Appendix C1

Evaluation of Corrective Action Alternatives: Corrective Action Area II, Bennington, Vermont

Prepared for
Saint-Gobain Performance Plastics

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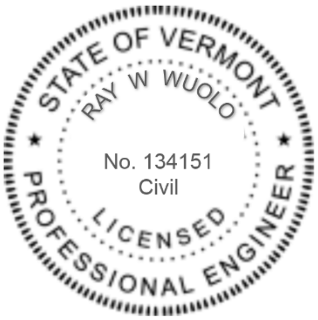

Abbreviations, Acronyms, and Units

ASTM	American Society for Testing and Materials
CAAI	Corrective Action Area I
CAAII	Corrective Action Area II
ECAA	evaluation of corrective action alternatives
GAC	granular activated carbon
iRULE	Investigation and Remediation of Contaminated Properties, Emergency Rule
ITRC	Interstate Technology and Regulatory Council
MMBTU	million British Thermal Units
MNA	monitored natural attenuation
O&M	operation and maintenance
PFAS	per- and polyfluoroalkyl substances
PFHpA	perfluoroheptanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
POET	Point of Entry Treatment
ppt	parts per trillion
VTANR	Vermont Agency of Natural Resources
VTDEC	Vermont Department of Environmental Conservation

Executive Summary

An evaluation of corrective action alternatives (ECAA) was completed for an area of Bennington, Vermont generally located east of Route 7 that has been identified by the Vermont Agency of Natural Resources (VTANR) as Corrective Action Area II (CAAII) due to the detection of per- and polyfluoroalkyl substances (PFAS) in some groundwater and certain drinking water supply wells within this area.

The objective of the ECAA is to identify potential corrective actions, evaluate those corrective actions against the prescribed criteria in Chapter 35-503 of the Investigation and Remediation of Contaminated Properties, Emergency Rule (iRULE; VTDEC, 2019), and select a remedy based on that evaluation. Pursuant to the iRULE, threshold evaluation criteria include: compliance with legal requirements and overall protection of human health and the environment. Modifying and balancing criteria under the iRULE include: long-term effectiveness and permanence; reducing toxicity, mobility, or volume; short-term effectiveness; implementability; cost; environmental impact and sustainability; and community acceptance[1]. Four different potential corrective action alternatives were considered in detail as part of this evaluation, including: installation and operation of Point of Entry Treatment (POET) systems; installation of municipal waterlines; well replacement; and monitored natural attenuation (MNA).

The following conclusions and recommendations for corrective action were drawn from the comparison:

- POET systems using granular activated carbon (GAC) filtration are a proven effective means of treating PFAS in drinking water supply wells. The continued operation and maintenance (O&M) of POETs already installed on private water supply wells containing PFAS provides a readily implementable long-term corrective action option for drinking water that would meet the threshold criteria set forth in the iRULE.

- Extending municipal waterlines and providing municipal water to residences would also meet the threshold criteria, and at certain residences within CAAII provides a more cost-effective option than long-term O&M of POET systems.

- Installation of replacement private wells, with deeper well casing grouted into bedrock and open-hole advanced to a greater depth, may be a viable corrective action. The results of a pilot-well replacement study in the Bennington area need to be further evaluated to determine the long-term effectiveness of this corrective active option.

[1]For the sake of clarity, throughout this report, the reader should understand that this report is intended only to address the corrective options that may achieve compliance with the current Vermont regulatory standards for PFAS. By using regulatory terms-of-art in discussing corrective action alternatives that will achieve those regulatory standards, Barr Engineering Co. is neither taking nor endorsing any position on any levels of PFAS regarding possible toxicity or any possible impact on human health or the environment.

- Natural groundwater flow processes are effectively removing PFAS from the groundwater system and, therefore, MNA and institutional controls may be a viable long-term corrective action option for groundwater impacts in areas where groundwater concentrations have been historically low, where receptors are not present, or when MNA and institutional controls are paired with a corrective action described above.

1.0 Introduction

This report presents the evaluation of corrective action alternatives (ECAA) for per- and polyfluoroalkyl substances (PFAS), primarily perfluorooctanoic acid (PFOA) present in some groundwater within Corrective Action Area II (CAAII) in Bennington, Vermont. CAAII is shown on Figure 1 and is generally located east of Route 7. CAAII is adjacent to Corrective Action Area I (CAAI), which is the subject of a Consent Order between the Vermont Agency of Natural Resources (VTANR) and Saint-Gobain Performance Plastics Corporation (Saint-Gobain), dated October 2, 2017.

1.1 Objectives

The objective of the ECAA is to identify potential corrective action alternatives, evaluate the potential actions against the prescribed criteria in Chapter 35-503 of the Investigation and Remediation of Contaminated Properties, Emergency Rule (iRULE; VTDEC, 2019) and recommend a corrective action based on that evaluation. The corrective action alternatives are designed to remediate PFAS in drinking water and groundwater where combined levels of PFOA, perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA), and perfluorononanoic acid (PFNA) exceed the Vermont regulatory standard of 20 parts per trillion (ppt) consistent with Chapter 35-503 of the iRULE.

1.2 Target Outcomes

Corrective action alternatives are intended to meet the overall outcome of achieving the threshold criteria set forth in the iRULE. The primary target outcome is to reduce the concentration of PFAS in drinking water below the applicable Vermont drinking water standard, which is currently 20 ppt for the combined concentration of PFOA, PFOS, PFHxS, PFHpA, and PFNA (VTDOH, 2018). This performance standard is currently being met through the installation of Point of Entry Treatment (POET) systems on private water wells with combined concentrations greater than 20 ppt.

Another target outcome for corrective actions is to reduce the mass of PFAS in the groundwater and thereby reduce the concentration below the performance standard. Reducing the mass in the groundwater will eventually result in concentrations of PFAS below the performance standard such that treatment prior to consumption will no longer be required. Active measures that remove mass from groundwater may reduce the time required to reach levels below the performance standard.

A third target outcome for corrective actions is to address source areas so as to eliminate or reduce further releases of constituents that may exceed regulatory standards. As any source areas potentially associated with Saint-Gobain are already being addressed under the October 2, 2017 Consent Order between VTANR and Saint-Gobain, this target outcome is not addressed in this ECAA. Other sources of PFAS in the Bennington area, not associated with Saint-Gobain, are similarly beyond the scope of this analysis.

1.3 Report Organization

The report is organized into the following sections:

- **Section 1.0 – Introduction.** This section provides the basis for the work and outlines the remaining sections of the report.
- **Section 2.0– Corrective Action Evaluation Method.** This section summarizes the criteria and the comparison rankings used to evaluate the corrective action alternatives.
- **Section 3.0– Corrective Action Alternatives.** This section summarizes the corrective actions that were evaluated and assesses each alternative against the evaluation criteria.
- **Section 4.0– Corrective Action Alternatives Not Evaluated in Detail.** This section describes the alternatives that were considered but were not assessed in detail during this evaluation.
- **Section 5.0 – Conclusions and Recommendations.**
- **Section 6.0 – References.**

2.0 Corrective Action Evaluation Method

This section summarizes the methods that were used to complete the corrective action evaluation including the criteria and the rankings that were used to compare the alternatives.

