health's Drinking Water Health Advisory (DWHA) of 20 ppt combined PFOA and perfluorooctanesulfonic acid (PFOS). This target outcome has already been met through the installation of Point of Entry Treatment (POET) systems on all private water wells with concentrations above 20 ppt.

Another target outcome for corrective action is to reduce the mass of PFOA in the groundwater and thereby reduce the concentration below 20 ppt. Reducing the mass in the groundwater will eventually result in groundwater concentrations of PFOA that no longer require treatment before consumption. Active measures that remove mass from groundwater may reduce the time required to reach levels below 20 ppt.

A third target outcome for corrective action is to remediate the sources of releases so as to eliminate or reduce further releases of constituents that may pose a threat to human health and the environment, and using treatment to address principal-threat wastes. Because operations at the Chemfab facilities had ceased by 2002, those facilities are not ongoing sources of releases of PFOA through airborne emissions and, therefore, this target outcome has already been met subject to any localized remediation that may be required at the Chemfab facilities themselves, which is beyond the scope of this analysis.

2.0 Evaluation Criteria

When one or more corrective action alternatives appear to be capable of achieving the target outcomes, eight attributes (called Balancing/Evaluation Criteria by the United States Environmental Protection Agency (EPA)) are used to select the “best” alternative. These eight evaluation criteria are:

- Overall Protectiveness of Human Health and the Environment
- Compliance with Applicable and Relevant Requirements
- Short-Term Effectiveness
- Long-Term Effectiveness and Permanence
- Reduction of Contaminant Mass, Mobility, and Toxicity
- Implementability
- Cost
- Community Acceptance

These evaluation criteria are generally most applicable and useful in selecting a remedy at a localized release location, such as a RCRA facility. The following discussion addresses their application to PFCs in groundwater from air emissions in the Bennington area.

2.1 Overall Protectiveness of Human Health and the Environment

For this evaluation, protection of human health is defined as providing a condition in which potable water has a concentration of PFOA+PFOS less than the DWHA of 20 ppt. No other pathway of concern for human exposure (e.g., contact with soil or consumption of produce or fish) has been identified by the Vermont Department of Environmental Conservation (VTDEC) to be associated with this PFOA release. Similarly, VTDEC has not identified non-human environmental exposure concerns. Discussion of this criterion for the corrective action alternatives is limited to protectiveness of human health.

2.2 Compliance with Applicable and Relevant Requirements

Compliance with applicable and relevant requirements in this evaluation means potable water concentrations of PFOA+PFOS equal to or less than the DWHA of 20 ppt.

2.3 Short-Term Effectiveness

The short-term effectiveness criterion is intended to deal with imminent threats to human health and the environment or when waste characteristics such as explosivity are present. Short-term effectiveness is typically used to address interim response measures in order to correct an acute exposure potential. The timely installation of POET systems on all wells with concentrations above 20 ppt constitutes an example of a corrective action with high short-term effectiveness.

2.4 Long-Term Effectiveness and Performance

The long-term effectiveness criterion addresses the ability of a response measure to function appropriately over many different expected conditions, such as changes in weather, land use, etc. Long-term effectiveness also addresses the potential for constructed systems to degrade over time and require replacement. Permanence is different than long-term effectiveness. Permanence generally refers to a corrective action's effectiveness with respect to the need for future human actions. Removal of a source typically has a high degree of permanence compared to a system that requires ongoing operation and maintenance.

2.5 Reduction of Contaminant Mass, Mobility, and Toxicity

Removal of the mass of a constituent from the environment by excavation, degradation, or extraction is a criterion that can be measured separately from containment of mass. Similarly, if a corrective action reduces (or increases) the mobility of a constituent or changes the toxic nature of the constituent, that criterion needs to be considered. In some cases, corrective actions may only partially accomplish the objectives of this criterion, such as degrading a constituent to a less toxic, but more mobile constituent.

2.6 Implementability

A corrective action's implementability refers to the difficulty and time required to perform the corrective action. Constructability, availability of permits, and availability of certain technologies are also a part of the implementability consideration.

2.7 Cost

Cost of corrective actions must be considered in the selection process. Cost estimates for corrective actions need to include engineering, site preparation, construction, materials, labor, sampling/analysis, waste management/disposal, permitting, health and safety measures, training, operation and maintenance. Where appropriate, present-worth calculations are used to compare costs between actions with high up-front capital costs and actions with high long-term operation and maintenance costs.

2.8 Community Acceptance

Corrective actions need to consider the potential for community objections to implementation. This criterion also needs to consider the level of community involvement required for the corrective action implementation.

3.0 Corrective Action Options

Eight different potential corrective action options were considered in detail as part of this evaluation including: (1) Installation and Operation of POET systems; (2) Installation of Municipal Water Lines; (3) Operation of Existing Wells at Full Capacity with POET Systems; (4) Dedicated Pump-and-Treat Well System with Reinjection; (5) Operation of Existing Wells and Dedicated Pump-and-Treat Well System with Reinjection; (6) Well Replacement; (7) Surficial Soil Excavation; and (8) Monitored Natural Attenuation. In addition, several other potentially applicable corrective action options, including physical barriers, cut-off walls, and reactive barrier walls, in situ treatment, and low-permeability capping were considered but screened out from further analysis because they were deemed to be inapplicable to the disperse plume of PFOA being addressed.

For all of the corrective action options, natural groundwater processes will continue to flush PFOA mass from the groundwater system and reduce PFOA concentrations at individual wells. A long-term monitoring program separate from monitoring of POET systems or pump-and-treat systems is assumed to be established (i.e., a monitored natural attenuation monitoring program), in which all existing private wells in the area are sampled every five years.

3.1 Installation and Operation of POET Systems on Wells

This corrective action involves the continued use and maintenance of POET systems that have already been installed on wells with PFOA+PFOS concentrations equal to or greater than 20 ppt (i.e., those wells with POETs already installed). These POET systems use granular activated carbon (GAC) in two serially-aligned closed vessels to remove PFOA from the incoming water via sorption. Two vessels are used to ensure that carbon replacement of the first vessel takes place before detectable concentrations reach the second vessel. The second vessel primarily serves as additional treatment, in the event there is breakthrough of PFOA from the first vessel.

Overall Protectiveness of Human Health and the Environment

POET systems eliminate exposure of PFOA and other PFCs via domestic water supplies and are therefore protective of human health where implemented. They have been installed at all locations in the corrective action area where potable water-supply wells have been tested and found to have PFOA+PFOS above 20 ppt. They also eliminate incidental exposure to water with elevated PFOA+PFOS concentrations because they treat well water before it is distributed through building plumbing.

Compliance with Applicable and Relevant Requirements

POET systems are shown through regular sampling to be capable of reducing PFC concentrations below detection limits and below all applicable standards and limits. They are installed by licensed professionals and use commercial double-vessel granular activated carbon systems.

Many groundwater constituents are removed by POET systems, such as certain metals, solvents, and petroleum products. As such, they can act as a preventative measure for undetected spills or leaks that may contaminate groundwater supplies.

Short-Term Effectiveness

POET systems are highly effective short-term corrective actions. They can be installed quickly (within days of detection) and require no short-term maintenance by the home owner. POET systems do not adversely affect system pressure or use of plumbing systems. They do not introduce any additives to the water at harmful levels. In this situation, POET systems have already been installed and, therefore, represent the best corrective action option for short-term effectiveness.

Long-Term Effectiveness and Permanence

POET systems have been shown to be effective corrective actions over the long term for PFCs. They have been used successfully on domestic wells in Minnesota since 2005 (12 years) for groundwater with concentrations of PFOA+PFOS well over 300 ppt. POET systems require periodic sampling of effluent from the first (upstream) GAC vessel to determine when vessel replenishment is required. The time required for vessel replenishment depends on water usage, vessel size, and the concentration of PFCs and other sorbing constituents in the influent. Over time, a regular maintenance schedule can be developed. Typically, the vessel change-out period is 2-5 years.

POET systems require maintenance, albeit only occasionally. They are a treatment at the point of entry into a structure and do not treat groundwater in the subsurface. They are not effective if bypassed or otherwise uninstalled on a well system.

