Final Report

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# Appendix K: Multi-Benefit Well Array Technology Analysis

Project 1007 Feasibility Study
Minnesota Pollution Control Agency

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Figure 160. Groundwater Areas of Concern

# Acronyms and Abbreviations

| | |
|---|---|
| % | percent |
| AACE | Association for the Advancement of Cost Estimating International |
| AOC | area of concern |
| BCI | Building Cost Index |
| CAPEX | capital expenditure |
| CCI | Construction Cost Index |
| CDWSP | Conceptual Drinking Water Supply Plan |
| CIP | clean-in-place |
| CSM | Conceptual Site Model |
| EBCT | empty bed contact time |
| ENR | Engineering News-Record |
| EPA | United States Environmental Protection Agency |
| FS | Feasibility Study |
| ft | feet |
| ft/s | feet per second |
| GAC | granular activated carbon |
| gfd | gallons per square foot per day |
| gpm | gallons per minute |
| gpm/sf | gallons per minute per square foot |
| HALT | Hydrothermal Alkaline Treatment |
| HBV | Health-Based Value |
| HDD | horizontal directional drilling |
| HFPO-DA | hexafluoropropylene oxide-dimer acid |
| HI | Hazard Index |
| hr | hour |
| HRI | Health Risk Index |
| HRL | Health Risk Limit |
| HVAC | heating, ventilation, and air conditioning |
| IDW | investigation derived waste |
| IX | ion exchange |
| kWh | kilowatt hour |
| lbs | pounds |
| MBWA | Multi-Benefit Well Array |
| MCL | Maximum Contaminant Level |
| MCLG | Maximum Contaminant Level Goal |
| MDH | Minnesota Department of Health |
| MDNR | Minnesota Department of Natural Resources |
| mg/L | milligram per liter |
| MGD | million gallons per day |

| | |
|---|---|
| min | minute |
| MPCA | Minnesota Pollution Control Agency |
| NCP | National Contingency Plan |
| ND | non-detect |
| NF | nanofiltration |
| ng/L | nanograms per liter |
| O&M | operations & maintenance |
| ODS | Oakdale Disposal Site |
| OPEX | operating expenditure |
| ORP | oxidation reduction potential |
| PDC | Prairie du Chien (Aquifer) |
| PFAS | Per- and Polyfluoroalkyl Substances |
| PFBA | perfluorobutanoic acid |
| PFBS | perfluorobutane sulfonic acid |
| PFHxA | perfluorohexanoic acid |
| PFHxS | perfluorohexane sulfonic acid |
| PFNA | perfluorononanoic acid |
| PFOA | perfluorooctanoic acid |
| PFOS | perfluorooctane sulfonic Acid |
| PIIC | Prairie Island Indian Community |
| POETS | point of entry treatment system |
| ppt | part per trillion |
| psi | pounds per square inch |
| RO | reverse osmosis |
| RSSCT | rapid small-scale column test |
| SCWO | Supercritical Water Oxidation |
| sf | square foot |
| SLR | surface loading rate |
| SMCL | Secondary Maximum Contaminant Level |
| T&O | taste and odor |
| TDS | total dissolved solids |
| TOC | total organic carbon |
| WBS | Work Breakdown Structure |
| WCL | Washington County Landfill |
| WTP | water treatment plant |

# K1 Introduction

As part of the Project-1007 Feasibility Study (FS), a Multi-Benefit Well Array (MBWA) is proposed to decrease migration of a per- and polyfluoroalkyl substances (PFAS) groundwater plume within the East Metropolitan (East Metro) region of the Twin Cities. The MBWA would reduce plume migration by pumping contaminated groundwater and adjusting the hydraulic gradient of the groundwater and would simultaneously provide clean drinking water to affected communities and return excess water to the aquifer in a manner that inhibits PFAS migration. The concept of the MBWA was initially proposed in 2021 (Wood, 2021). While the MBWA was not incorporated into the 2021 Conceptual Drinking Water Supply Plan (CDWSP), it did provide an alternative drinking water supply for the Cities of Lake Elmo and Oakdale as opposed to the municipal supply wells proposed in the CDWSP. At the time that the 2021 report was published, the Conceptual Site Model (CSM) of PFAS impacts was not fully understood as the investigation stage of the FS was still in progress. The initial MBWA proposed in 2021 focused on impacts to the City of Lake Elmo resulting from PFAS migration from the Washington County Landfill (WCL) but did not focus on impacts from the former Oakdale Disposal Site (ODS). The purpose of this appendix is to expand on the initial idea of a MBWA and provide conceptual plans for the different alternatives proposed in Section 11 of this FS to provide a range of potential solutions that have varying costs and implementability.

This appendix evaluates:

- Drinking water demands
- The potential location of the extraction and injection wells
- Required piping to connect the conceptual MBWA to a municipal supply system.
- Water treatment alternatives that would provide for groundwater PFAS treatment in order to improve the long-term groundwater quality and drinking water supply for the Cities of Oakdale and Lake Elmo.

Three conceptual MBWA scenarios were considered as part of four remedial alternatives considered in this FS, specifically Alternatives 5, 6, 7, and 8. Each scenario was evaluated with an extraction well configuration, drinking water treatment plant, drinking water storage and distribution, and injection well configuration. These scenarios provide a conceptual framework for how a MBWA would be implemented in the East Metro; should a MBWA be selected as the remedial alternative, it is expected that further modifications would be required to integrate the remedial action into the affected communities' drinking water supply plans.

## K1.1 Alternatives/Scenarios

Historical contamination from industrial activities has resulted in widespread PFAS impacts throughout the drinking water aquifers of many communities in the East Metro of the Twin Cities. Source zones (WCL and ODS), communities, and relevant groundwater Areas of Concern (AOCs) are shown in Figure 160 of Appendix A. Eight remedial alternatives are proposed and evaluated in this FS, as described in Section 11 of the FS and evaluated in Sections 12 and 13 of the FS, to address PFAS migration through the East Metro, with alternatives providing various levels of treatment. Four of the proposed remedial alternatives would incorporate the concept of a MBWA as a remedial strategy. In a MBWA, water would be extracted from pumping wells for plume control. The extracted water would be treated to drinking water standards and a portion of it would be distributed to the community, replacing some or all consumer demand from the current municipal well arrays. The remaining water that exceeded drinking water demand would be injected downgradient of higher concentration areas to further improve plume control through hydraulic mounding.

Incorporation of a MBWA could be done either as a localized MBWA that only addresses impacts in a specific area of the Site and provides drinking water to a single community or a regional MBWA that addresses impacts across the entire Site with drinking water supply to both Oakdale and Lake Elmo with the possibility of expanding to additional communities if needed.

For example, a localized MBWA in City of Lake Elmo would extract water from Lake Elmo, provide drinking water only to Lake Elmo residents, and inject excess water around the City of Lake Elmo for plume control. Alternatively, a regional MBWA would address impacts across the Site and treated water would be supplied to water treatment plants in Lake Elmo and Oakdale with a shared injection well network. This could be adapted to meet future drinking water demands and provide drinking water to additional communities if needed (e.g. West Lakeland or the planned Prairie Island Indian Community [PIIC] development).