2.1 Corrective Action Evaluation Criteria

Corrective actions are evaluated against the nine criteria specified in Chapter 35-503 of iRULE (VTDEC, 2019), as summarized below. Compliance with legal requirements and overall protection of human health and the environment are threshold criteria under the iRULE that must be satisfied for consideration of an alternative. The remaining seven criteria are balancing/modifying criteria used to select the overall alternative.

This evaluation approach is typically applied when selecting a remedy at a localized release location, such as a Resource Conservation and Recovery Act (RCRA) facility. The following discussion addresses the application of the evaluation criteria in the context of meeting the performance standard for groundwater in CAAII.

2.1.1 Compliance with Legal Requirements

Compliance with legal requirements in this evaluation means potable water concentrations of PFAS less than the performance standard for groundwater for CAAII. This is a threshold criterion under the iRULE.

2.1.2 Overall Protection 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 PFAS less than the performance standard. 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). 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.

Alternatives are evaluated for whether they can meet the performance standard by either eliminating, reducing, or controlling exposures to levels established by the corrective action objectives. This is a threshold criterion under the iRULE.

2.1.3 Long-Term Effectiveness and Permanence

The long-term effectiveness criterion addresses the ability of a corrective action 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 the effectiveness of an alternative 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 (O&M).

2.1.4 Reducing Toxicity, Mobility, and Volume

Alternatives are evaluated by the degree to which they can reduce toxicity, mobility, or volume through removal or treatment or if a corrective action reduces (or increases) the mobility of a constituent or changes the toxic nature of the constituent. 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.

2.1.5 Short-Term Effectiveness

The short-term effectiveness criterion is intended to deal with imminent threats to human health. In addition, short-term effectiveness considers the short-term risks that might be posed to sensitive receptors during implementation of an alternative, potential impacts to workers during corrective action and the effectiveness and reliability of protective measures (e.g., personal protection equipment), and potential environmental impacts of the corrective action and effectiveness and reliability of mitigation measures during implementation.

2.1.6 Implementability

A corrective action’s implementability refers to the degree of difficulty in implementing the corrective action. Constructability, administrative feasibility, and availability of technologies, services, and materials are also factors in the consideration of implementability.

2.1.7 Cost

The estimated cost of each corrective action alternative is assessed in the selection process, as measured by capital costs, O&M costs, and net present value cost. Net present value calculations are used to compare alternatives with high up-front capital costs against alternatives with high long-term O&M costs.

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 20-year project life. 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 action alternatives, which would involve biannual sampling at each active well. Long-term annual costs also include estimates for routine maintenance, periodic equipment replacement, treatment costs (e.g., granular activated carbon [GAC] replacement), and monitoring of treatment systems.

2.1.8 Environmental Impact and Sustainability

Environmental impact and sustainability considers waste generation and disposal requirements and best management practices to reduce the environmental impact. The environmental impact of each alternative was quantitatively assessed by conducting a life cycle analysis in accordance with the American Society for Testing and Materials (ASTM) Standard Guide for Greener Cleanups (ASTM, 2016).

2.1.9 Community Acceptance

Community acceptance considers the extent to which the community may support, have reservations about, or oppose each alternative or components of each alternative. This criterion also needs to consider the level of community involvement required to implement the corrective action.

2.2 Comparison of Corrective Action Alternatives

Each of the corrective action alternatives described in Section 3 were compared against the nine criteria specified in Chapter 35-503 of iRULE (VTDEC, 2019). For each alternative, a subjective ranking of "low", "medium", or "high", as related to meeting the goals of each of the nine criteria was assigned (Table 2). The meanings of the rankings are described below.

2.2.1 "Low" Ranking

A ranking of low is considered the least favorable ranking and is assigned to a particular corrective action alternative criteria if the criteria's goal cannot be met. For example, the corrective action alternative would be assigned a low ranking if the alternative:

- Does not meet the threshold criterion.
- Does not meet drinking water standards in potable water in the short or long term.
- Does not substantially reduce mass or concentration of PFAS in the groundwater system.
- Cannot be implemented because of physical or technological constraints.
- Has a large impact on the environment (e.g., high greenhouse gas emission, high energy use).
- Causes substantial regional disturbance or disruption to individual residences or the community in the short or long term.

2.2.2 "Medium" Ranking

A ranking of medium is considered a moderately favorable ranking. For example, the corrective action alternative would be assigned a medium ranking if the alternative:

- Partially complies with relevant standards.
- Can potentially be implemented but possesses substantial risk that it would not be effective.
- Removes mass by some means.
- Has shown to be effective in some settings, but may not be as effective in this setting (e.g., at smaller scales).
- May receive some community acceptance but it is anticipated that issues would likely be encountered.

2.2.3 "High" Ranking

A ranking of high is considered the most favorable ranking and is assigned to a particular corrective action alternative criteria if the criteria's goal can be met. For example, the corrective action alternative would be assigned a high ranking if the alternative:

- Provides potable water supplies that meet performance standards.
- Is protective of human health in the short- and long-term.
- Reduces the mass and/or concentration in the groundwater system.
- Is a proven technology that has been shown to be implementable at the scale of the current setting and with the constituent of concern (PFAS).
- Has a minimal impact on the environment (e.g., minimal greenhouse gas emission, low energy use).
- Would receive widespread community acceptance with minimal disruption and the alternative can be implemented quickly.

3.0 Corrective Action Alternatives

Four corrective action alternatives were considered as part of this evaluation and include:

- Installation and operation of POET systems;
- Installation of municipal waterlines;
- Well replacement; and
- Monitored natural attenuation.

In addition, several other potentially applicable corrective action alternatives were initially considered but were not included in detailed analysis, including: physical barriers, cut-off walls, and reactive barrier walls; in situ treatment; low-permeability capping; pump-and-treat systems using existing private water supply wells or dedicated extraction and reinjection wells; and surface soil excavation. Many of these alternatives were evaluated in greater detail as part of the *Comparative Analysis of Corrective Action Options* for CAAI (Barr, 2017a). These alternatives were deemed to be inapplicable due to technical infeasibility and limited effectiveness and/or community acceptance. These alternatives are discussed further in Section 4.

As described in Section 2.2, each corrective action alternative was assigned a subjective ranking of "low", "medium", or "high", as related to meeting the goals of each of the nine criteria (Table 2). By comparing the overall achievement of criteria goals for the corrective actions, a single corrective action or set of corrective actions can be identified and recommended for implementation.

Regardless of the corrective action alternative(s) selected, natural groundwater processes will continue to flush PFAS mass from the groundwater system and reduce PFAS concentrations at individual wells. In order to evaluate groundwater quality data and analyze groundwater quality trends, it is recommended that natural attenuation be monitored. Similar to the corrective actions approved for CAAI (Barr, 2018b), it is assumed that a select number of existing private wells in CAAII will be monitored on a quarterly basis for a limited time (estimated two years) for monitored natural attenuation (MNA) concurrent with the corrective action alternative(s) selected.

3.1 Installation and Operation of POET Systems on Wells

This corrective action involves the continued O&M of POET systems already installed on private drinking water wells with PFAS concentrations greater than the performance standard. The POET system locations within CAAII are shown on Figure 2. These POET systems use GAC in two serially-aligned closed vessels to remove PFAS from the incoming water via sorption and are considered whole-house water treatment systems. 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 PFAS from the first vessel.