Reduction of Contaminant Mass, Mobility, and Toxicity

POET systems remove PFOA mass from the groundwater – combined with the water well, they are essentially a small pump-and-treat system. The amount of mass removal of PFOA from the groundwater system is dependent on the pumping rate and overall well usage. Total mass removal from groundwater is small compared to the overall mass in the groundwater system. With POET systems installed, the recycling of PFCs back into the groundwater system via the structure’s septic system is eliminated. POET systems do not affect the subsurface mobility or toxicity of PFOA but substantially reduce mobility in the supply stream to the system in which they are installed, as well as the exposure to humans.

Implementability

POET system implementability is very high. Commercial systems are available from several vendors at varying sizes. Implementation requires a licensed supplier/vendor and licensed plumber but no additional permits. Engineering is typically not required. Again, POET systems are already installed in this situation so they represent the best corrective action option from an implementability standpoint.

Cost

The estimated cost of installing and operating POET systems as the corrective action is listed in Table 1 and includes operations and maintenance (O&M) costs related to the POET systems and the separate long-term MNA monitoring program in which all existing private wells in the area are sampled every five years.

O&M costs for the POET systems include the labor and materials for ongoing maintenance (e.g., GAC vessel and filter replacement) and laboratory costs for PFC analyses to confirm treatment effectiveness. The O&M costs are presented as a range assuming a treatment period of 20-30 years. The range of costs accounts for those wells that are expected to require less than 30 years of treatment as natural groundwater processes reduce PFOA concentration at the well to below the DWHA. Based on the modeling information contained in the CSM, it is believed that the average period of operation and maintenance for POETs will be closer to 20 years and, therefore, the actual costs of a corrective action that relies upon POETs and groundwater MNA will be closer to the lower cost estimate set forth in Table 1.

Community Acceptance

Community acceptance of POET systems is high. Their installation requires minimal disruption to the building owner and they have a very small interior footprint. They are generally viewed as being reliable.

3.2 Installation of Municipal Water Lines

Installation of municipal water lines to well owners involves either (1) the extension and connection of structures to an existing municipal water system in areas not currently served or (2) the connection of structures to existing water lines already installed in the service area.

Overall Protectiveness of Human Health and the Environment

Replacement of well water with municipally supplied water eliminates human health exposure via potable water by changing the source of water from well water to a public water supply. The public water supply is required to regularly monitor water quality at the source and water within the distribution system. Some levels of treatment are applied to the water, depending on the source.

Compliance with Applicable and Relevant Requirements

Public water suppliers are required to provide water that meets or exceeds federal and state standards for a wide variety of constituents, including POA+PFOS.

Short-Term Effectiveness

Planning, engineering, and construction of water-line extensions takes 1-3 years to complete. During this period, well users may be exposed to PFCs in groundwater unless POET systems have been installed. All well owners with concentrations of PFOA+PFOS above 20 ppt have been provided with POET systems.

Long-Term Effectiveness and Permanence

Extension of municipal water lines is considered a permanent corrective action in terms of human exposure. Its long-term effectiveness is deemed to be high. The water supply is typically as reliable or more reliable than private wells.

Reduction of Contaminant Mass, Mobility, and Toxicity

Extension of municipal water lines has no effect on contaminant mass, mobility, or toxicity.

Implementability

Water-line extensions require engineering studies, approval from planning commissions or other municipal/utility boards, detailed cost estimation, bidding, and construction. During construction, there are typically disruptions to traffic, earth work, and modifications to landscaping. There may be a need to modify water connections at structures to accommodate differences in pressure and piping.

Cost

The estimated cost of installing municipal water lines as the corrective action is listed in Table 1 and includes capital costs for design and construction of the municipal water lines, two years of POET system O&M costs during municipal water line construction, a salvage credit for the POET systems upon removal from the residential water supply, and O&M costs for the long-term monitoring program.

The capital cost estimate for municipal water lines in Table 1 is based on preliminary engineering cost estimates provided by the State of Vermont on March 30, 2017; no O&M costs are assumed for the municipal water lines. The salvage value for the POET systems is 15 percent of the capital cost for the systems installed to date, and accounts for both the salvage value and the expense of removal of the systems.

Community Acceptance

Community acceptance of municipal water lines is generally but not uniformly high. Most home owners and businesses view municipal water as more reliable than private wells. Some well owners object to perceived loss of control of their water supply and others object to cost of service charges. Water quality may be perceived as better as or not as good as well water. The use of wells by well owners with elevated PFOA+PFOS that receive municipal water may need to be addressed. The State and residents living in the area of interest have generally indicated that municipal water line extensions are the preferred corrective action within the community, due in part to the incidental benefits they bestow to the community and residents (e.g., fire protection, increased property values).

3.3 Operation of Existing Wells at Full Capacity with POET systems

Wells with POET systems are essentially low-flow pump-and-treat wells that remove mass from the groundwater system. Private wells typically operate at low flows for only small portions of a day. Higher amounts of mass removal can be achieved by operating wells at higher flow rates either continuously or much more frequently than required for domestic water use. For purposes of this evaluation, it is assumed that all wells currently equipped with POET systems would retain those systems.

The groundwater-flow and solute-transport model was used to assess this corrective action’s effectiveness at PFOA removal from groundwater by pumping existing residential wells at maximum rates continuously and treating the pumped water using the installed POET systems. The assumptions for this evaluation include the following:

- A subset of wells with simulated PFOA concentrations exceeding 20 ppt at the end of 2015 are pumped.

- Available well construction information was used to assign each well to either the unconsolidated material (model layer 1) or the bedrock (model layer 2). It was assumed that all pumped wells are completed (open) through the saturated unconsolidated material or the fractured rock (i.e. fully penetrate either layer 1 or 2 of the model) and half of the available drawdown was utilized in calculating the pumping capacity of each well. This assumption is necessary because construction details for the various wells are not precisely known. This assumption errs on the side of the wells being able to produce (pump) at rates higher than what they might actually be capable of. The total pumping rate for the system is 5,940 gallons per minute (gpm) from 79 residential wells.

- Water pumped by an individual well is assumed to be treated to zero concentration PFOA.

- Treated water is returned to the water table at the same rate it is pumped in a model cell next to the model cell containing the pumped well. This simulates the infiltration of treated water through septic systems or injection in cases in which the required infiltration rates would overwhelm the septic system.

Overall Protectiveness of Human Health and the Environment

POET systems eliminate exposure to PFOA and other PFCs via domestic water supplies and are therefore protective of human health where implemented. They have been installed at all locations where potable water-supply wells have been tested to have PFOA+PFOS above 20 ppt. They also eliminate incidental exposure through water because they treat well water before it is distributed through building plumbing.

Compliance with Applicable and Relevant Requirements

POET systems are shown through regular sampling to be capable of reducing PFC concentrations below detection limits and below all applicable standards and limits. They are installed by licensed professionals and use commercial double-vessel granular activated carbon systems.

Many groundwater constituents are removed by POET systems, such as certain metals, solvents, and petroleum products. As such, they can act as a preventative measure for undetected spills or leaks that may contaminate groundwater supplies.

Short-Term Effectiveness

POET systems are highly effective short-term corrective actions. They can be installed quickly (within days of detection) and require no short-term maintenance by the home owner. POET systems do not adversely affect system pressure or use of plumbing systems. They do not introduce any additives to the water at harmful levels. In this situation, POET systems have already been installed and, therefore, represent the best corrective action option for short-term effectiveness.

Long-Term Effectiveness and Permanence

POET systems have been shown to be effective corrective actions over the long term for PFOA and PFOS. POET systems require periodic sampling of effluent from the first (upstream) GAC vessel to determine when vessel replenishment is required. The time required for vessel replenishment depends on water usage, vessel size, and the concentration of PFCs and other sorbing constituents in the influent. With continuous operations, vessel replenishment, sampling, and operation would be much more frequent than with typical residential well usage.