A localized or regional MBWA is proposed as part of the Site-wide remedial approach in four of the eight remedial alternatives, specifically Alternatives 5, 6, 7, and 8. In total, three conceptual scenarios are considered for the MBWA, named Scenarios 1 – 3 that are incorporated into the Site-wide alternatives. The Site-wide alternatives also address impacts in surface water, sediment, and the source areas. Scenarios are summarized in Table K.1. Proposed piping networks are given in Figure K.1 (Scenario 1), Figure K.2 (Scenario 2), and Figure K.3 (Scenario 3). More details on each alternative can be found in Section 11 of the FS. The total treatment volumes are based on the extraction well pumping rates required to meet the projected drinking water demand for each community, plus additional volume to provide groundwater injection for plume control. The volume of drinking water provided to the City of Lake Elmo would be the same between Scenarios 1-3, and the volume of drinking water provided to the City of Oakdale would be the same in Scenarios 1 and 2. Since all scenarios are designed to meet each community’s drinking water demand, the difference in total treatment volumes between scenarios is solely related to the volume of additional water treated that would be used for injection. Injection rates are expected to vary over the year based on changes in drinking water demand. If one of these MBWAs are pursued, additional analysis would be required to determine the implications of fluctuating demand on the injection rate and plume control.

Table K.1: MBWA Scenarios.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| FS Alternative | 8 | 7 | 5 & 6 |
| Scenario Figure | Figure K.1 | Figure K.2 | Figure K.3 |
| AOCs Addressed (1) | AOC 2 (WCL Bedrock Aquifers) | AOC 2 (WCL Bedrock Aquifers) | AOC 2 (WCL Bedrock Aquifers) |
| | AOC 4 (Downgradient ODS Bedrock Aquifers) | AOC 4 (Downgradient ODS Bedrock Aquifers) | AOC 4 (Downgradient ODS Bedrock Aquifers) |
| | AOC 7 (Raleigh Creek + Eagle Point Lake Groundwater) | AOC 7 (Raleigh Creek + Eagle Point Lake Groundwater) | - |
| | AOC 10 (West Lakeland Groundwater) | - | - |
| Total Treatment Volume | 10,800 gpm | 9,850 gpm | 5,130 gpm |
| Maximum Injection Rate (2) (gpm) | 7,000 | 6,000 | 3,500 |
| Impacted Areas Addressed | Oakdale, Lake Elmo, West Lakeland | Oakdale, Lake Elmo | Lake Elmo |
| Communities provided drinking water | Oakdale and Lake Elmo | Oakdale and Lake Elmo | Lake Elmo |
| Communities protected from further impacts | Northern Lake Elmo, Maplewood, Woodbury, Afton, Baytown | Northern Lake Elmo, Maplewood, Woodbury | Northern Lake Elmo, Woodbury |
| Number of extraction (include new vs. repurposed) | 13 new wells, 2 existing Oakdale supply wells | 10 new wells, 2 existing Oakdale supply wells | 8 new wells |
| Number of injection (include new vs. repurposed) | 6 new wells, 3 existing Oakdale supply wells | 4 new wells, 3 existing Oakdale supply wells | 5 new wells |

Legend: gpm = gallons per minute.

(1) AOCs are further described in **Section 7**.

(2) Maximum Injection Rate is calculated using average daily demand. When demand exceeds the average daily demand, injection rates would be lower. During low demand periods, injection rates could be higher, though field injection studies are required to verify maximum practical injection rate.

## K1.2 Potential Implementation Changes

It is important to note these conceptual scenarios have been developed to maximize groundwater plume capture. These scenarios are theoretical only and are intended to demonstrate how a MBWA could be implemented in a community. If a MBWA is chosen as the remedy, additional work would be needed to integrate a MBWA with the affected communities' drinking water supply plans, the specifics of which are discussed later on in this appendix. Additional changes may also be made to the network based on updates to the Conceptual Site Model and injection testing. The injection rates are based on injection capacity modeling. More injection wells may be required if the injection capacity is found to be less than the modeled rate. Alternatively, fewer wells could be utilized if the injection capacity is found to be higher than modeled.

The placement of wells and treatment plants were also determined for this evaluation based on potential land availability. In more developed areas, well locations were limited. In some areas, improved capture could be achieved with different well placement but this was determined to not be feasible due to lack of available property. Additionally, placement of the water treatment plants may need to be adjusted based on land availability which would impact the costs associated with the piping.

To spread the capital costs across a longer timeframe, implementation of each scenario could be phased such that drinking water treatment and supply are prioritized, followed by groundwater injection. The extraction wells and water treatment plants in the Cities of Lake Elmo and Oakdale could be constructed as separate phases as well. Subsequent phases could expand the system capacity with additional extraction and injection wells and associated pipelines located in Lake Elmo, Oakdale, Woodbury, and West Lakeland.

## K1.3 PFAS Current Drinking Water Regulations

Drinking water provided to communities would be treated to meet all applicable Federal and State drinking water standards. In April 2024, the United States Environmental Protection Agency (EPA) published final regulatory standards for six PFAS in drinking water (EPA, 2024). The standards include maximum contaminant levels (MCLs) for perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), and hexafluoropropylene oxide dimer acid (HFPO-DA) and its ammonium salts (referred to as “GenX” chemicals). PFAS mixtures containing two or more of PFHxS, PFNA, GenX, and perfluorobutane sulfonic acid (PFBS) are regulated using the Hazard Index (HI). However, as of the publication of this report the EPA has announced its intention to rescind the MCLs for PFHxS, PFNA, and Gen X as well as the HI; as this change has not been finalized, the MCLs are still used as reference values for the purposes of this study. EPA MCLs, as well as the non-enforceable maximum contaminant level goals (MCLGs) for regulated PFAS are presented in Table K.2.

Table K.2: EPA Drinking Water Standards for PFAS.

| Compound | Acronym | EPA MCL (ng/L) (1) | EPA MCLG |
|---|---|---|---|
| Perfluorooctanoic acid | PFOA | 4 | Zero |
| Perfluorooctane sulfonic acid | PFOS | 4 | Zero |
| Perfluorohexane sulfonic acid | PFHxS | 10 | 10 |
| Perfluorononanoic acid | PFNA | 10 | 10 |
| Hexafluoropropylene oxide-dimer acid and its ammonium salts | HFPO-DA / GenX | 10 | 10 |
| Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS | HI | 1 (unitless) Hazard Index | 1 (unitless) Hazard Index |

(1) ng/L = nanograms per liter, also known as parts per trillion (ppt).