Compliance with Legal Requirements

POET systems are shown through regular sampling to be capable of reducing PFAS concentrations below detection limits and below the performance standard. They have been installed at locations in the corrective action area where potable water-supply wells have been tested and found to have PFAS concentrations above the performance standard. Based on the ability of POET systems to meet the performance standard, this alternative would have a high score.

Overall Protection of Human Health and the Environment

POET systems eliminate exposure of PFAS via private water supplies and are therefore protective of human health. They also eliminate incidental exposure to water with elevated PFAS concentrations because they treat well water before it is distributed through building plumbing. Based on the ability of POET systems to provide safe drinking water, this alternative would have a high score.

Long-Term Effectiveness and Permanence

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 PFAS and other sorbing constituents in the influent. Over time, a regular maintenance schedule is developed. In CAAI, the vessel change-out period is typically once every two years based on recommendations from the POET system installation and maintenance contractor (Culligan).

If selected as the corrective action alternative for CAAII, it is assumed an O&M schedule similar to the one established in the corrective action plan for CAAI (Barr, 2018b) would be used. GAC is currently the most common water treatment method used to remove PFAS and has been demonstrated to treat PFAS (ITRC, 2018). Based on the frequency of vessel change-out and the ongoing O&M required for these systems, this alternative would have a low score.

Reducing Toxicity, Mobility, or Volume

POET systems do not affect the subsurface mobility or any potential toxicity of PFAS but substantially reduce mass and mobility in the supply stream to the system in which they are installed. POET systems are essentially a small-scale pump-and-treat system that removes PFAS from the groundwater system at a rate dependent on PFAS concentration, the pumping rate, and overall well usage. Although total mass removal from groundwater is limited compared to the overall mass within the groundwater system and the removal associated with natural flushing processes, with POET systems installed, the recycling of PFAS back into the groundwater system via the structure’s septic system is eliminated. PFAS mass would also be reduced in the groundwater system through natural flushing processes. Based on the mass reduction from the POET systems and the natural flushing processes, this alternative would have a high score.

Short-Term Effectiveness

POET systems are highly effective short-term corrective actions to eliminate imminent threats to human health. They can be installed quickly (within days of detection) and require no short-term maintenance by the homeowner. 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. Based on the quick installation and ability to eliminate threats to human health, this alternative would have a high score.

Implementability

POET systems are already installed in CAAII at private wells exceeding the performance standard. If additional POET systems are required, they are easy to implement. GAC is currently the most common water treatment method used to remove PFAS (ITRC, 2018) and 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. Based on the ease of implementation, this alternative would have a high score.

Cost

The estimated cost of installing, operating, and maintaining POET systems in CAAII is listed in detail in Table 1 and summarized in Table 2. Costs are also included for a long-term biannual monitoring program for existing private wells without a POET system (i.e., private wells with PFAS concentrations below the performance standard) similar to the monitoring program implemented in CAAI.

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 PFAS analyses to confirm treatment effectiveness. The O&M costs assume a treatment period of up to 20 years. The estimated costs account for those wells that are expected to require less than 20 years of treatment as natural groundwater processes reduce PFAS concentration at the well to below the performance standard. Based on the modeling information from the CSM (Barr, 2017b), it is believed that the average period of O&M for POETs will be less than 20 years and the costs shown in Table 1 for this alternative reflect that assumption.

Environmental Impact and Sustainability

During implementation of this alternative, approximately 60 metric tons of greenhouse gases would be emitted and approximately 1,930 million British Thermal Units (MMBTU) of energy would be consumed. The largest contributor to environmental impacts would be the energy required to produce and process the materials needed for POET maintenance, including sediment filters and GAC.

Best management practices that could be implemented during this alternative include regenerating spent GAC for other non-potable uses. Based on quantitative analysis and comparison to the other alternatives, this alternative would have a high environmental sustainability.

Community Acceptance

The community generally accepts of use of POET systems. Their installation requires minimal disruption to the property owner and they have a very small interior footprint. GAC is currently the most common water treatment method used to remove PFAS (ITRC, 2018) and POETs equipped with GAC are generally viewed as being reliable. Based on the high level of community acceptance, this alternative would have a high score.

3.2 Installation of Municipal Waterlines

For properties currently served by a private well, the installation of municipal waterlines involves either (1) the extension of and subsequent connection to an existing municipal water system or (2) the connection to existing waterlines already installed in the service area. The existing and potential waterline alignments are shown on Figure 3.

Compliance with Legal Requirements

Public water suppliers are required to provide water that meets or exceeds federal and state standards for a wide variety of constituents, including PFAS. Based on the ability of municipal water to meet the performance standard, this alternative would have a high score.

Overall Protection of Human Health and the Environment

Replacement of wells with municipally-supplied water eliminates human exposure by changing the source of water from groundwater to a public water supply. The public water supplier is required to regularly monitor water quality at the source and within the distribution system. Some levels of treatment are applied to the water, depending on the source. Based on the ability of municipal water to provide safe drinking water, this alternative would have a high score.

Long-Term Effectiveness and Permanence

Depending on the construction materials used, municipal waterlines have a life expectancy of 75-100 years (ASCE, 2017). After the waterline is connected to the house, there is little need for future human actions with the exception of unexpected conditions (e.g., waterline breaks). Source water treatment may change with time if the water quality of the source water changes. Based on the long life expectancy of municipal waterlines, this alternative would have a high score.

Reducing Toxicity, Mobility, or Volume

PFAS mass would be reduced in the groundwater system through natural flushing processes. There would be no effect on PFAS mobility or any potential toxicity. Based on the mass reduction from the natural flushing processes, this alternative would have a high score.

Short-Term Effectiveness

Planning, engineering, and construction of waterline extensions may take 1-2 years to complete; however, during this time, POET systems, already installed at private wells exceeding the performance standard, can continue to operate. Therefore, although the short-term effectiveness of waterline installation is low, the overall short-term effectiveness is considered high due to the presence of the POET systems.

Implementability

Waterline 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.

Implementation challenges for isolated properties limit the viability of municipal waterline extension as a universal corrective action for CAAII. For example, connecting a single home at the end of a long waterline may result in water quality problems due to stagnation of the water in the supply line. For that reason, municipal waterline extensions may not be implementable for all affected properties and this alternative has been given a medium score.

Cost

The estimated cost of installing municipal waterlines as the corrective action is listed in detail in Table 1 and summarized in Table 2 and includes capital costs for design and construction of the municipal waterlines, approximately one year of POET system O&M costs during municipal waterline construction, and costs for the long-term monitoring program.

The capital cost estimate for municipal waterlines in Table 1 is based on preliminary engineering cost estimates provided to the State of Vermont in a memorandum from MSK Engineering & Design on October 3, 2018 and updated waterline extents provided on April 3, 2019. No municipal waterline O&M costs are assumed for the municipal waterlines.

Environmental Impact and Sustainability

During implementation of this alternative, approximately 3,300 metric tons of greenhouse gases would be emitted and approximately 50,000 MMBTU of energy would be consumed. The largest contributor to environmental impacts would be the energy required to produce and process materials such as piping for the water mains and service connections, the sand bedding for the pipes, and the asphalt and concrete for road restoration.