Reduction of Contaminant Mass, Mobility, and Toxicity

POET systems remove PFOA mass from the groundwater – combined with the water well, they are essentially a small pump-and-treat system. The amount of mass removal of PFOA from the groundwater system depends in part on the pumping rate and overall well usage. With POET systems installed, the recycling of PFCs back into the groundwater system via the structure's septic system is eliminated. POET systems do not affect the subsurface mobility or toxicity of PFOA but substantially reduce mobility in the supply stream to the system they are installed, as well as the exposure to humans.

Implementability

POET system implementability is very high. Commercial systems are available from several vendors at varying sizes. Implementation requires a licensed supplier/vendor and licensed plumber but no additional permits. Engineering is typically not required. Again, POET systems are already installed in this situation so they represent the best corrective action option from an implementability standpoint.

However, continuous operation of residential wells would likely cause much higher levels of well maintenance than typical usage, including replacement of pumps on an estimated two-year basis. There would also be a one-time cost to install plumbing to accommodate continuous operation. Moreover, the ability of septic systems to accommodate and infiltrate the increased flows would likely limit how much wells could pump. There would also likely be long-term damage to septic systems and drain fields, due to flushing of natural bacteria from the septic system. This could lead to reduced destruction of pathogens and poor leach field operations.

Finally, it is unclear that there is an authority that could require individual well owners to operate their well systems at any specified rate. Accordingly, the ability to implement this corrective action is low.

Cost

The estimated cost of operating existing, POET-equipped residential water wells at full capacity as the corrective action is listed in Table 1. The total cost includes capital costs for equipping the residential wells as extraction wells capable of onsite treatment (including pumps, pipes, and POET systems sized for a flow rate of 75 gpm) and O&M costs for the pump-and-treat system, the POET systems that will remain in operation (i.e., those not on retrofitted existing wells), and the associated long-term monitoring program. The estimated capital costs are relatively small compared to the cost of O&M for the treatment systems, the extraction wells, and the long-term monitoring program. It is assumed that water wells with PFOA concentrations exceeding 20 ppt in 2015 that would not be reconstructed as extraction wells would retain the POET systems. The POET system O&M costs include the labor and materials for ongoing maintenance to the standard and high-capacity POET systems (e.g., GAC vessel and filter replacement) and laboratory costs for PFC analyses to confirm treatment effectiveness. O&M costs for the existing wells operating as extraction wells include the power consumption, labor of operations personnel (one hour per well per month), and assume and that pumps will be replaced and wells will be redeveloped every five years. The long-term monitoring program assumes all existing private wells in the area are sampled every five years; the associated cost estimate for the program includes the labor cost for sample collection and laboratory analytical fees.

Community Acceptance

Community acceptance of POET systems is high. Their installation requires minimal disruption to the building owner and they have a very small interior footprint. They are generally viewed as being reliable.

Community acceptance of wells operating continuously and flowing into septic systems would likely be very low, particularly if and when septic systems begin to overflow.

3.4 Dedicated Pump-and-Treat Well System with Reinjection

Pump-and-treat systems are well-established corrective measures that are applied to a wide variety of settings. They generally do a good job of containment/control of affected groundwater but are less efficient at mass removal. As described in the CSM Report (*Barr, 2017. Conceptual Modeling of PFOA Fate and Transport: North Bennington, Vermont, February 2017*), the groundwater model was used to evaluate the effectiveness of a pump-and-treat system to remove PFOA from groundwater in the area of interest. In the modeled scenarios, groundwater is captured at dedicated pumping wells and assumed to be treated to zero concentration PFOA by being piped to a central location where a treatment system can be used to remove PFOA, and then injected in upgradient areas near the edge of simulated PFOA concentrations. Other assumptions for this evaluation include the following:

- Fifty pump-and-treat wells, completed in the bedrock, are simulated along discharge zones for the aquifer system (Walloomsac River and adjacent tributaries) in areas of relatively high simulated PFOA concentration at the end of 2015. The locations of these wells are shown on Figure 2.
- Two-thirds of the available drawdown was assumed in calculating the pumping capacity of each well. This results in a combined pumping rate of 4,960 gpm from the fifty pumping wells.
- Water pumped by an individual well was assumed to be treated to zero concentration PFOA at a treatment facility located at the site of the Water Street Chemfab facility.
- Treated water is re-injected in both the unconsolidated aquifer and the bedrock aquifer in areas upgradient of the discharge zones near the limits of the simulated plume exceeding 20 ppt PFOA. Locations of the injection wells are shown on Figure 2.

A total of 6.8 miles of buried raw-and-treated-water main, sized to accommodate the pumping from the wells, would be required to plumb the pump-and-treat system described above. Each well is fitted with pump, discharge line, pitless unit, controls, and power.

The purpose of re-injection is to increase flushing rates through the aquifer by increasing hydraulic gradients. Reinjection can be an effective enhancement to pump-and-treat systems at some sites. Pumped water could be treated at the well head but it is extremely unlikely that pumped water that is treated could be infiltrated into the ground near each well head without dedicating sizable acreage to infiltration ponds. For this reason, a centralized treatment plant and reinjection at upgradient wells were assumed.

There are many possible well configurations that could be examined, including adding more wells (and more total pumping). Additional wells would result in more mass removal over time. However, the total amount of pumping would need to be balanced with well interference effects on existing residential wells. Detailed engineering analyses would be required to locate wells and pumping rates.

Overall Protectiveness of Human Health and the Environment

This corrective action would have little or no protection on human health through the operation of the pump-and-treat system alone. No pumping system can be devised that would intercept PFOA-containing groundwater from the majority of private wells in the area. Private well owners would have to continue to rely on POET systems to remove PFOA from their water supply.

Compliance with Applicable and Relevant Requirements

Pumped water would require treatment to at least below 20 ppt before reinjection. A Class III or Class V Underground Injection Control (UIC) permit from EPA would be required.

Short-Term Effectiveness

In the short term, the system would have little effect on PFOA concentrations in the water supply and in groundwater.

Long-Term Effectiveness and Permanence

Over several years, pumping and mass removal would begin to reduce PFOA concentrations in the groundwater, compared to a no-action situation. However, the mass reduction and concentration reduction would be small compared to the natural flushing of groundwater through the system. Long term, dual-porosity effects and matrix dispersion would likely result in a “tail” effect of long-term, low-level PFOA concentrations.

Reduction of Contaminant Mass, Mobility, and Toxicity

Pumping wells and treatment of the pumped water will remove PFOA and other PFCs from the groundwater system. However the overall mass reduction, compared to no-action is minimal over time. Mobility and toxicity of PFOA would not be affected.

Implementability

Pump-and-treat systems are accepted corrective action for many settings. Well installation would require access and easements to well sites. Well locations would need to be selected with consideration for well spacing, effectiveness, and ability to be connected to a raw water distribution line. Power would be required for each well site.

Raw water lines would be needed to connect the various well sites to a central treatment facility. Engineering and permitting would be required. Construction would take 1-3 years and there would be disruption to existing infrastructure.

A central treatment plant, using GAC vessels, would need to be designed and constructed. For this evaluation, the former Chemfab facility at Water Street was assumed for this use. The treatment system would require controls, holding tanks, and pumps and infrastructure to discharge to the injection wells. Periodic change-out of carbon in the vessels would be part of regular operation and maintenance.

Extraction wells would likely require continuous maintenance, involving well re-development and pump replacement on 5-year intervals.

Injection systems are very problematic to operate. Biofouling of injection wells is a common problem, requiring frequent maintenance, down-time, and well redevelopment. Balancing injection rates with aquifer conditions can be a challenging engineering problem. Considerable monitoring would be necessary to satisfy EPA UIC permitting requirements. For all of these reasons, the ability to implement this corrective action is low.

Cost

The estimated cost for the corrective action involving a dedicated pump-and-treat and injection well system is listed in Table 1 and includes capital costs for construction of a central treatment plant, injection/extraction wells, and raw water lines between the wells and the treatment plant and O&M costs for these systems over an assumed 30-year treatment period and the long-term monitoring program.