The HI MCL is a dimensionless value calculated based on the concentrations of HFPO-DA, PFBS, PFNA, and PFHxS relative to PFAS-specific health-based water concentrations shown here as the denominators. The HI can result in value greater than 1 even if no individual compound is above the final MCL. For example, a water source that had a concentration of 5 ng/L for each of HFPO-DA, PFNA, and PFHxS and 1000 ppt of PFBS would be below each individual compound’s MCL, but would have an HI of 2, meaning the water would require further treatment prior to use as drinking water, even though none of the individual PFAS species are above the applicable MCL.

$$HI = \frac{[HFPO-DA]\, ng/L}{10\, ng/L} + \frac{[PFBS]\, ng/L}{2000\, ng/L} + \frac{[PFNA]\, ng/L}{10\, ng/L} + \frac{[PFHxS]\, ng/L}{10\, ng/L}$$

Minnesota-specific standards must also be considered, for both drinking water applications and for injection into groundwater. The Minnesota Department of Health (MDH) has set several categories of criteria for different PFAS species, including some species not currently regulated by EPA MCLs, namely perfluorobutanoic acid (PFBA) and perfluorohexanoic acid (PFHxA) (MDH, 2024). For groundwater, these include Health Risk Limits (HRLs), and Health-Based Values (HBVs) for different exposure durations. HRLs and Groundwater HBVs are both limits used to evaluate potential health risks to humans from exposures to a chemical and the most conservative exposure durations should be regarded as treatment goals. While HRLs have been formalized in Minnesota rules, HBVs have not yet been promulgated.

MDH has also developed a Health Risk Index (HRI) that calculates an additivity value for multiple PFAS. Additivity is considered for every health endpoint for which MDH has developed an HRL or HBV. For PFAS, potential health endpoints are the liver system, immune system, developmental, thyroid (specifically the endocrine mediated effect on the thyroid), and cancer. Additivity is further evaluated based on exposure duration, with durations specified as Acute, Short-term, Subchronic, Chronic, and Cancer. In the case of PFAS species, regulated by MDH, no species have Acute standards, and all Short-term, Subchronic, and Chronic values are the same with a compound. The Cancer exposure values are used for calculating the cancer HRI for compounds with a cancer health endpoint (PFOA and PFOS).

Additivity is specifically calculated for each endpoint, shown below, and the highest value is used. EPA additivity (i.e. HI) is also applicable but would not be higher than the MDH additivity unless the water sample contains HFPO-DA or PFNA. Note that all values are in ng/L and that, because the EPA MCL for PFHxS is lower (10 ng/L) than the MDH HRL (47 ng/L), the EPA MCL is used for calculations with PFHxS.

$$Developmental\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L} + \frac{[PFHxA]\ ng/L}{200\ ng/L}$$

$$Liver\ System\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L} + \frac{[PFHxS]\ ng/L}{10\ ng/L} + \frac{[PFBA]\ ng/L}{7{,}000\ ng/L}$$

$$Immune\ System\ HRI = \frac{[PFOA]\ ng/L}{0.24\ ng/L} + \frac{[PFOS]\ ng/L}{2.3\ ng/L}$$

$$Thyroid\ HRI = \frac{[PFHxA]\ ng/L}{200\ ng/L} + \frac{[PFHxS]\ ng/L}{10\ ng/L} + \frac{[PFBA]\ ng/L}{7{,}000\ ng/L} + \frac{[PFBS]\ ng/L}{100\ ng/L}$$

$$Cancer\ HRI = \frac{[PFOA]\ ng/L}{0.0079\ ng/L} + \frac{[PFOS]\ ng/L}{7.6\ ng/L}$$

Similar to the HI, exceedance of a calculated HRI may occur without exceedance of any individual species. For example, for the Thyroid HRI, a PFHxA concentration of 100 ng/L, a PFHxS concentration of 5 ng/L, a PFBA concentration of 3,500 ng/L, and a PFBS concentrations of 50 ng/L would be below the regulatory limit of each individual compound, but the HRI would be 2. Note that in this scenario, as the compounds used for HRIs are different than the HI, and due to the significantly lower MDH HRL for PFBS, the HI would only be 0.525. HRIs do not regulate PFNA or HFPO-DA but are more conservative for PFBS and also regulate PFBA and PFHxA. Thus, water with higher concentrations of PFBA, PFBS, and PFHxA are more likely to exceed an HRI than the HI.

Table K.3: MDH Groundwater Standards for PFAS.

| Compound | MDH 2024 Groundwater HRLs (ng/L) | MDH 2024 Groundwater HBVs (ng/L) | MDH 2024 Cancer HBVs (ng/L) |
|---|---|---|---|
| PFBA | 7,000 | - | - |
| PFOA | 35 | *0.24* | *0.0079* |
| PFBS | 100 | - | - |
| PFHxA | 200 | - | - |
| PFHxS | 47 | - | - |
| PFOS | 300 | 2.3 | 7.6 |
| HFPO-DA (Gen-X) | 10 | - | - |

*Italicized* values indicate a concentration below the method detection limit at the time of writing this report. Detection limits for PFAS as of April 2025 are on the order of 1-2 ng/L.

The MCLGs set by the EPA for PFOS and PFOA are zero, thus the FS treatment targets for groundwater for PFOS and PFOA compounds have been set to non-detect. For the remainder of compounds, treatment targets are set to the lowest regulatory standard values, as summarized in Table K.4. As previously discussed, calculation of HI and HRIs is critical because both the HI and HRI can be exceeded without any individual species exceeding a regulatory limit. At this time, treatment targets below regulatory standards are not proposed for individual compounds, as it is expected that the low treatment targets for PFOA and PFOS would exceed the non-detect treatment goal prior to indices calculated with shorter-chain PFAS. Additionally, in practice, detection of PFOA or PFOS would simultaneously trigger a media changeout based on the individual treatment target of PFOA and PFOS as well as most HRIs, given the current detection limits of PFOA and PFOS. Should PFHxA, PFHxS, PFBS, and PFBA be observed in concentrations that would cause a treated effluent to exceed the Thyroid HRI, treatment targets for these four compounds should be reconsidered. At this time, however, these 4 compounds are not expected to be triggers for changeouts or regulatory exceedances, thus treatment targets lower than the lowest applicable regulatory standard are not proposed.

Table K.4: Treatment Targets for Groundwater to be Used in Drinking Water Distribution of Aquifer Injection.

| Compound | Lowest Standard | Lowest Standard Value | Treatment Target |
|---|---|---|---|
| PFOA | MDH Cancer HBV | < 0.0079 ng/L | Non-Detect |
| PFOS | MDH Groundwater HBV | < 2.3 ng/L | Non-Detect |
| PFHxS | EPA MCL | < 10 ng/L | < 10 ng/L |
| HFPO-DA | EPA MCL | < 10 ng/L | < 10 ng/L |
| PFNA | EPA MCL | < 10 ng/L | < 10 ng/L |
| PFBS | MDH HRL | < 100 ng/L | < 100 ng/L |
| PFHxA | MDH HRL | < 200 ng/L | < 200 ng/L |
| PFBA | MDH HRL | < 7000 ng/L | < 7000 ng/L |
| HI (1) | EPA MCL | < 1 | < 1 |
| HRI (1) | MDH | < 1 | < 1 |

(1) Calculation of HI and HRI must be performed whenever speciated PFAS testing is performed to verify water is below both indices. HI and HRI can be exceeded even when individual compounds are not regulatory values.