Best management practices that could be implemented during this alternative include using an alternate material for pipe bedding, such as crushed concrete, and using recycled concrete and asphalt for road restoration. Based on quantitative analysis and comparison to the other alternatives, this alternative would have a low environmental sustainability.

Community Acceptance

Community acceptance of municipal waterlines is generally, but not uniformly, high. For some in the community, the disruption from ongoing, widespread waterline construction may be viewed as a nuisance. Most homeowners and businesses view municipal water as more reliable than private wells; however, some well owners object to perceived loss of control of their water supply and others object to cost of service charges. Water quality perceptions will likely vary and could be viewed as better than or not as good as well water. The state and residents living in CAAI and CAAII have generally indicated that municipal waterline 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). Based on the high level of community acceptance, this alternative would have a high score.

3.3 Private Well Replacement

This corrective action involves replacement of the 163 private water wells with PFAS concentrations exceeding the performance standard with wells cased into bedrock and open holes drilled to greater depths in bedrock than the existing private wells. This corrective action alternative assumes that replacement wells, designed as described above, will result in PFAS concentrations below the performance standard. This assumption is currently supported by the initial results of a pilot-well replacement study in the Bennington area. The private wells considered for replacement are currently equipped with POET systems. The locations of POET systems within CAAII are shown on Figure 2.

Compliance with Legal Requirements

Replacement water wells would be constructed and tested in accordance with applicable state guidance and requirements for new well construction and reporting. Demonstration that PFAS concentrations in newly-installed private wells are below the performance standard would be evaluated on a well-by-well basis and would be required before bypassing the POET system. Long-term monitoring of the replacement well (assumed biannually for 20 years) would be performed to ensure the water remains potable.

Assuming installation of new private wells cased into bedrock and drilled to greater open-hole depths is successful at reducing PFAS below the performance standard at a given location, then this corrective action alternative has a high compliance with legal requirements. It is anticipated that some replacement wells will not meet the performance standard and that this alternative would not comply with the legal requirements without the use of a POET system. Based on this assumption, this alternative would not achieve full compliance with legal requirements. For the purpose of the assessment of these criteria, private well replacement has been given a ranking of medium.

Overall Protection of Human Health and the Environment

It is anticipated that well replacement will be effective at meeting the performance standard at most but not all locations. O&M of POET systems would continue until it was demonstrated that the replacement well could reliably provide a potable water supply with PFAS concentrations below the performance standard. Based on the likelihood that most but not all replaced wells would be able to provide safe drinking water, this alternative has been given a medium score.

Long-Term Effectiveness and Permanence

Depending on the construction materials used, water wells have a life expectancy of 25-100 years (Glotfelty, 2017). It is likely that the life expectancy of the equipment associated with the well (well pump, pressure tank, etc.) would be less. After the well is completed, the POET system will continue to operate until it has been demonstrated that the replacement well could provide potable water below the performance standard. The POET system will need to continue to be maintained during this period. Therefore, this alternative would have a medium score.

Reducing Toxicity, Mobility, or Volume

PFAS mass would be reduced in the groundwater system through natural flushing processes. There would be no effect on PFAS mobility or any potential toxicity. Based on the mass reduction from the natural flushing processes, this alternative would have a high score.

Short-Term Effectiveness

A total of 163 wells in CAAII currently have concentrations above the performance standard and would be replaced under this alternative. Based on the number of wells, it is anticipated that it would take 4-6 years to complete. During this time, POET systems will need to continue to operate to provide potable water that meets the performance standard. Therefore, although the short-term effectiveness of well replacement alternative is low, the overall short-term effectiveness is considered high due to the presence of the POET systems.

Implementability

The number of wells requiring replacement (163) would necessitate significant property access coordination and well construction activities, and would likely extend over a period of years depending on access issues and the availability of licensed well drillers. The ability to implement this corrective action alternative also depends upon whether groundwater in deeper bedrock is an appropriate and viable source of water at each location where PFAS exceeds the performance standard. There may be certain locations in which new deeper wells will not result in PFAS concentrations below the performance standard or may not be viable due to engineering considerations or hydrogeologic conditions (e.g., low-yielding bedrock). Well replacement may be a suitable alternative to POET systems or municipal waterline installation at select locations; however, the successful replacement of all 163 candidate wells is not assured. Therefore, this alternative would have a score of medium.

Cost

The estimated cost to replace the 163 water wells in CAAII currently equipped with POET systems is listed in detail in Table 1 and summarized in Table 2. Costs include capital costs for well construction, costs for maintaining and sampling POET systems prior to well replacement (assumes wells are replaced at a rate of 40 wells per year) and O&M costs for two years of POET operations following well installation. The O&M costs also include the long-term monitoring program and assumes that potable water wells will be sampled biannually.

Environmental Impact and Sustainability

During implementation of this alternative, approximately 660 metric tons of greenhouse gases would be emitted and approximately 5,530 MMBTU of energy would be consumed. The largest contributor to environmental impacts would be the energy required to produce and process materials required to implement this alternative (i.e., casing, grout, piping, etc.).

Best management practices to consider when implementing this alternative would be to select the replacement well location and depth that minimizes the quantity of materials required. Based on quantitative analysis and comparison to the other alternatives, this alternative would score medium for environmental sustainability.

Community Acceptance

While the disruption from ongoing, widespread drilling may be viewed as a nuisance in the community, it is anticipated that the community acceptance would likely be high if this corrective action were utilized on a small-scale basis. Based on the initial pilot-scale implementation of this alternative in CAAI, this alternative would have a high score.

3.4 Monitored Natural Attenuation

MNA involves collecting data to confirm that the natural processes acting on the constituents are 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 PFAS, there are no indicator parameters to monitor. Reductions in PFAS concentration over time are almost entirely due to physical flushing of water through the groundwater system.

For the evaluation of the MNA corrective action alternative, it is assumed that no additional corrective actions (e.g., POET systems, municipal waterlines, and well replacement) would be performed. The groundwater system would continue to be monitored and re-evaluated with the expectation that, over time, natural processes would flush PFAS from the groundwater system. As this process progresses, PFAS concentrations in wells would be reduced below the performance standard and these wells could be used without treatment. Well locations within CAAII are shown on Figure 2.

Compliance with Legal Requirements

A long-term monitoring plan would be established to demonstrate that MNA of PFAS is occurring; however, concentrations of PFAS in groundwater would remain above the performance standard for a period of time and this alternative would not be in compliance with legal requirements if it were not paired with one of the above-referenced corrective actions. Therefore, this alternative was given a low score.

Overall Protection of Human Health and the Environment

MNA alone would not eliminate potential human exposures to PFAS concentrations above the performance standard in the short term. Therefore, this alternative was given a low score.

Long-Term Effectiveness and Permanence

For this alternative, there are no POET systems that would need to be maintained or construction activities that would be completed (i.e., waterline construction or well drilling). Future actions that would be required to implement the alternative would be minimal and would primarily involve groundwater sampling to monitor PFAS concentrations in CAAII. Based on the low level of operation and maintenance, this alternative would have a high score.

Reducing Toxicity, Mobility, or Volume

PFAS mass would be reduced in the groundwater system through natural flushing processes. There would be no effect on PFAS mobility or any potential toxicity. Based on the mass reduction from the natural flushing processes, this alternative would have a high score.