The estimated capital costs assume that no POET systems would be operating on residential water wells, and that a salvage credit for these systems would apply. Estimated capital costs for piping are based on unit costs developed for the preliminary engineering design work for municipal water line construction in the corrective action area.

The estimated O&M costs assume that no POET systems would be operating, and that treatment O&M costs would be incurred at the central treatment plant alone. O&M costs are also estimated for the piping and extraction/injection wells required to route the raw and treated water, including power consumption and pump replacement for extraction wells and booster stations on the header piping, labor for operations personnel, and periodic redevelopment/reconditioning for both extraction and injection wells.

Community Acceptance

The community would likely perceive substantial disruption during construction without any meaningful benefit to residential water quality. Community acceptance would likely be low.

3.5 Operation of Existing Wells and Dedicated Pump-and-Treat Well System with Reinjection

This corrective action is similar to the Distributed Well Pump-and-Treat with Reinjection option but includes pumping and treating discharge of existing residential wells operating at full capacity. The purpose of re-injection is to increase flushing rates through the aquifer by increasing hydraulic gradients. Reinjection can be an effective enhancement to pump-and-treat systems at some sites. This corrective action assumes 50 pumping wells, with a combined pumping rate of 4,960 gpm and 100 injection wells, with a combined injection rate of 4,960 gpm. Locations of these wells are shown on Figure 23. Treatment is assumed to be at a central location. For cost estimating purposes, the former Chemfab facility at Water Street is used. POET systems are assumed to be in use at residential wells with PFOA exceeding 20 ppt.

Overall Protectiveness of Human Health and the Environment

POET systems eliminate exposure to PFOA and other PFCs via domestic water supplies and are therefore protective of human health where implemented. They have been installed at all locations where potable water-supply wells have been tested to have PFOA+PFOS above 20 ppt. They also eliminate incidental exposure through water because they treat well water before it is distributed through building plumbing.

Compliance with Applicable and Relevant Requirements

Pumped water would require treatment to at least below 20 ppt before reinjection. A Class III or Class V Underground Injection Control (UIC) permit from EPA would be required.

Short-Term Effectiveness

In the short term, the system would have little effect on PFOA concentrations in groundwater but would have high effectiveness at removing PFOA from the water supply, due to the use of POET systems. POET systems are highly effective short-term actions. They can be installed quickly (within days of detection) and require no short-term maintenance by the home owner. POET systems do not adversely affect system pressure or use of plumbing systems. They do not introduce any additives to the water at harmful levels. In this situation, POET systems have already been installed and, therefore, represent the best corrective action option for short-term effectiveness.

Long-Term Effectiveness and Permanence

Over several years, pumping and mass removal would begin to reduce PFOA concentration in the groundwater, compared to a no-action situation. However, the mass reduction and concentration reduction would be small compared to the natural flushing of groundwater through the system. Injection of treated water would marginally increase the flushing rates. Long term, dual-porosity effects and matrix dispersion would likely result in a "tail" effect of long-term, low-level PFOA concentrations.

POET systems have been shown to be effective corrective actions over the long term for PFOA and PFOS. POET systems require periodic sampling of effluent from the first (upstream) GAC vessel to determine when vessel replenishment is required. The time required for vessel replenishment depends on water usage, vessel size, and the concentration of PFCs and other sorbing constituents in the influent. With continuous operations, vessel replenishment, sampling, and operation would be much more frequent than with typical residential well usage.

Reduction of Contaminant Mass, Mobility, and Toxicity

Pumping wells and treatment of the pumped water will remove PFOA and other PFCs from the groundwater system. However the overall mass reduction, compared to no-action is minimal over time. Mobility and toxicity of PFOA would not be affected.

Reinjection of water (particularly oxygenated water) can have the unintended consequence of mobilizing naturally occurring constituents in the groundwater system, such as arsenic and selenium.

Implementability

POET system implementability is very high. Commercial systems are available from several vendors at varying sizes. Implementation requires a licensed supplier/vendor and licensed plumber but no additional permits. Engineering is typically not required. Again, POET systems are already installed in this situation so they represent the best corrective action option from an implementability standpoint.

However, continuous operation of residential wells would likely cause much higher levels of well maintenance than typical usage, including replacement of pumps on an estimated two-year basis. There would also be a one-time cost to install plumbing to accommodate continuous operation. It is likely that well pumping rates will not be the limiting condition – the ability of septic systems to accommodate and infiltrate the increased flows would likely limit how much wells could pump. There would also likely be long-term damage to septic systems and drain fields, due to flushing of natural bacteria from the septic system. This could lead to reduced destruction of pathogens and poor leach field operations.

It is unclear that there is an authority that could require individual well owners to operate their well systems at any specified rate.

Pump-and-treat systems are accepted corrective action for many settings. Well installation would require access and easements to well sites. Well locations would need to be selected with consideration for well spacing, effectiveness, and ability to be connected to a raw water distribution line. Power would be required for each well site.

Raw water lines would be needed to connect the various well sites to a central treatment facility. Additional piping would be required to convey the treated water to the various injection well sites. Engineering and permitting would be required. Construction would take 1-3 years and there would be disruption to existing infrastructure.

A central treatment plant, using GAC vessels, would need to be designed and constructed. For this evaluation, the former Chemfab facility at Water Street was assumed for this use. The treatment system would require controls, holding tanks, and pumps and infrastructure to discharge to the injection wells. Periodic change-out of carbon in the vessels would be part of regular operation and maintenance.

Extraction wells would likely require continuous maintenance, involving well re-development and pump replacement on 5-year intervals.

Injection systems are very problematic to operate. Biofouling of injection wells is a common problem, requiring frequent maintenance, down-time, and well redevelopment. Balancing injection rates with aquifer conditions can be a challenging engineering problem. Considerable monitoring would be necessary to satisfy EPA UIC permitting requirements.

Accordingly, while the ability to implement the POET component of this corrective action is high, the ability to implement the rest of this corrective action is low.

Cost

The estimated cost for the corrective action in which existing wells are operated as pump-and-treat wells while also operating a dedicated pump-and-treat and injection system is listed in Table 1. The cost estimate includes capital and O&M costs with the assumptions for the individual corrective actions combined in this option (existing residential wells and dedicated pump-and-treat wells) listed above.

Community Acceptance

The community would likely perceive substantial disruption during construction without any meaningful benefit to residential water quality. Community acceptance would likely be low.

3.6 Well Replacement

This corrective action involves replacement of the 270 water wells with PFOA concentrations exceeding 20 ppt and currently equipped with POET systems, with wells that are drilled and cased deep in the bedrock. It is assumed that replacing a well with a deeper version will result in PFOA concentrations below 20 ppt.

Overall Protectiveness of Human Health and the Environment

This corrective action would have high protection of human health, as the POET system would be maintained on the existing well until it was demonstrated that the replacement well could reliably provide a water supply with PFOA below 20 ppt.

Compliance with Applicable and Relevant Requirements

Demonstration that PFOA in the pumped water is below 20 ppt would be required before ceasing use of the POET system. The replacement water well would be constructed and tested in accordance with applicable state guidance and requirements for new well construction.

Short-Term Effectiveness

In the short term, the system would have little effect on PFOA concentrations in groundwater. However, it would have high effectiveness at removing PFOA from the water supply.

Long-Term Effectiveness and Permanence

Replacement wells would be effective over the long term at reducing PFOA concentrations in the water supply, but not in the groundwater system. Monitoring of the well would be performed to ensure the long-term effectiveness of well replacement as a means to remove PFOA from the water supply.

Reduction of Contaminant Mass, Mobility, and Toxicity

Replacing affected wells would not change contaminant mass, mobility, or toxicity, other than to no longer capture mass that was previously extracted with the water well discharge. In other words, replacing affected wells would leave more PFOA mass in the groundwater than if POET systems continued to be used.

Implementability

The high number of wells to replace would require a significant well construction effort, which could extend over a period of months or years depending on the availability of licensed well drillers. The ability to implement this corrective action also depends upon whether groundwater in deeper bedrock is an appropriate and viable source of water at each location where PFOA has been detected in existing wells at concentrations above 20 ppt. There may be certain locations in which new wells will not result in PFOA concentrations below 20 ppt or may not be viable due to engineering considerations. Accordingly, well replacement may be implemented relatively easily in some locations and not others, and, therefore, may be a suitable alternative to POET systems at select locations.