# K2 Drinking Water Needs/Demands

Projected drinking water demands for Oakdale and Lake Elmo were based off projections presented in the CDWSP and were used as the basis of evaluation for this FS. The 2020 demand and the projected 2040 demand for Oakdale and Lake Elmo in gallons per minute (gpm) are presented in Table K.5. Information on existing community infrastructure and capacity is summarized in the below sections. Community summaries are based on information provided in the CDWSP; changes to community infrastructure and planned updates since the publishing of the CDWSP may not be fully reflected here.

Table K.5: Existing and Projected Drinking Water Demand for Oakdale and Lake Elmo.

| Parameter | Unit | Oakdale | | Lake Elmo | |
|---|---|---|---|---|---|
| | | 2020 | 2040 (1) | 2020 | 2040 (1) |
| Population | - | 28,500 | 36,000 | 11,020 | 22,304 |
| Population Served | - | 30,360 | 36,740 | 7,300 | 21,165 |
| Avg Daily Demand | gpm | 1,750 | 2,130 | 540 | 1,600 |
| Max Daily Demand | gpm | 3,990 | 4,860 | 1,600 | 4,330 |

(1) Projections for 2040 are based on the CDWSP.

## K2.1 Oakdale Capacity and Existing Infrastructure

Oakdale currently has PFAS impacts to its municipal water system, which serves nearly all of their community. The City of Oakdale is completing a water systems study that will inform future needs. Based on the CDWSP, new municipal wells are not required from a capacity perspective to meet Oakdale's 2040 maximum daily demand and firm capacity requirements, though additional wells could be required to meet future maximum daily demand. However, based on historical sampling conducted at municipal and non-municipal wells in Oakdale, any additional municipal wells brought online, existing or new, will require PFAS treatment. Currently 96% of the city's population is served by the existing municipal water distribution system, thus, no water main extensions were proposed previously in the CDWSP.

Oakdale's municipal water system consists of seven active municipal wells (Wells 1, 2, 3, 5, 7, 9, and 10). Well 6 was taken out of service due to high iron and manganese levels but could be put back into service with treatment, and Well 8 was taken out of service due to PFAS impacts. Well 8 is also the farthest well away from the existing treatment facility and the closest to a source area (ODS). Oakdale is currently not using Wells 1, 2, and 7, as those wells are out of compliance with EPA Drinking Water MCL standards and are not receiving treatment. For this feasibility study, these three wells were selected to be converted into injection wells for Scenario 1 and 2. The loss in capacity would be addressed by additional extraction wells which would also improve the capture of PFAS in this area.

Oakdale has four water towers for water supply storage. Oakdale's existing treatment facility has 2,400 gpm (3.4 million gallons per day [MGD]) of capacity and currently treats Wells 5 and 9 with granular activated carbon (GAC). The CDWSP notes that Wells 3 and 10 are located in the northern region of the city and do not require treatment based on their HI values, however now that PFAS levels are above MDH standards, these wells require treatment. With additional treatment required, Oakdale is expecting to expand the capacity of their existing water treatment plant and determine if existing wells should be piped to this water treatment plant or if new wells should be installed closer to the plant to reduce costs associated with piping. The on-going water systems study by the City of Oakdale is exploring drinking water demands and treatment needs, thus the assumptions made for this feasibility study are expected to change.

## K2.2 Lake Elmo Capacity and Existing Infrastructure

Lake Elmo currently has PFAS impacts in its municipal water system, which serves a portion of the community, while the rest of the community currently relies on private wells for drinking water. Many private wells are PFAS-impacted and are treated with point of entry treatment systems (POETSs); additional homes are expected to be connected to municipal supply in the future. In addition, a portion of the community and one of their municipal wells lie within an area which is subject to Court-ordered aquifer use restrictions within a 5-mile radius of White Bear Lake. Additional discussion of this Court Order can be found in Section 12 of the FS. In addition to information in the CDWSP, The City conducted studies of the water system, supply, and capacity in 2024, which were used in this appendix.

Lake Elmo has a municipal water system consisting of three active wells (Wells 2, 4, and 5). Previously, there were two additional wells, Wells 1 and 3; however, sample data from Well 3 indicated the well was contaminated with PFAS and was never equipped or placed into service. Well 1 was a multi-aquifer well that was taken out of service due to PFAS impacts. Well 2 has also been impacted by PFAS and the City has recently evaluated temporary and permanent treatment options until alternative water supply sources are available. The City intends to construct new production wells (Wells 6, 7, and 8) with planned locations to the south growth area. Recent studies by the City of Lake Elmo identified potential water treatment plant options to meet the 2040 projected demand.

Currently, Lake Elmo has two operating water storage tanks. An additional 1-million-gallon water storage tank (Tank 3) may be installed in the southeastern area to help the city meet increasing water demands and meet storage requirements. The wells in the northeastern part of the city are required to maintain proper pressures in the drinking water distribution system. Long term, the city is considering constructing two water treatment plants, one in the south to treat the planned wells and one in the northeast to treat Wells 2, 4, and 5.

## K2.3 West Lakeland Township Existing Infrastructure

As part of the CDWSP, surveys were sent to West Lakeland Township and at the time of the survey, residents preferred to remain on private wells as opposed to transferring to municipal supply. Many homes have POETSs and additional POETSs are in the process of being installed based on updated PFAS standards. While it is unknown if public supply will be installed in the future, one of the MBWA scenarios and multiple FS alternatives include installation of extraction wells as a potential remedial action in West Lakeland Township. As such, modeling efforts have been made to ensure groundwater extraction does not significantly impact water levels within private wells.

## K2.4 Prairie Island Indian Community (PIIC) Capacity and Existing Infrastructure

PIIC, which is currently located in Goodhue County, Minnesota, owns 111 acres of undeveloped land in West Lakeland Township in Washington County, MN on the northeast corner of Manning Avenue and Interstate-94. The property in West Lakeland Township is intended to be a housing development. PIIC has submitted an initial site plan indicating a proposed 80 residential lots and 11.67 acres for commercial development. One existing irrigation well on the property has a 12-inch casing pipe and an estimated capacity between 600-800 gpm (0.86 – 1.15 MGD). Based on these details, the estimated future demand for PIIC is approximately 200,000 gpd (139 gpm). At this time, providing water to PIIC is not part of the conceptual MBWA plans but could be added in the future. Communications should remain open to ensure future remedial designs could incorporate a remedy at PIIC.