Short-Term Effectiveness

The MNA corrective action alone would not be effective at addressing exposure to PFAS concentrations above the performance standard and therefore would have a low score.

Implementability

Implementability of MNA is high, as it is a commonly applied corrective action alternative 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 detail in Table 1 and summarized in Table 2 and assumes that only long-term monitoring would be required to complete the corrective action alternative.

Environmental Impact and Sustainability

This alternative would have no significant environmental impacts. Based on quantitative analysis and comparison to the other alternatives, this alternative would have a high environmental sustainability.

Community Acceptance

Without being paired with one of the other above-referenced corrective actions, monitored natural attenuation alone would likely result in low community acceptance due to its inability to eliminate exposure to PFAS concentrations above the performance standard in the short term. However, MNA is a commonly accepted corrective action alternative when it is combined with other protective measures.

4.0 Corrective Action Alternatives Not Evaluated in Detail

This section describes other potentially applicable corrective action alternatives that were initially considered but deemed to be inapplicable due to technical infeasibility and/or limited effectiveness and community acceptance. Many of these alternatives were evaluated in greater detail as part of the *Comparative Analysis of Corrective Action Options* for CAAI (Barr, 2017a).

Due to the nature and extent of PFAS in the environment in CAAII, many corrective action alternatives are not applicable to PFAS. While they may be appropriate for some settings, they fail to successfully meet the criteria for corrective action alternative selection in this setting. Corrective action alternatives that were initially considered but not further evaluated are provided below with the reasons that they were deemed to be inapplicable and to not warrant detailed analysis.

4.1 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 chemical constituents 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 an ineffective option for corrective action in this instance and were not further considered.

Reactive barriers are low-permeability barriers with one or more “gates”, i.e., 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. GAC and zero-valent iron have been shown to be media that could act as permeable gates to reduce PFAS 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 PFAS 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 an ineffective option for corrective action in this instance and were not further considered.

4.2 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.

PFAS is highly stable in the environment and does not readily degrade under a wide variety of conditions. Currently, there are no known in situ treatment technologies for PFAS 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.

4.3 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 a large area, such 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.

4.4 Pump-and-Treat Systems

Pump-and-treat systems involve pumping groundwater from the subsurface, treating it to reduce concentrations to acceptable levels, and discharging the treated water to surface water, injection wells, or an infiltration gallery. Two pump-and-treat scenarios are described in the *Comparative Analysis of Corrective Action Options* for CAAI (Barr, 2017a): operation of a dedicated pump-and-treat system with reinjection and operation of existing POET-equipped wells at full capacity. Neither of these scenarios is practical when applied at the regional scale of CAAII.

Additionally, implementation of a pump-and-treat system for treatment of groundwater impacted with PFAS at a regional scale is not common practice. As described in the Interstate Technology and Regulatory Council (ITRC) *Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS) fact sheet* (ITRC, 2018), full-scale operations of GAC treatment systems have focused on higher priority private and public water supply and residential point-of-use treatment. Accordingly, a pump-and-treat system was determined to be an ineffective alternative for corrective action in this instance and was not further considered.

4.5 Surface Soil Excavation

Surface soil excavation can be an effective way to remove a source of PFAS which may otherwise serve as a continuing source of groundwater contamination, but does not result in destruction of PFAS (ITRC, 2018). This alternative was evaluated in detail in the *Comparative Analysis of Corrective Action Options* for CAAI (Barr, 2017a). Surface soil excavation typically occurs to depths of 1 to 2 feet, and would not be effective at removing PFAS impacts that have migrated deeper into the soil column. Excavation to a depth which may remove a greater mass of PFAS would not be feasible at the regional scale within the corrective action area, and the available soil concentration data (Barr, 2018a) do not suggest that deeper excavation would remove a greater mass of PFAS or produce a substantial reduction of PFAS concentrations in groundwater. Excavation of surface soil across the corrective action area would encounter substantial implementability challenges related to property access; staging, stockpiling, transporting, and disposing of excavated soils; and dust control, erosion, and restoration at excavated areas. Accordingly, surface soil excavation was determined to be an ineffective alternative for corrective action in this instance and was not further considered.

4.6 POET Using Other Treatment Technologies

POET systems currently used throughout the corrective action area use GAC as the primary mechanism to remove PFAS. Other treatment technologies, such as precipitation/flocculation/coagulation, biochar, ion exchange, redox manipulation, and membrane filtration, may in limited circumstances be effective ways to treat PFAS in groundwater (ITRC, 2018). However, GAC is currently the most common water treatment method used to remove PFAS (ITRC, 2018), and has shown to be an effective, implementable, and cost-efficient way to treat PFAS. Other treatment technologies are less commonly used and/or have limitations compared to GAC. Accordingly, POET use with a treatment technology other than GAC was not further considered.

5.0 Conclusions and Recommendations

5.1 Summary of Corrective Action Alternatives

Based on the results of this evaluation, a summary of each corrective action alternative and its ability to meet the objectives of the ECAA is provided below:

Installation and Operation of POET Systems on Private Wells. POET systems are proven to be an effective means for removing PFAS from drinking water wells and have already been installed on CAAII private wells in which PFAS was detected above the performance standard. Accordingly, POET systems provide an easily implementable and cost-effective corrective action that is fully protective of human health and the environment in the short and long term. Moreover, POET systems remove PFAS mass from the groundwater system and prevent reintroduction of PFAS through septic systems. Continued O&M of the existing POET systems are anticipated to have high community acceptance.

Installation of Municipal Waterlines. Municipal waterline extensions may be preferable to POETs at certain locations due to the proximity to existing waterlines, the number and density of POET-equipped wells in the area to which the waterline would be extended, and/or elevated concentrations of PFAS that may result in a POET system operating for a longer period than in other areas. In such instances, waterline extensions may be more cost-effective and would likely have a greater community acceptance.

Waterline extensions are considered similarly protective of human health and the environment as POET systems. However, waterline extensions do not enhance PFAS mass removal from the groundwater system and cannot be extended to all affected locations in CAAII due to water-quality concerns related to water stagnation in lines connecting isolated properties. Waterline extensions would not be as easily implemented as POET systems, which have already been installed.

Well Replacement. In certain areas, replacing existing private wells with new wells drilled deeper into bedrock and constructed with deeper casing grouted into bedrock may be a viable, long-term corrective action. Private well replacement may be most effective where shallow wells with concentrations of PFAS above the performance standard are located within a larger area of wells with PFAS concentrations below the performance standard. In such areas, private well replacement may address PFAS detections above the performance standard; however, for most of CAAII, new well construction would not likely be an effective remedy.

A pilot-well replacement study was completed in CAAI and is currently under evaluation for broader application. This pilot-program focused on constructing new wells with casing set at sufficient depth to hydraulically isolate the new well’s open hole from the unconsolidated aquifer and shallow bedrock. Initial results from the pilot-study are positive; however, the long-term effectiveness of replacement wells reducing PFAS concentrations has not been determined.

Monitored Natural Attenuation. MNA, without POETs or waterline extensions, would not meet the minimum requirement of providing well users with water that meets the performance standard and would, therefore, be unacceptable. MNA would be similarly effective at long-term removal of mass and concentration reduction as other, more aggressive corrective action alternatives. Therefore, it has utility if used with other methods that are protective of human health.