Cost

The estimated cost to replace the 270 water wells currently equipped with POET systems is listed in Table 1 and includes capital costs for well construction, a salvage credit for the POET systems, and O&M costs for two years of POET operations. The O&M costs for the long-term monitoring program are also assumed to apply for this corrective action.

Community Acceptance

The disruption from ongoing, widespread drilling would likely be viewed as a nuisance in the community. As a result, community acceptance would likely be low if this corrective action were utilized on a large area-scale basis. However, acceptance to the replacement of individual wells on a location-by-location basis would likely be higher.

3.7 Surficial Soil Excavation

This corrective action focuses on excavating the upper soil layers from the areas of highest predicted air deposition (i.e. those areas where air modeling indicates an average infiltration concentration of 20 ppt or higher). However, in the intervening years since air emissions ceased, most of the deposited PFOA has likely migrated deeper into the soil column (several feet or more) and likely has already reached the water table. For evaluation purposes, the following are assumed:

- Excavation depth is 1 foot below ground surface. This depth of excavation targets the upper horizons (O and A) of the soil column.
- Excavation would not take place in wooded areas. The potential for permanent damage to mature trees would likely be unacceptable and excavation between trees would be impractical. Excavation is assumed in areas with isolated trees.

- Excavation underneath buildings or paved areas would not take place. Soils under these areas would not have been subject to deposition if they were in place at the time of deposition.
- Excavation would not take place where bedrock crops out or on slopes greater than 1.5:1 for reasons of safety and accessibility.
- Soil would be removed and transported to an approved low-temperature incinerator in the region.

Overall Protectiveness of Human Health and the Environment

This corrective action would not be protective of human health. Soil concentrations of PFCs have been found to be well below the Vermont Department of Health soil screening value (SSV) (Section 4.1). Exposure to these compounds from growing and consuming of produce has been found to be low. Moreover, removal of upper soil zones is not expected to result in measureable decreases in groundwater concentrations since the majority of PFOA that may been deposited onto surficial soils as a result of historic airborne emissions from the former Chemfab facilities has likely already migrated to deeper soils or the groundwater table.

Compliance with Applicable and Relevant Requirements

Area-wide soil concentrations are currently below the applicable SSV limits and are not expected to increase due to the cessation of emissions at the former Chemfab facilities.

Short-Term Effectiveness

In the short term, soil excavation would have little effect on PFOA concentrations in groundwater.

Long-Term Effectiveness and Permanence

Soil excavation is expected to produce only a nominal reduction in PFOA concentrations in groundwater, compared to monitored natural attenuation. Most of the deposited PFOA has already migrated below accessible depths for excavation on an area-wide basis. Moreover, limitations on accessibility in wooded areas would further minimize long-term effectiveness.

Reduction of Contaminant Mass, Mobility, and Toxicity

Soil excavation would remove the mass in the shallow soil. However, this mass is a small percentage of the total mass in the unsaturated zone and groundwater system and thus represents only a nominal reduction in overall mass and mobility.

Implementability

Performing an area-wide excavation would be very difficult, requiring staging, stockpiling, and shipping of soils. Truck traffic would likely increase substantially. Issues such as dust control, erosion, and revegetation would be challenging. Access to private property is not guaranteed and would likely need to be negotiated on a case-by-case basis. Accordingly, the ability to implement area-wide soil excavation would be very low.

Cost

The estimated cost to remove the upper soil layers across the corrective action area is listed in Table 1 and include the capital costs associated with soil excavation, transportation, and disposal and the O&M costs of the long-term monitoring program. Assumptions used to develop the cost estimate (e.g., depth of excavation) are summarized above and also include an assumed excavation and disposal cost of $175 per cubic yard and an analysis of land use and slope data within the corrective action area shown on Figure 1. The total cost is dominated by capital costs for soil excavation, which are significant when assuming excavation would occur over the corrective action area.

Community Acceptance

The disruption from extensive soil excavation would be very high. A strong case would need to be made that such disruption would be sufficiently beneficial to the community to proceed. Therefore, it is likely that community acceptance would be low.

3.8 Monitored Natural Attenuation

Monitored natural attenuation (MNA) involves collecting data to confirm that the natural processes acting on the constituents are indeed occurring and that concentrations are decreasing over time. For many constituents in groundwater, MNA involves not only the tracking of concentrations of the constituent of concern but also indicator parameters that indirectly indicate that biological and chemical process and conditions that act on the constituent of concern are also proceeding. In the case of PFOA, there are no indicator parameters to monitor. Reductions in PFOA concentration over time are due almost entirely to physical flushing of water through the groundwater system.

For the MNA corrective action, it is assumed that no additional corrective actions (e.g., POET systems, pump-and-treat) would be performed. The groundwater system would continue to be monitored and re-evaluated with the expectation that, over time, natural processes would flush PFOA from the groundwater system. As this process progresses, PFOA concentrations in wells would be reduced below 20 ppt and these wells could be used without treatment.

Overall Protectiveness of Human Health and the Environment

MNA alone would have little or no protection on human health, but could be combined with other corrective actions such as POET systems or water line extensions to provide a remedy that is protective of human health and the environment.

Compliance with Applicable and Relevant Requirements

A long-term monitoring plan would be established to demonstrate that MNA of PFOA is occurring. The lack of POET systems and/or water-line extensions would not provide compliance with the DWHA of 20 ppt PFOA+PFOS.

Short-Term Effectiveness

The MNA corrective action alone would not be effective in the short-term at meeting the target outcomes.

Long-Term Effectiveness and Permanence

MNA would be effective in the long-term at meeting some of the target outcomes (e.g., mass reduction), but by itself would not meet other target outcomes on either the short- or long-term (e.g., human health protection).

Reduction of Contaminant Mass, Mobility, and Toxicity

MNA would reduce mass through natural flushing processes, which have been shown to be nearly as effective at mass reduction as the pump-and-treat corrective actions described above. There would be no effect on PFOA mobility or toxicity.

Implementability

Implementability of MNA is high, as it a commonly applied corrective action with the sole requirement of developing and implementing a long-term monitoring program.

Cost

The estimated cost for the MNA corrective action is listed in Table 1 and assumes that only the O&M long-term monitoring would be required to complete the corrective action. A POET system salvage credit is also assumed to apply for the corrective action.

Community Acceptance

The lack of effectiveness in protecting human health would result in very low community acceptance for MNA alone. However, MNA is a commonly accepted corrective action when it is combined with other protective measures such as POETs or water line extensions.

3.9 Corrective Action Options Not Evaluated in Detail

Different types of corrective actions have been implemented at various sites and for various constituents. Many corrective actions are not applicable to PFOA or to the nature and extent of PFOA in the environment in the Bennington area. While they may be appropriate for some settings, they fail to meet many of the criteria for corrective action selection in this setting. Some corrective actions that were initially considered but not further evaluated in this analysis are listed below with the reasons that they were deemed to be inapplicable.

Physical Barriers, Cut-Off Walls, and Reactive Barrier Walls

Subsurface barrier and cut-off walls (e.g., sheet-pile walls, slurry walls, grout curtains) are used in certain settings to physically isolate waste and contamination from flowing groundwater and thereby render such materials inaccessible to the environment. In order for subsurface barriers to be effective, they must be keyed into low-permeability strata (e.g., unfractured clay or bedrock) – otherwise, groundwater will flow underneath the barrier. The bedrock in the region is sufficiently permeable and sufficiently thick to make barrier walls technologically infeasible on a regional scale. Accordingly, physical barriers and cut-off walls were determined to be ineffective options for corrective action in this instance and were not further considered.