## K2.5 2050 Projections

At the outset of this project, 2040 population projections and corresponding drinking water demand projections were the most current projections available. In December 2024, the Metropolitan Council released initial 2050 demand estimates for the Cities of Lake Elmo and Oakdale as part of the White Bear Lake Area Comprehensive Plan. Initial demand projections are summarized in Table K.6. Due to the timing of these updated projections, it is outside the scope of this FS to incorporate these demand projections. However, while proposed treatment capacity in the MBWA scenarios may be unable to meet the 2050 demand, pumping rates at current wells could be increased and additional wells could be added to the well array design as needed. A phased approach with sufficient room for expansion of treatment capacity would allow for construction of drinking water plants that meet the 2040 projected demand with the ability add additional treatment trains in the future to meet 2050 or ultimate projected demands. This would avoid the installation of excess treatment capacity that is not needed for 15-20 years in the future, saving costs now and allowing more prudent expenditure of funds. While not considered in these initial cost estimates, should full-scale design proceed, modeling efforts would account for the potential for increased treatment capacity in the future and ensure that piping and other components (e.g. excess control panel and electrical capacity) throughout the plant could handle increased treatment flowrates. As such, projected 2050 demands are not discussed further in this appendix.

Table K.6: Metropolitan Council 2050 Projected Drinking Water Demand for Oakdale and Lake Elmo.

| Projected Demand | Units | Oakdale | | | Lake Elmo | | |
|---|---|---|---|---|---|---|---|
| | | Low | Mid | High | Low | Mid | High |
| 2050 Average Daily | gpm | 1,967 | 2,314 | 2,661 | 1,182 | 1,700 | 2,303 |
| 2050 Maximum Daily | gpm | 4,505 | 5,300 | 6,095 | 4,419 | 6,359 | 8,614 |
| Ultimate Average Daily | gpm | 1,967 | 2,314 | 2,661 | 1,347 | 1,938 | 2,626 |
| Ultimate Maximum Daily | gpm | 4,505 | 5,300 | 6,095 | 5,038 | 7,249 | 9,820 |

# K3 Well Configuration

The conceptual well configurations presented in this FS for Alternatives 5-8 were developed through particle tracking and modeled aquifer drawdown elevation analysis. A combination of extraction and injection wells are proposed to increase plume capture and reduce downgradient PFAS migration. The extraction wells, installed in areas with high concentrations of PFAS, remove groundwater which is then treated to remove the PFAS. Treated water is then split between municipal supply and injection back into the Jordan Aquifer. Injection of treated water increases the groundwater elevations downgradient of the locations with high PFAS concentrations, mounding the groundwater and providing additional hydraulic control to reduce downgradient plume migration. Injection does not occur outside the plume extent because of how widespread PFAS impacts across the Site. Instead, the focus is on the containing higher PFAS concentrations. Generally, areas greater than 75 ng/L PFOS and/or PFOA were targeted for extraction while injection generally occurs in areas with no PFOS and/or PFOA detections up to approximately 15 ng/L. There are some exceptions in order to utilize existing infrastructure and based on access considerations, which could be modified during full-scale design if one of the proposed alternatives were to be selected. The following summarizes the efforts to develop the well configurations presented within this FS.

Two modeled configurations were used as starting points in MBWA development. The first configuration represents current supply well pumping conditions without any remedial actions. The wells and pumping rates selected to represent the current supply well network were identified based on annual extraction rates obtained from water appropriation permitting documents (MDNR, 2022). The second configuration evaluated was the draft 2021 MBWA developed by WSP (Wood, 2021), referred to as WSP/Wood in this document. This second configuration primarily focuses on impacts downgradient from the WCL within the City of Lake Elmo and does not address groundwater impacts surrounding and downgradient of ODS, groundwater impacts resulting from infiltration from Raleigh Creek and Eagle Point Lake, or groundwater impacts within West Lakeland.

Both MBWA configurations were adapted into the AECOM steady-state groundwater flow model to run predictive simulations of PFAS plume migration under each configuration. Further details can be found in the AECOM Groundwater Model Report (AECOM, 2024). Calibrated groundwater flow fields are used for particle tracking to simulate the future movement of particles within and between hydrogeologic units over a specified time period, with the particles serving as a proxy for PFAS molecules. As part of the particle tracking process, areas and target aquifers were identified from which particles were released. The particle release areas for the Project 1007 model were selected to represent elevated PFAS areas as indicated by aquifer-specific plume maps and do not represent the extent of all PFAS impacts in groundwater. The tracking was simulated for 50-year (and when necessary 100-year) time intervals. Depending on the configuration run, particles were released from the three primary impacted drinking water aquifers: the St. Peter Aquifer, the Prairie du Chien (PDC) Aquifer, and the Jordan Aquifer (AECOM, 2024). The particle tracking results under the current pumping conditions served as a baseline assessment of plume migration without the MBWA implementation. With no changes in pumping conditions, PFAS impacts were modeled to continue to migrate towards municipal supply wells in Woodbury, spread westward from Oakdale toward Maplewood, spread eastward from West Lakeland towards the St. Croix River, and migrate vertically into deeper unimpacted aquifers in all communities. These scenarios are shown in Figure K.4 (first encountered bedrock and Prairie du Chien Aquifer) and Figure K.5 (Jordan Aquifer).

The WSP/Wood MBWA configuration incorporated strategically placed extraction and injection wells focused on impacted areas downgradient of the WCL within Lake Elmo and does not address impacts in Oakdale or West Lakeland. As a result, impacts in these areas are shown to continue to spread south-southwest from Oakdale, east from West Lakeland, and into deeper aquifers. Additionally, known impacts southwest of Eagle Point Lake are shown to continue to migrate south toward Woodbury. These scenarios are shown in Figure K.6 (Prairie du Chien Aquifer) and Figure K.7 (Jordan Aquifer).

Subsequent MBWA configuration iterations were evaluated with specific objectives. As extraction well locations significantly alter groundwater flow regimes and plume capture, consideration was given to the horizontal and vertical placement of extraction wells. Three variations in aquifer screening were evaluated: multi-aquifer screening in the PDC and Jordan Aquifers, screening in the PDC Aquifer, and screening in the Jordan Aquifer. Pumping rates were selected to not exceed allowable drawdown (50% of available head). Additionally, the total volume of water extracted, as determined by the number of extraction wells and associated pumping rates, was checked to ensure sufficient volume to meet the demand of injection wells placed to facilitate plume capture and control in relation to extraction wells and with consideration of the maximum allowable injection capacity as determined by an injection capacity study of the PDC and Jordan Aquifers (Shandilya, 2021). Additionally, the net extracted water was monitored to ensure sufficient volume to meet the projected 2040 demand by the cities of Lake Elmo and Oakdale, as provided below and reported in the CDWSP (MPCA, 2021). For all well placements, efforts were made to repurpose the existing supply well network where possible and to identify property access constraints.

Configuration iterations were assessed with several key model outputs. Particle tracking was used as an assessment of plume capture from impacted areas over a 50-year operation period of the proposed MBWA. Drawdown contour maps aided in injection well placement and groundwater elevation contour maps informed understanding of general groundwater flow regimes.