5.2 Recommendations

Given that no single corrective action alternative fully satisfies the selection criteria, the recommended corrective action for CAAII is a combination of:

- Continued O&M of existing POET systems in areas where municipal waterlines either are not implementable or are significantly more expensive than continued O&M of POET systems.
- Installation of municipal waterlines in areas where waterlines may be more easily implemented or cost less than long-term O&M of existing POET systems, due to the proximity to existing waterlines, the number and density of wells with POET systems, and/or elevated concentrations of PFAS that may result in a POET system operating for a longer period than in other areas.
- Replacement of selected wells at locations where shallow wells with concentrations of PFAS above the performance standard are located within a larger area of wells with PFAS concentrations below the performance standard.
- Long-term monitoring of wells with concentrations of PFAS below the performance standard and monitoring of groundwater within CAAII to assess natural attenuation.

6.0 References

American Society of Civil Engineers (ASCE), 2017. 2017 Infrastructure Report Card, Drinking Water, 2017.

American Society for Testing and Materials (ASTM) E2893-16e1, Standard Guide for Greener Cleanups, ASTM International, West Conshohocken, PA, 2016.

Barr Engineering Co. 2017a. Comparative Analysis of Corrective Action Options: North Bennington, Vermont. April 2017.

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Barr Engineering Co., 2018a. Conceptual Site Model Site Investigation Report: Bennington, Vermont, prepared for Saint-Gobain Performance Plastics, March 2018.

Barr Engineering Co., 2018b. Corrective Action Plan, Corrective Action Area I – Operational Unit B, North Bennington and Bennington, prepared for Saint-Gobain Performance Plastics, dated May 2018.

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Vermont Department of Environmental Conservation (VTDEC), 2019. Investigation and Remediation of Contaminated Properties Rule, State of Vermont Agency of Natural Resources Department of Environmental Conservation Waste Management and Prevention Division. Emergency Rule, filed January 8, 2019.

Vermont Department of Health (VTDOH), 2018. Memorandum from Mark A. Levine MD, Commissioner to Emily Boedecker, Commissioner re: Drinking Water Health Advisory for Five PFAS (per- and polyfluorinated alkyl substances), July 10, 2018.

Tables

Table 1
Estimated Costs for Corrective Action Alternatives
Corrective Action Area II
Bennington, Vermont
Saint-Gobain Performance Plastics

Alternative	Net Present Value	
Alternative 1 - Installation and Operation of POET Systems on Wells		
POET Sampling and Operation and Maintenance (O&M)[1]	$	3,000,000
Long-Term Monitoring (LTM) Sampling[2]	$	3,000,000
Engineering and Regulatory Oversight	$	380,000
Contingency (10% of sampling labor/expense, O&M costs)	$	370,000
Alternative 1 - Total Estimated Present Value Costs:	**$6,800,000**	
Estimated Range of Costs:	**+50%**	**$ 10,000,000**
	-30%	**$ 4,800,000**
Alternative 2 - Installation of Municipal Waterlines		
Waterline Installation[3]	$	18,000,000
POET Sampling and O&M[4]	$	380,000
LTM Sampling[5]	$	2,200,000
Engineering and Regulatory Oversight	$	600,000
Contingency (10% of sampling labor/expense, O&M, waterline installation costs)	$	1,900,000
Alternative 2 - Total Estimated Present Value Costs:	**$23,000,000**	
Estimated Range of Costs:	**+50%**	**$ 35,000,000**
	-30%	**$ 16,000,000**
Alternative 3 - Well Replacement		
Well Replacement[6]	$	12,000,000
POET Sampling and O&M[7]	$	1,300,000
LTM Sampling[8]	$	3,700,000
Engineering and Regulatory Oversight	$	3,400,000
Contingency (10% of sampling labor/expense, O&M, well replacement costs)	$	1,400,000
Alternative 3 - Total Estimated Present Value Costs:	**$22,000,000**	
Estimated Range of Costs:	**+50%**	**$ 33,000,000**
	-30%	**$ 15,000,000**
Alternative 4 - Monitored Natural Attenuation		
Well Sampling[9]	$	4,100,000
Engineering and Regulatory Oversight	$	190,000
Contingency (10% of sampling labor/expense costs)	$	180,000
Alternative 4 - Total Estimated Present Value Costs:	**$4,500,000**	
Estimated Range of Costs:	**+50%**	**$ 6,800,000**
	-30%	**$ 3,200,000**

Notes:

Net present values were calculated using 3% interest rate over a 20 year period.

1 - Assumes 163 POETs in year 1 and that the number of POETs decrease with time (i.e., concentrations of PFAS will decrease with time due to flushing of the groundwater system).

2 - Assumes biannual (twice per year) sampling of 141 wells without POETs (i.e., concentrations of PFAS below the performance standard) in year 1. The number of LTM wells will increase over 20 year period to account for decreasing PFAS concentrations (i.e., groundwater flushing).

3 - Assumes that municipal waterlines will be installed in one year (subject to contractor availability and engineering design) at the potential waterline locations identified in Figure 3 and that excess soil will be managed within CAAII.

4 - Assumes POET sampling and O&M will continue during municipal waterline installation.

5 - Assumes biannual sampling of wells not located along waterline alignment.

6 - Assumes that 163 wells with POETs (i.e., PFAS concentrations greater than performance standard) will be replaced; concentrations of PFAS will decrease with time (i.e., no additional wells will need to be replaced); concentrations of PFAS will be below the performance standards after well has been replaced. Assumes that 40 wells will be replaced each year (subject to change, based on driller availability) and water generated during well construction will not need to be treated before discharging.

7 - Assumes that POET sampling and O&M will be maintained prior to well replacement and will continue for two years following well replacement.

8 - Assumes biannual sampling of all wells within CAAII without POETs (i.e., PFAS concentrations below the performance standard); number of LTM wells increases over 20 year period after POET system has been removed from replacement wells.

9 - Assumes all POETs will be removed and no POET sampling or O&M will be completed; 304 wells within CAAII will be sampled biannually for 20 years.

The estimated range of costs is associated with the most likely cost of the project based on the level of design that has been completed and the uncertainties in the project as scoped (e.g., quantity uncertainties for soil excavation pending additional testing, variability in transportation and disposal cost, variability in project schedule/phasing, etc.). These costs do not include future scope changes that are not part of the planned project or risk contingency.