Reactive barriers are low-permeability barriers with one or more “gates” – openings in the subsurface barrier that are filled with selected permeable media that interacts with dissolved constituents and reduces their mobility or changes their toxicity. Flowing groundwater is “funneled” to these “gates” by the low-permeability subsurface barriers. Granular activated carbon and zero-valent iron have been shown to be media that could act as permeable gates to reduce PFC concentrations. However, as with cut-off walls, funnel-and-gate reactive barrier systems require a low-permeability strata to key into in order to prevent underflow. While they may be suitable for certain small-scale release sites, they are not suitable for regional-scale settings. Furthermore, neither subsurface barriers nor reactive barriers would be effective at reducing concentrations of PFOA in wells in the area because they require installation at the downgradient end of the regional flow system. Accordingly, reactive barriers were also determined to be ineffective options for corrective action in this instance and were not further considered.

In Situ Treatment

In situ treatment technologies involve the introduction of substances into the subsurface that react with the constituent of concern or otherwise change the subsurface environment and render the constituent less mobile or less toxic. In situ treatment is typically used for organic substances that degrade into less-toxic substances when subsurface conditions are changed to promote natural degradation processes. PFOA is highly stable in the environment and does not readily degrade under a wide variety of conditions. There are no known in situ treatment technologies for PFOA that could be applied at a large scale. Accordingly, in situ treatment was determined to be an ineffective option for corrective action in this instance and was not further considered.

Low-Permeability Capping

Placing a low-permeability cap is common in certain landfill settings to prevent infiltrating precipitation from reacting with subsurface constituents and causing mobilization in the groundwater. Installing a low-permeability cap over such a large area as the corrective action area is infeasible and would do significant harm to the regional hydrology. Accordingly, capping was determined to be an ineffective option for corrective action in this instance and was not further considered.

4.0 Comparison of Corrective Action Alternatives

The various corrective action alternatives described in the previous sections were evaluated against the criteria using a subjective ranking system of "low", "medium", and "high" for meeting the goals of each of the criteria. The following describes the meanings of the rankings:

- "Low": A ranking of low is assigned to a particular corrective action alternative criteria if the criteria's goal cannot be met because of physical or technological constraints (implementability), does not meet the minimum requirement of being protective of human health, does not substantially reduce mass or concentration in the groundwater system, does not meet drinking water standards in the short term in groundwater, or does not meet drinking water standards in potable water. If substantial regional disturbance or disruption to individual residences is anticipated in the short term or long term, a ranking of "low" is assigned for community acceptance.
- "Medium": A ranking of medium is assigned to a particular corrective action if the action can potentially be implemented but possesses substantial risk that it would not be effective. Medium is assigned to corrective actions that remove mass by some means, partially comply with relevant standards, or has shown to be effective in other settings (although at much smaller scales) but may not be as effective in this setting. Medium rankings for corrective action have a moderate likelihood of receiving some community acceptance but anticipated issues would likely be encountered.
- "High" A ranking of high is assigned to a particular corrective action if it is protective of human health in the short-term and provides acceptable potable water supplies. It is a proven technology that has been shown to be implementable at the scale of the current setting and with the constituent of concern (PFOA). A high ranking indicates that the corrective action would receive widespread community acceptance with minimal disruption and the action can be implemented quickly.

The results are presented in Table 2.

For cost comparison, the estimated cost for each alternative is presented as a present-worth valuation of estimated capital cost and long-term O&M costs assuming a 30-year project life, unless noted otherwise. A summary of the cost estimates is presented in Table 1. For cost estimating purposes, it is assumed that a groundwater monitoring program would be required for all corrective actions, which would involve one sampling event every 5 years at each active well, with staggered sampling performed yearly. Long-term annual costs also include estimates for routine maintenance, periodic equipment replacement, energy, treatment costs (e.g., GAC replacement), and monitoring of treatment systems. For the corrective actions in which POET systems are not used (e.g., municipal water lines), a salvage value for the POET systems of 15% is assumed, which accounts for both the salvage value and the expense of removal of the systems.

A ranking of the corrective action options is provided in Table 3, along with a rationale for the assigned rank.

5.0 Recommendations for Corrective Action

The following options were determined to not meet the objectives of corrective action:

- **POETs with Existing Wells Operating at Full Capacity.** This action was found to remove mass from the groundwater system at only a marginally higher rate than through natural attenuation alone. There are significant implementability issues with this alternative – primarily the inability to infiltrate the pumped water by septic systems, or by other means. Domestic wells, pumps, and appurtenances were not designed to operate continuously at maximum rates. O&M costs are high and uncertain. Community acceptance would be low.

- **Dedicated Pump-and-Treat Wells with Reinjection.** Pumping groundwater with PFOA would not result in any materially greater reduction in the mass of PFOA in groundwater than natural attenuation alone. However, capital costs would be extremely high, due in large part for the need for a buried raw-and-treated water-line system that would be more expensive than municipal water-line extensions. Moreover, operating a pump-and-treat system would not be protective of human health and would require either POETs or water-line extensions. Pumping wells could also interfere with residential wells and reduce well yield.

- **Monitored Natural Attenuation.** Monitored natural attenuation, without POETs or water-line extensions, would not meet the minimum requirement of providing well users with water that meets Vermont's health standard of 20 ppt for PFOA+PFOS and would therefore be unacceptable. Monitored natural attenuation would be nearly as effective at long-term removal of mass and concentration reduction as other, more aggressive corrective actions. Therefore, it has utility if used with other methods that are protective of human health.

- **Surficial Soil Excavation.** Excavation and removal of surficial soils would not be protective of human health because soil removal would not address the presence of PFOA in well water in the short or medium term. In the long term, there is a possibility that would be an aid in expediting natural attenuation processes; however, it is likely that most of the aerially deposited PFOA has already migrated below accessible depths in the soil column and has likely already reached the water table. Extensive soil excavation would not be able to address forested areas or areas with steep slopes and would be extremely disruptive to the community for a long period of time.

- **Well Replacement.** In certain area, replacing existing wells with new, deeper wells that are constructed with adequate sealing methods may be a viable, long-term corrective action. Well replacement will likely only be effective where a small number of wells with concentrations of PFOA above 20 ppt are situated within a larger area where most wells have concentrations below 20 ppt. In such areas, existing well construction may be partially responsible for the PFOA detections. However, for most of the area, well construction would likely not be an effective remedy.

The recommended corrective action for Area 1 is a combination of (1) continued operation and maintenance of existing POET systems; (2) installation of municipal waterlines and/or the drilling of replacement wells in certain areas where long-term operation and maintenance of POETs may be inefficient due to the length of time POETs may be required or due to problems with the existing well construction; and (3) long-term monitoring of groundwater. The reasons for a combination of corrective actions are:

- POET systems are proven to be an effective means for removing PFOA from drinking water supply wells and have already been installed on all wells in which PFOA has been detected above 20 ppt. Accordingly, POET systems present an easily implementable corrective action that is fully protective of human health and the environment in the short term and the long term, and that is cost-effective. Moreover, POET systems remove some mass from the groundwater system and treat the water to prevent recycling through septic systems. The systems allow well owners to continue to operate in the accustomed manner and therefore likely have high community acceptance.

- While POET systems present an effective means for removing PFOA from drinking water supply wells, they do not result in a substantial reduction in PFOA mass in groundwater itself. Accordingly, continued monitoring of PFCs in groundwater would have to take place to confirm that PFOA concentrations in groundwater are attenuating. The proposed monitoring program would have all wells sampled and analyzed once every 5 years, with the location of wells staggered over the area so that each year, the spatial variability can be assessed in terms of temporal trends.

- There may be instances in which water-line extensions would be preferable to POETs due to the length of time that POETs may be required to be operated and maintained. In such instances, water-line extensions may be more cost-effective and likely would have a greater community acceptance. However, water-line extensions are not any more protective of human health or the environment than POET systems and would result in less mass removal of PFOA from the groundwater system than POET systems. Water-line extensions would also not be as effective in the short-term or implemented as easily as POET systems, which have already been installed. Accordingly, limited use of water-line extensions in areas where POET systems are anticipated to be required for a lengthy period of time may be appropriate.