Configurations, purpose, modifications from previous iterations, results, and corresponding figures are summarized in Table K.7. Initial configurations sought to determine the key driving factors of capture and their sensitivity to model adjustments. Following configurations prioritized optimal capture based on well placement. For clarity, these incremental changes are not discussed. Scenario 1 is the finalized configuration that captures impacts from all release areas in the PDC and Jordan aquifers. Scenarios 2 and 3 were developed from Scenario 1 to provide less complex and lower cost alternatives for evaluation as part of this FS. Table K.7 is intended to provide a summary of the larger changes in the iterative process to show how the well configuration was developed.

For the final configurations used in the appendix (Scenarios 1-3), individual well attributes for both extraction and injection wells are summarized in the following tables:

- Scenario 1: Table K.8
- Scenario 2: Table K.9
- Scenario 3: Table K.10

Table K.7: Development and Modification of Well Configurations.

| Configuration Number | Purpose | Modifications from Previous Iteration | Results | Figure |
|---|---|---|---|---|
| 1 (1) | Supplement the WSP/Wood configuration with additional wells to address impacts in Oakdale and West Lakeland. | Additional extraction and injection wells placed in Oakdale and West Lakeland. | Failed to achieve capture of particles released from two locations within the Jordan. The number of extraction wells was found to be excessive. Simulated drawdown was calculated to exceed the 50% available head threshold at several extraction wells. | Figure K.8<br>Figure K.9 |
| 2 (1) | Compare capture efficacy of extraction wells screened across the PDC and Jordan versus extraction wells screened in the Jordan. | Rerun configuration with wells screened only in the Jordan. | Capture did not vary significantly based on the screened aquifer(s), suggesting either approach to suffice for plume control. | Figure K.10<br>Figure K.11 |
| 3 (1) | Determine the impact of injection wells on capture. | All injection wells removed from network and all extraction wells screened in the Jordan. | Capture did not vary significantly based on the screened aquifer(s), suggesting either approach to suffice for plume control. | Figure K.12<br>Figure K.13 |
| 4 (1) | Address impacts released from areas that were not captured by previous extraction well network and refine pumping rates or extraction well placement to prevent excessive drawdown. | Injection wells placed per Configuration 3 results, redundant extraction wells removed, and various extraction wells relocated. | Failed to fully capture particles released from the Raleigh Creek area from PDC. | Figure K.14<br>Figure K.15 |
| 5 (1) | Compare capture efficacy of extraction wells screened in the PDC versus the Jordan (as modeled in Configuration 4). | Rerun configuration with wells screened only in the PDC. | Failed to capture particles release from ODS and Raleigh Creek areas from the Prairie du Chien and allows spread of impacts within PDC from these areas. | Figure K.16<br>Figure K.17 |
| 6 (1) | Adjust well placement to address property access and existing well network considerations. | Align all wells with property access considerations and, where appropriate, with existing Oakdale municipal wells and proposed Lake Elmo municipal wells. | Failed to capture WCL impacts released from the Jordan but was otherwise successful. | Figure K.18<br>Figure K.19 |
| Scenario 1 (1) | Optimize plume control and capture with the same considerations for property access and municipal wells based on the results of Configuration 6. Assess reducing the number of extraction wells | Adjust pumping rates and well placement downgradient of WCL. Remove excess extraction wells. | Successfully captured all impacts from releases in both the PDC and the Jordan. | Figure K.20<br>Figure K.21 |
| Scenario 2 | Optimize plume control and capture under a reduced system extent that does not include West Lakeland. | Using the finalized Scenario 1 configuration as a base, extraction and injection wells were removed from West Lakeland. Adjustments were made to maintain water balance. | Successfully captured ODS, WCL, Raleigh Creek, and Eagle Point Lake impacts from releases in both the PDC and the Jordan. Impacts in West Lakeland were not captured. | Figure K.22<br>Figure K.23 |
| Scenario 3 | Optimize plume control and capture under a reduced system extent that does not include Oakdale or West Lakeland. | Using the finalized Scenario 1 configuration as a base, extraction and injection wells were removed from Oakdale and West Lakeland. Adjustments were made to maintain water balance. | Successfully captured WCL, Raleigh Creek, and Eagle Point Lake impacts from releases in both the PDC and the Jordan. ODS impacts were partially captured by Oakdale supply wells. Impacts in West Lakeland were not captured. | Figure K.24<br>Figure K.25<br>Figure K.26<br>Figure K.27 |

Notes:

(1) Configurations 1-6 were run in a previous version of the groundwater model and were not re-evaluated following model adjustments.

(2) Scenario 1 in this appendix is the final MBWA Scenario.

Table K.8: Scenario 1 Well Attributes.

| Well ID | Max Pumping Rate (gpm) | Approximate Horsepower | **Well Bottom** (Depth Below **Ground) (ft)** | Downstream Pressure (psi) | Well Status |
|---|---|---|---|---|---|
| **Injection Wells** | | | | | |
| IR-4-m2 | 800 | — | 500 | — | New |
| IR-5-m | 550 | — | 458-542 | — | Existing |
| IR-6-m | 700 | — | 501-581 | — | Existing |
| IR-10-m | 900 | — | 467-563 | — | Existing |
| IR-19 | 600 | — | 290 | — | New |
| IR-15 | 900 | — | 500 | — | New |
| IR-11-m | 750 | — | 500 | — | New |
| IR-1-rev-m | 900 | — | 340 | — | New |
| IR-2-rev-1-m | 900 | — | 320 | — | New |
| **Extraction Wells** | | | | | |
| ER-9-m2 | 800 | 170 | 500 | 57 | New |
| 127287 - Oakdale 5 | 950 | Existing Well | 436-520 | 53 | Existing |
| 611059 - Oakdale 9 | 950 | Existing Well | 441-515 | 53 | Existing |
| ER-13-m2 | 850 | 170 | 500 | 39 | New |
| ER-10 | 750 | 160 | 380 | 93 | New |
| ER-11-m | 700 | 140 | 380 | 73 | New |
| E-18 | 700 | 150 | 300 | 113 | New |
| E-10-m | 400 | 100 | 340 | 110 | New |
| E-9-m | 400 | 100 | 340 | 106 | New |
| ER-3-m | 600 | 120 | 380 | 93 | New |
| LE_6A-m | 700 | 120 | 440 | 62 | New |
| LE_7A-m | 700 | 125 | 440 | 76 | New |
| ER-6-m2 | 800 | 165 | 280 | 143 | New |
| ER-7-m | 800 | 175 | 300 | 147 | New |
| ER-8-m | 500 | 110 | 300 | 147 | New |

Table K.9: Scenario 2 Well Attributes.