Table 2
Corrective Action Criteria Scoring Summary
Evaluation of Corrective Action Alternatives
Corrective Action Area II
Bennington, Vermont
Saint-Gobain Performance Plastics

Corrective Action	Corrective Action Evaluation Criteria								
	Compliance with Legal Requirements[1]	Overall Protection of Human Health and the Environment[2]	Long-Term Effectiveness and Permanence[3]	Reducing Toxicity, Mobility, or Volume[4]	Short-Term Effectiveness[5]	Implement-ability[6]	Present Value Cost (millions)[7]	Environmental Sustainability[8]	Community Acceptance[9]
Installation and Operation of POET Systems on Wells	High	High	Low	High	High	High	$6.8	High	High
Installation of Municipal Waterlines	High	High	High	High	High	Medium	$23	Low	High
Private Well Replacement	Medium	Medium	Medium	High	High	Medium	$22	Medium	High
Monitored Natural Attenuation	Low	Low	High	High	Low	High	$4.5	High	Low

Notes:

1 Compliance with legal requirements is evaluated by considering the alternative's ability to provide potable water with concentrations of per- and polyfluoroalkyl substances (PFAS) less than the performance standard for groundwater

2 Overall protection of human health and the environment is evaluated by considering the alternative's ability to provide potable water with a concentration of PFAS less than the performance standard

3 Long-term effectiveness and permanence is evaluated by considering the alternative's ability to function appropriately through expected conditions and the level of operation and maintenance required, potential for constructed systems to degrade over time, and the need for future human actions

4 Reducing toxicity, mobility, or volume is evaluated by considering the alternative's ability to reduce toxicity, mobility, or volume of PFAS through removal or treatment

5 Short-term effectiveness is evaluated by considering the alternative's ability to mitigate imminent threats to human health and the environment during the implementation of the alternative

6 Implementability is evaluated by considering the degree of difficulty in implementing the corrective action, including consideration of constructability, administrative feasibility, and availability of technologies, services, and materials

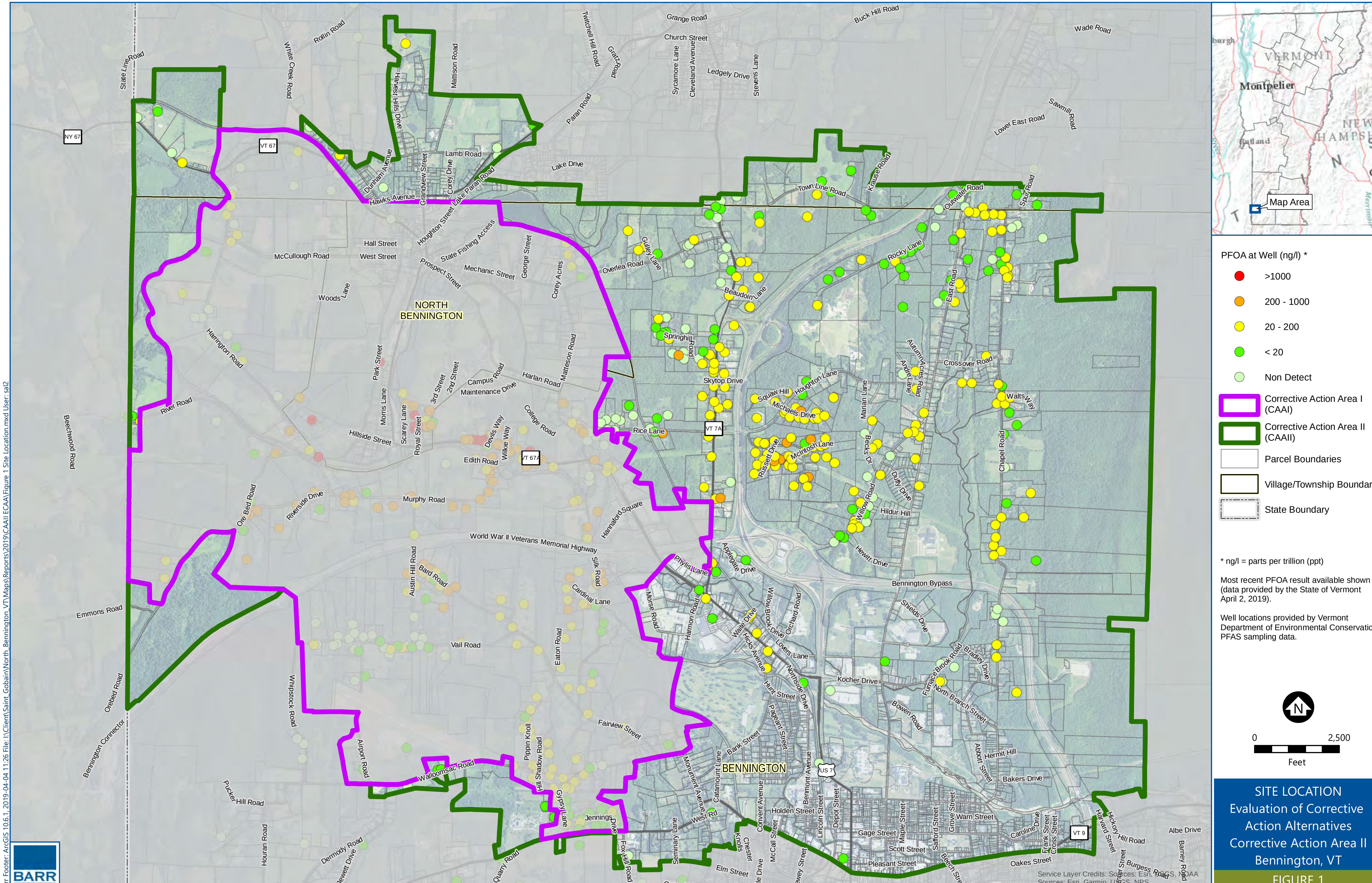
7 Present value costs consider up-front capital costs and long-term operation and maintenance costs

8 Sustainability is evaluated by considering waste generation and disposal required for the alternative

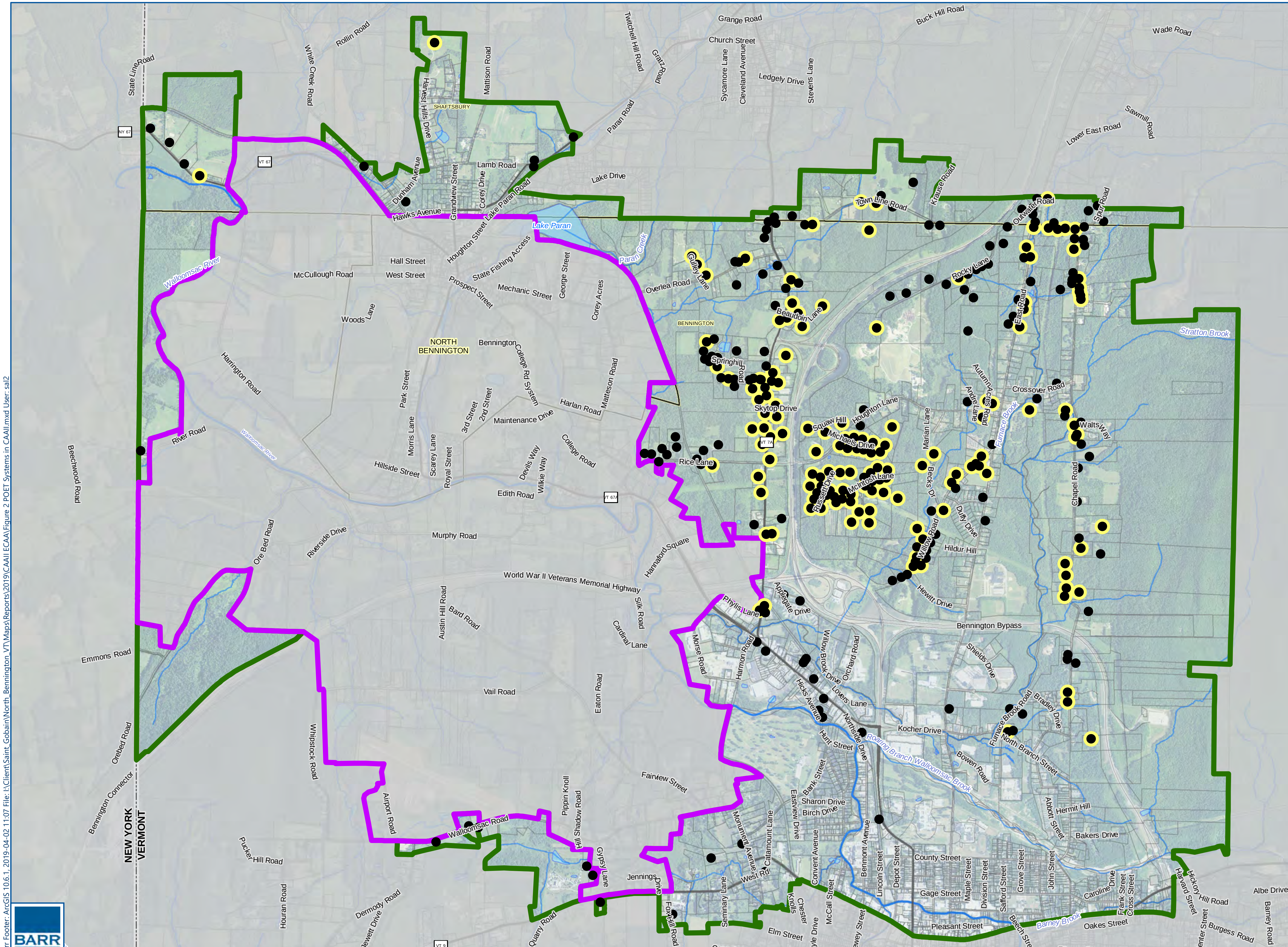
9 Community acceptance is evaluated by considering the extent to which the community may support, have reservations about, or oppose the alternative or components of the alternative