- In addition to the above corrective action elements, a program for replacing selected wells with new wells is under consideration. A pilot program has been proposed to replace some wells in isolated areas with new, deeper wells. Attention will be paid to well construction to ensure that the unconsolidated aquifer is hydraulically sealed from the open-hole interval in the bedrock. POET systems will continue to be used on the water supply until it can be verified with reasonable certainty that the new wells deliver groundwater that meets Vermont drinking water requirements. If successful, well replacement may be employed instead of long-term POET system use in some wells.

Tables

Table 1
Summary of Estimated Cost (in $ millions) for Corrective Actions
North Bennington, Vermont
Saint-Gobain

	POET		Municipal Water Lines		Existing Wells as Pump/Treat		Dedicated Pump/Treat		Existing Wells & Dedicated Pump/Treat		Well Replacement		Monitored Natural Attenuation		Surficial Soil Excavation	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
Municipal Water Lines	--	--	$19.18 (3)	$0.00	--	--	--	--	--	--	--	--	--	--	--	--
POET Systems	--	$10.6-17.0 (1)	($0.14)	$0.92	$1.30	$21.05	($0.14)	--	$1.30	$21.05	($0.14)	$0.92	($0.14)	--	($0.14)	--
Central Treatment Plant	--	--	--	--	--	--	$15.00	$17.80	$15.00	$17.80	--	--	--	--	--	--
Piping	--	--	--	--	--	--	$42.70	$11.10	$42.70	$11.10	--	--	--	--	--	--
Extraction Well	--	--	--	--	--	--	$12.20	$23.60	$12.20	$23.60	--	--	--	--	--	--
Injection well	--	--	--	--	--	--	$10.00	$9.00	$10.00	$9.00	--	--	--	--	--	--
Residential Well Replacement	--	--	--	--	--	--	--	--	--	--	$45.40	--	--	--	--	--
Residential Well Retrofit to Extract	--	--	--	--	$5.30	$37.30	--	--	$5.30	$37.30	--	--	--	--	--	--
Soil Excavation	--	--	--	--	--	--	--	--	--	--	--	--	--	--	$750.00	--
Long-term Monitoring (2)	--	$2.70	--	$2.70	--	$2.70	--	$2.70	--	$2.70	--	$2.70	--	$2.70	--	$2.70
Total (millions)	$0.00	$13.3-19.7	$19.04	$3.62	$6.60	$61.05	$79.77	$64.20	$86.50	$122.55	$45.27	$3.62	$(0.14)	$2.70	$749.86	$2.70
Combined Total	**$13.3-19.7**		**$22.66**		**$67.65**		**$143.97**		**$209.05**		**$48.89**		**$2.56**		**$752.56**	

(1) O&M cost range is 20-30 year treatment period for all POET systems installed to-date
(2) All corrective actions have similar long-term monitoring of wells, uses currently available information
(3) Preliminary water line cost estimates submitted by VTDEC on March 30, 2017: $6.05M for Village of North Bennington and $13.13M for Town of Bennington

Table 2
Summary of Corrective Action Criteria Scoring
North Bennington, Vermont
Saint-Gobain

Corrective Action *	Corrective Action Evaluation Criteria							
	Overall Protectiveness of Human Health and the Environment	Compliance with Applicable and Relevant Requirements	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Contaminant Mass, Mobility, and Toxicity	Implement-ability	Present-Worth Cost (millions)	Community Acceptance
Installation and Operation of POET Systems on Wells	High	High	High	High	Medium	High	$13.3-19.7	Medium-High
Installation of Municipal Water Lines **	High	High	Medium	High	Medium	Medium	$22.66	Medium-High
Operation of Existing Wells at Full Capacity with POET systems	High	High	High	High	Medium	Low	$67.65	Low
Dedicated Pump-and-Treat Well System with Reinjection **	Low	Medium	Low	Low	Medium	Low	$143.97	Low
Operation of Existing Wells and Dedicated Pump-and-Treat Well System with Reinjection	High	High	High	High	Medium	Low	$209.05	Medium
Well Replacement	Medium	High	High	High	Medium	Low	$48.89	Medium-High
Surficial Soil Excavation	Low	Medium	Low	Low	Medium	Low	$752.56	Low
Monitored Natural Attenuation Only **	Medium-Low	Low	Medium	High	Medium	High	$2.56	Low

* All corrective action alternatives assume natural attenuation processes will continue to remove PFOA mass from the aquifer and reduce PFOA concentrations at wells potentially affected by air deposition.

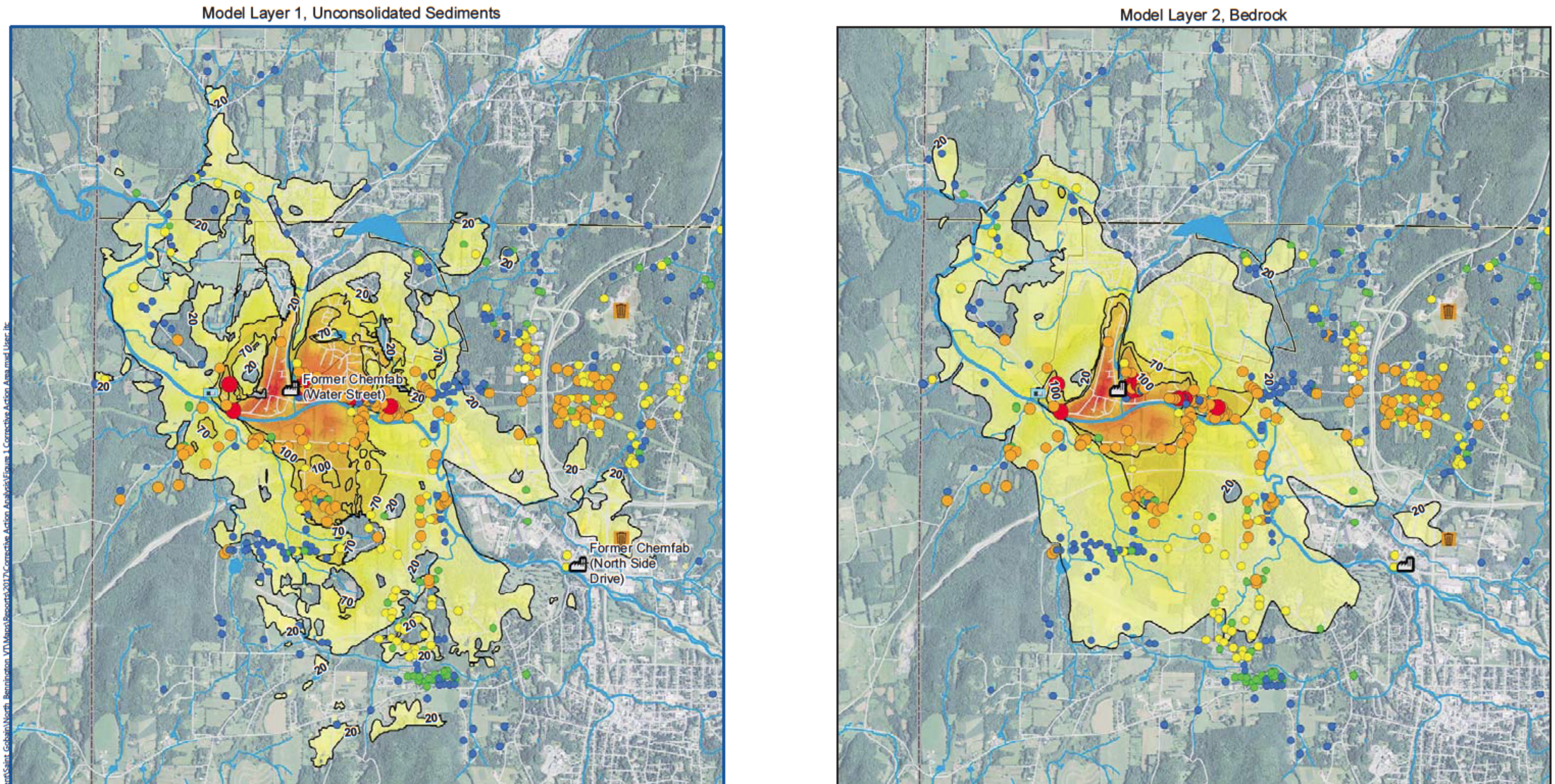
** No POET systems or other single-well treatment