| Well ID | Max Pumping Rate (gpm) | Approximate Horsepower | **Well Bottom** (Depth Below **Ground) (ft)** | Downstream Pressure (psi) | Well Status |
|---|---|---|---|---|---|
| **Injection Wells** | | | | | |
| IR-4-m2 | 700 | — | 500 | — | New |
| IR-5-m | 550 | — | 458-542 | — | Existing |
| IR-6-m | 700 | — | 501-581 | — | Existing |
| IR-10-m | 850 | — | 467-563 | — | Existing |
| IR-19 | 550 | — | 290 | — | New |
| IR-15 | 900 | — | 500 | — | New |
| IR-11-m | 700 | — | 500 | — | New |
| **Extraction Wells** | | | | | |
| ER-9-m2 | 950 | 205 | 500 | 60 | New |
| 127287 - Oakdale 5 | 550 | Existing Well | 436-520 | 54 | Existing |
| 611059 - Oakdale 9 | 550 | Existing Well | 441-515 | 53 | Existing |
| ER-13-m2 | 650 | 170 | 500 | 39 | New |
| ER-10 | 750 | 170 | 380 | 110 | New |
| ER-11-m | 700 | 150 | 380 | 87 | New |
| E-18 | 675 | 160 | 300 | 125 | New |
| E-10-m | 400 | 80 | 340 | 105 | New |
| E-9-m | 400 | 80 | 340 | 101 | New |
| ER-3-m | 600 | 120 | 380 | 91 | New |
| LE_6A-m | 800 | 120 | 440 | 62 | New |
| LE_7A-m | 800 | 125 | 440 | 75 | New |

Table K.10: Scenario 3 Well Attributes.

| Well ID | Max Pumping Rate (gpm) | Approximate Horsepower | **Well Bottom (Depth Below Ground) (ft)** | Downstream Pressure (psi) | Well Status |
|---|---|---|---|---|---|
| **Injection Wells** | | | | | |
| IR-10-m-2 | 550 | — | 540 | — | New |
| IR-17 | 800 | — | 440 | — | New |
| IR-19 | 500 | — | 290 | — | New |
| IR-15 | 900 | — | 500 | — | New |
| IR-11-m | 750 | — | 500 | — | New |
| **Extraction Wells** | | | | | |
| ER-10 | 750 | 155 | 380 | 87 | New |
| ER-11-m | 700 | 135 | 380 | 64 | New |
| E-18 | 675 | 140 | 300 | 102 | New |
| E-10-m | 400 | 80 | 340 | 102 | New |
| E-9-m | 400 | 80 | 340 | 97 | New |
| ER-3-m | 600 | 120 | 380 | 86 | New |
| LE_6A-m | 800 | 115 | 440 | 54 | New |
| LE_7A-m | 800 | 120 | 440 | 68 | New |

# K4 Water Treatment Options

Five treatment train options were evaluated for their ability to meet drinking water quality requirements for the proposed WTPs in Lake Elmo and Oakdale. Each option would include pretreatment for iron and manganese, and in locations where water hardness is high, pre-treatment by water softening or pH adjustment may be necessary to mitigate potential scaling within the treatment system. Five treatment trains were evaluated for the treatment of PFAS to compare costs and treatment efficiencies, especially if lower treatment targets were identified in the future. GAC is a process step for all treatment trains; however, in some of them, GAC is used as the primary method for PFAS removal while in others, GAC is used as a pretreatment for or in parallel with other technologies such as high pressure semi-permeable membranes (nanofiltration [NF] or reverse osmosis [RO] membranes) or ion exchange (IX) resin. Treatment trains considered are summarized below:

- Option A: GAC would be used to remove PFAS from extracted groundwater. The full treated water volume would pass through GAC vessels, and PFAS removal would only be accomplished with GAC.
- Option B: Drinking water would be treated using a combination of GAC and NF/RO high pressure membranes. Flow would be split between GAC and NF/RO treatment processes. The NF/RO system removes short-chain PFAS from the flow from that train in addition to long-chain PFAS. Treated flow from the GAC would be blended with treated flow (membrane permeate) from the NF/RO system to decrease the concentration of short-chain PFAS in the distributed water. NF/RO membranes would also provide softened water as an added benefit. Membrane permeate would be remineralized with caustic soda or lime prior to blending the permeate and treated GAC effluent.
- Option C: GAC would be used to remove long-chain PFAS from extracted groundwater, with the full treated water volume being treated by GAC. A portion of the treated GAC effluent would be further treated with NF/RO high pressure membranes to remove short-chain PFAS, then be

reblended with the portion of GAC effluent that did not undergo additional treatment to result in decreased short-chain PFAS in the distributed water. Similar to Option B, finished effluent water would be softened as a result of membrane treatment, and membrane permeate would be remineralized with caustic soda or lime prior to final blending.

- Option D: GAC would be used to remove long-chain PFAS from extracted groundwater, with the full treated water volume treated by GAC. The entire GAC effluent would then be polished by IX resin to remove short-chain PFAS. GAC vessels would be run as lead/lag followed by a single IX polishing vessel.
- Option E: GAC would be used as a pretreatment for the full treated water volume to remove TOC from extracted groundwater as well as some long-chain PFAS. The GAC effluent would then be treated by IX resin to remove the remaining long-chain PFAS and some short-chain PFAS. GAC vessels would be run as a single sacrificial vessel, followed by two IX vessels operated in lead/lag configuration.

Each Option A to E assumes that a new WTP would be constructed for both of the Cities of Lake Elmo and Oakdale for the purpose of cost estimating. The WTP at Oakdale may be able to be expanded or retrofitted depending on the final remedial alternative selected. This would be evaluated at that time. Each WTP would be housed within a treatment building including all process equipment, process piping, electrical equipment, plumbing, and heating, ventilation, and air conditioning (HVAC) equipment. The details of the specific treatment process equipment and configurations are presented herein.

Design parameters for the system design parameters relating to GAC and IX are based on rapid small-scale column tests (RSSCTs) and pretreatment studies conducted with Site-specific water that is representative of the PFAS concentrations and water chemistry of what would be extracted by the MBWA. These results are presented in Appendix H (Groundwater Treatability Study for PFAS Treatment for Project 1007 Bench-Scale Study Report). Additional discussions with the communities will also determine their preferred treatment options, especially with regards to the removal of short-chain PFAS. These conversations are also crucial in tying this MBWA plan into the existing infrastructure. While GAC and IX are the only adsorbents considered in this appendix, other adsorbents could be considered in the future if performance is found to be superior to GAC or IX. For example, novel adsorbents such as DEXSORB® by Cyclopure are currently approved for drinking water use, and ongoing research and development is expected to bring new adsorbents to market. Additionally, treatment technologies that are currently not approved for drinking water treatment such as foam fractionation may be approved for drinking water treatment in the future and could greatly reduce the GAC and IX usage. These technologies are discussed further in Technology Screening in Section 9 of the FS and Appendix D (Remedial Technology and Action Screening: Detailed Descriptions and Analysis).