Low – there is low likelihood that the criterion objective can be met by the corrective action alternative
Medium – there is moderate likelihood that the criterion objective can be met by the corrective action alternative
High – there is high likelihood that the criterion objective can be met by the corrective action alternative

Figures



SITE LOCATION
Evaluation of Corrective Action Alternatives
Corrective Action Area II
Bennington, VT
FIGURE 1



- Well Location
- Yellow halo indicates that well has a POET *
- Corrective Action Area I (CAAI)
- Corrective Action Area II (CAAII)
- Parcel Boundary
- Township/Village Boundary
- State Boundary

Well locations provided by Vermont Department of Environmental Conservation PFAS sampling data.

Well and POET location information shown for CAA II Only.

* POET = Point of Entry Treatment

N

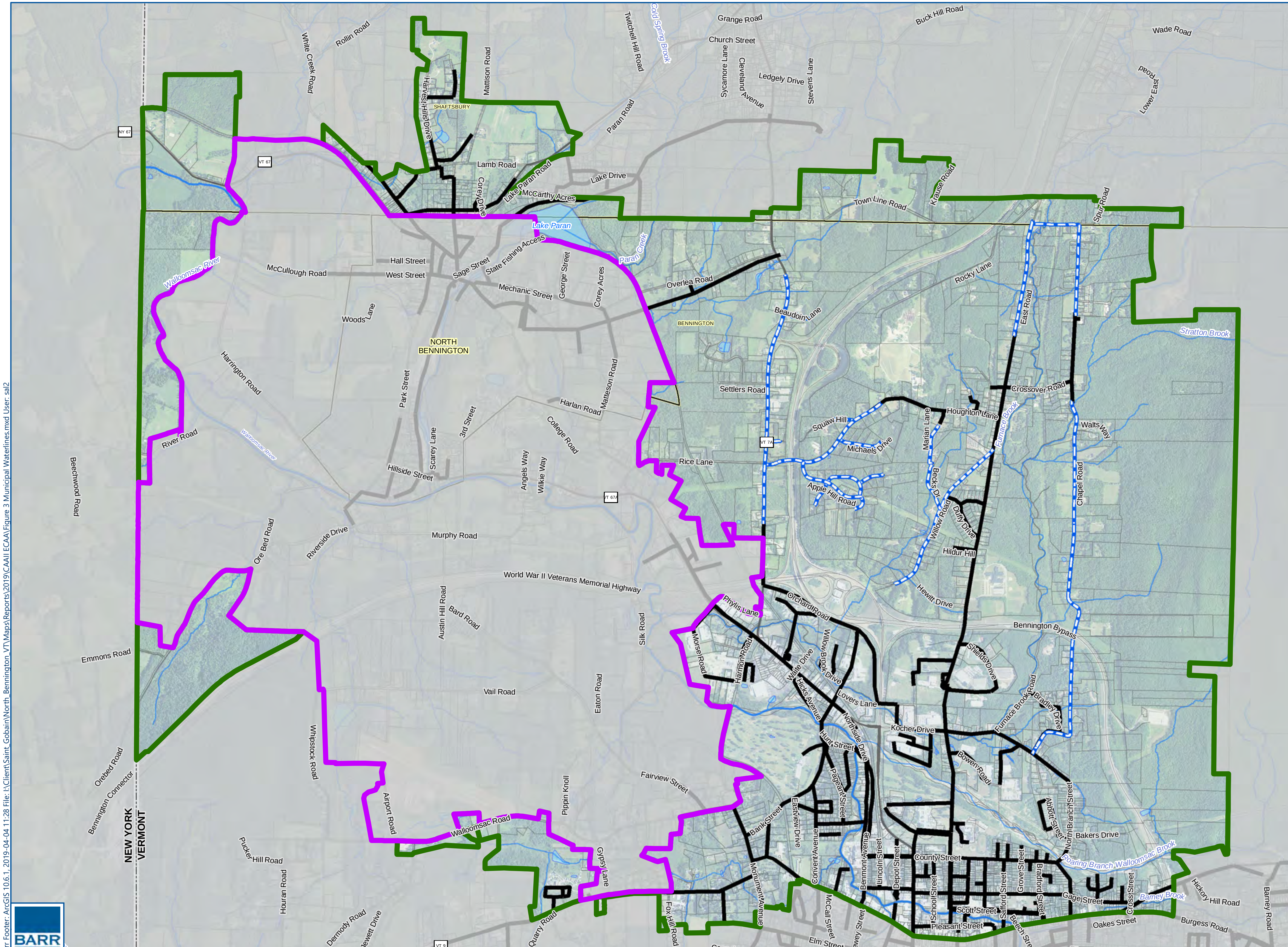
0 2,500

Feet

POET SYSTEMS IN CAAII
Evaluation of Corrective Action Alternatives
Corrective Action Area II
Bennington, VT

FIGURE 2

BARR



- Potential Municipal Waterline
- Municipal Waterline
- Corrective Action Area I (CAAI)
- Corrective Action Area II (CAAII)
- Parcel Boundary
- Township/Village Boundary
- State Boundary

Potential municipal waterlines for CAAII are based on data provided by the State of Vermont, dated April 3, 2019.

N

0 2,500

Feet

MUNICIPAL WATERLINES
Evaluation of Corrective Action Alternatives
Corrective Action Area II
Bennington, VT

FIGURE 3