Table 3
Corrective Action Rankings
North Bennington, Vermont
Saint-Gobain

Corrective Action*	Ranking	Rationale for Ranking
Installation and Operation of POET Systems on Wells	1	This corrective action is currently implemented and has been shown to effectively protect human health and the environment over the short- and long-term at the lowest cost of all of the alternatives evaluated. This corrective action requires periodic monitoring and operation/maintenance.
Installation of Municipal Water Lines	2	This corrective action has high long-term effectiveness at protecting human health and high community acceptance. It is ranked lower than POET systems due to the higher cost for the same ability to meet target outcomes as well as delays in implementation and lower short-term implementability. It is also difficult to modify or to decommission portions at a later date.
Well Replacement	3	This corrective action is protective of human health where existing well construction is deficient and modern well construction methods with deeper wells will result in acceptable water quality. Because there is the potential for PFOA to enter the new well at a future date, this corrective action is ranked lower than POET and municipal water line actions. This corrective action may not be applicable for all areas and would have high capital cost if many wells were replaced.
Operation of Existing Wells at Full Capacity with POET systems	4 (tie)	This corrective action is currently implemented at low pumping rates and has been shown to effectively protect human health and the environment over the short- and long-term. It is ranked lower than current operation of POETs and water-line extensions because the higher flow rates will require substantially higher maintenance. It is ranked lower than well replacement because of the operational challenges of operating wells continuously and discharging water to septic systems. It likely would be difficult to implement because existing wells are not designed for continuous pumping and septic systems would not be capable of accepting high waste-water volumes.
Monitored Natural Attenuation Only	4 (tie)	This corrective action is readily implementable and has the lowest cost. It is ranked lower than POETs, water-line extensions, and well replacement because, alone, it does not protect human health in the short term. As a stand-alone corrective action it has low human health protection capabilities and would need to be implemented with other corrective actions.
Operation of Existing Wells and Dedicated Pump-and-Treat Well System with Reinjection	6	This corrective action is currently partially implemented through the existing Poet network which is protective of human health. It has very high capital cost and long-term costs and is therefore ranked below POETs, water-line extensions, and well replacement. For the modest improvement in mass removal over monitored natural attenuation, it has substantially higher operation and maintenance and will likely not be accepted by the public. Construction also results in considerable regional disruption and very high costs – therefore it is ranked below MNA. This corrective action would not meaningfully expedite the removal of PFOA from the groundwater system.
Dedicated Pump-and-Treat Well System with Reinjection	7	This corrective action would be very difficult to implement, would not be protective of human health, and has very highest capital cost and long-term costs. Therefore, it is ranked below all other corrective action alternatives, except surficial soil excavation. This corrective action would not meaningfully expedite the removal of PFOA from the groundwater system and would be very disruptive due to construction of multiple raw-water and treated-water lines.
Surficial Soil Excavation	8	This corrective action would remove some PFOA from the upper unsaturated zone but it would be exceedingly difficult to implement. It has low overall effectiveness, very high capital cost, high disruption of community, low mass removal from the groundwater system, and the potential for permanent destruction of natural resources. Alone, it does not protect human health in the short term. Therefore, it was ranked lower than other corrective action alternatives.

* All corrective action alternatives assume natural attenuation processes will continue to remove PFOA mass from the aquifer and reduce PFOA concentrations at individual wells

Figures



Simulated 2016 Groundwater Concentration

20 70 100 1000

PFOA (ppt)

Former Chemfab Facility

Landfill

Wastewater Treatment Plant

Awaiting Results

VTDEC PFOA Sampling Results 8/2/2016

- Non-Detect (ND)
- < 20 ppt
- 20 - 100 ppt
- 100 - 1000 ppt
- > 1000 ppt

County Boundary

Village Boundary

Township Boundary

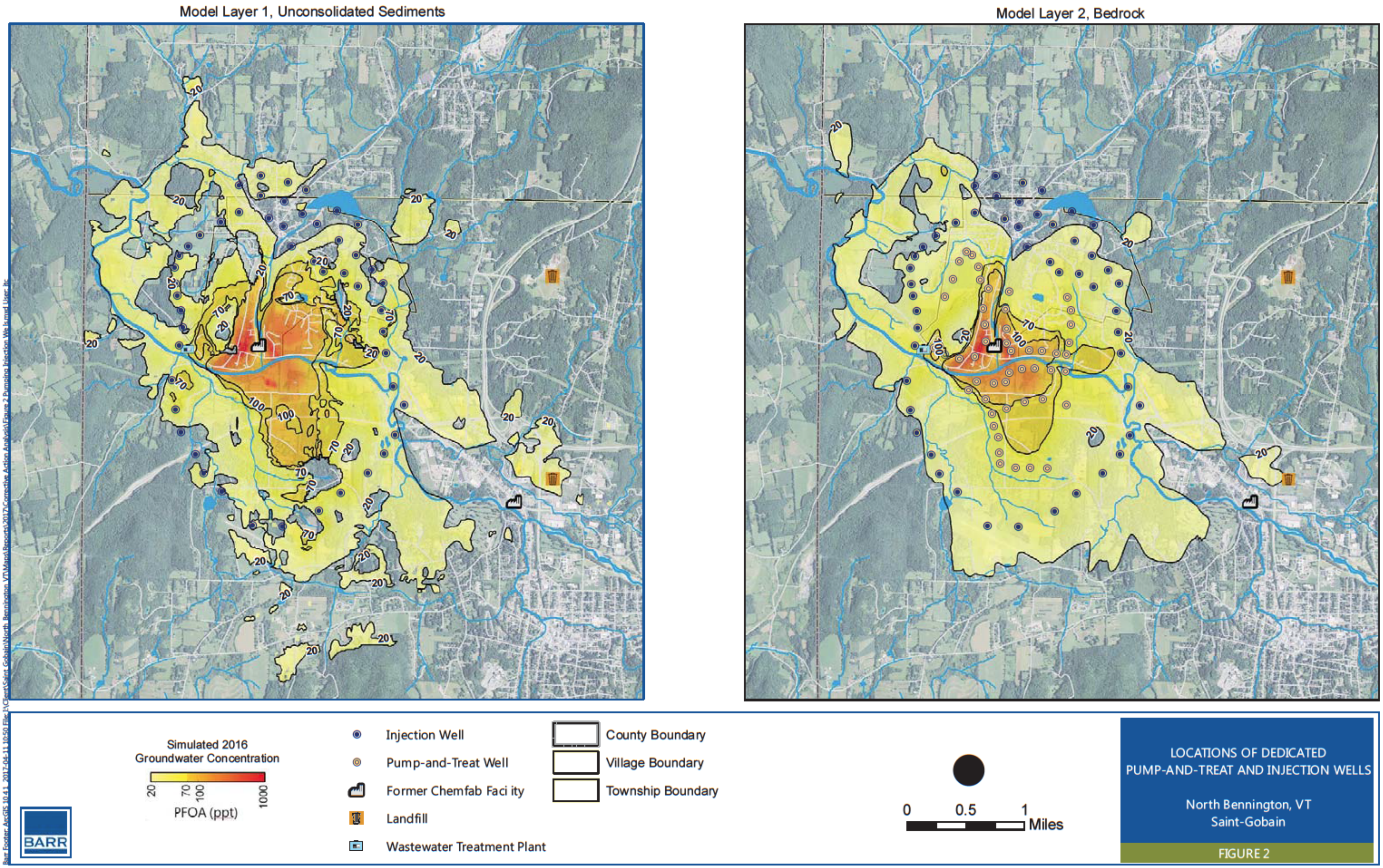
0 0.5 1 Miles

CORRECTIVE ACTION AREA

North Bennington, VT
Saint-Gobain

FIGURE 1

BARR



LOCATIONS OF DEDICATED PUMP-AND-TREAT AND INJECTION WELLS

North Bennington, VT
Saint-Gobain

FIGURE 2