## K4.1 General Treatment Plant Operations

### K4.1.1 Water Quality/Treatment Needs

Significant Site investigation was conducted as part of this FS. Comprehensive results are available in the CSM in Section 5 and in Appendix C (Project 1007 Remedial Investigation Report). Water quality data from monitoring wells located closest to the proposed extraction wells were used to estimate influent to each WTP by assuming blending of water from all applicable extraction wells. The results of the analysis were evaluated for each scenario to determine the estimated blended influent loads and concentrations to the proposed water treatment plants for both Lake Elmo and Oakdale. The blended flows and PFAS concentrations to each water treatment plant are presented in Table K.11 as well as applicable PFAS standards. Table K.12 provides other water quality parameters including iron, manganese, and total hardness along with the EPA's non-enforceable National Secondary Drinking Water Regulations. The presented standards were used as the treatment objectives for the proposed treatment options.

Table K.11: MBWA PFAS Water Quality Parameters.

| **Location** | Pumping Rates | PFBA | PFOA | PFOS | PFBS | PFHxA | PFHxS | PFNA | HFPO-DA | Hazard Index (1) | MDH HRIs (2) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Developmental | Liver System | Immune System | Thyroid | Cancer |
| Units: | gpm | ppt | ppt | ppt | ppt | ppt | ppt | ppt | ppt | - | - | - | - | - | - |
| EPA Limit: | - | - | 4 | 4 | 2000 | - | 10 | 10 | 10 | 1 | - | - | - | - | - |
| Relevant MN Standard | - | 7,000 | 0.0079 | 2.3 | 100 | 200 | 47 | - | 10 | - | 1 | 1 | 1 | 1 | 1 |
| Treatment Targets (3) | - | 7,000 | ND (4) | ND | 100 | 200 | 10 | 10 | 10 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 |
| Scenario 1 – Blended Raw Water | | | | | | | | | | | | | | | |
| Lake Elmo WTP | 5,650 | 1,171 | 343 (5) | 423 | 28 | 82 | 55 | 1.6 | ND | 6.32 | 1,610 | 1,620 | 1,610 | 6.36 | 43,470 |
| Oakdale WTP | 5,150 | 5,541 | 545 | 440 | 19 | 127 | 34 | 1.6 | ND | 3.95 | 2,460 | 2,470 | 2,460 | 5.02 | 69,050 |
| Scenario 2 – Blended Raw Water | | | | | | | | | | | | | | | |
| Lake Elmo WTP | 6,150 | 5,489 | 650 | 462 | 36 | 167 | 68 | 1.7 | ND | 7.74 | 2,910 | 2,920 | 2,910 | 6.36 | 82,340 |
| Oakdale WTP | 3,700 | 1,368 | 369 | 600 | 20 | 70 | 40 | 2 | ND | 4.65 | 1,800 | 1,800 | 1,800 | 5.02 | 46,790 |
| Scenario 3 – Blended Raw Water | | | | | | | | | | | | | | | |
| Lake Elmo WTP | 5,125 | 5,565 | 633 | 431 | 34 | 163 | 63 | 1.64 | ND | 7.21 | 2,830 | 2,830 | 2,820 | 8.25 | 80,180 |

(1) PFBS, PFHxS, PFNA, and HFPO-DA are included in the Hazard Index (HI) calculation. See **Section 1.3** (PFAS Current Drinking Water Regulations) for more details on the HI calculation.

(2) See **Section 1.2** for more details on the calculation of individual HRIs.

(3) Note: HRIs and HI can be exceeded even if individual compound treatment targets are achieved. Calculation of HRIs and HI are critical to maintain compliance. In practice, it is expected that PFOA and PFOS being observed above ND would be the trigger for media changeouts. However, if PFHxA, PFHxS, PFBA, and PFBS all be observed in treated water samples, the Thyroid HRI could be exceeded. As treatment is expected to reduce the Thyroid HRI to <1, lower treatment targets for PFHxA, PFHxS, PFBA, and PFBS are not proposed at this time. Nevertheless, calculation of HRIs will be critical, and should the Thyroid HRI be exceeded before PFOA or PFOS breakthrough is observed, lower treatment targets may be necessary in the future.

(4) ND: Non-Detect.

(5) Values in red are above the applicable EPA or MDH limit.

Table K.12: MBWA Other Water Quality Parameters.

| **Location** | Pumping Rates | Iron | Manganese | Total Hardness |
|---|---|---|---|---|
| Units: | gpm | mg/L (1) | mg/L | mg/L as $CaCO_3$ |
| Target (2) | - | 0.3 | 0.05 | - |
| Scenario 1 – Blended Raw Water | | | | |
| Lake Elmo WTP | 5,650 | 5.17 (3) | 0.04 | 224 |
| Oakdale WTP | 5,150 | 1.83 | 0.12 | 127 |
| Scenario 2 – Blended Raw Water | | | | |
| Lake Elmo WTP | 6,150 | 2.62 | 0.07 | 218 |
| Oakdale WTP | 3,700 | 2.37 | 0.09 | 104 |
| Scenario 3 – Blended Raw Water | | | | |
| Lake Elmo WTP | 5,125 | 2.43 | 0.07 | 201 |

(1) mg/L = milligrams per liter, also known as parts per million (ppm).
(2) Treatment targets for iron and manganese are from the EPA's non-enforceable National Secondary Drinking Water Regulations, or Secondary Maximum Contaminant Levels (SMCL).
(3) Values in red are above the applicable EPA SMCL.

Concentrations noted in red (PFOA, PFOS, PFHxS, HI, and HRIs) in Table K.11 exceed EPA and MDH standards and thus necessitate treatment. PFOA and PFOS are responsible for exceedances to the Developmental, Liver System, Immune System, and Kidney System HRIs, and treatment to below detection for PFOA and PFOS would generally achieve an HRI of less than 1 for the Developmental, Immune System, and Kidney System HRIs. The Liver System HRI also includes PFBA and PFHxS; treatment of PFHxS to below treatment targets would also be required to achieve compliance with the Liver System HRI. The Thyroid HRI is also exceeded, largely due to PFHxS exceedances, though PFBA, PFHxA, and to a lesser extent PFBS play a part in this as well. PFBA concentrations at the Oakdale WTP in Scenario 1 and the Lake Elmo WTP in Scenarios 2 and 3 are approaching the MDH PFBA HRL concentration (7,000 ng/L) which may require additional treatment considerations in regard to the Thyroid HRI, as PFBA is harder to remove than other species. Discussions with the Cities of Lake Elmo and Oakdale regarding their treatment objectives and the potential for lower drinking water standards related to PFBA, PFHxS, and PFHxA should be continued as this may impact the selected treatment train.

Items noted in red in Table K.12 exceed EPA non-enforceable secondary standards for iron and manganese and should be treated for removal at each water treatment plant. Manganese can cause black to brown color in treated water and a bitter, metallic taste while iron can cause rusting, reddish to orange color in the water, and metallic taste. Iron and manganese can also have nuisance effects on treatment processes and equipment and are thus typically removed toward the beginning of the treatment train. Additionally, a hardness concentration greater than 150mg/L as CaCO3 is considered "hard" water and can create scaling issues in pipes, valving, and process equipment. Where total hardness concentrations exceed 150 mg/L as $CaCO_3$, as is the case in all the scenarios at the Lake Elmo WTP, an antiscalant pretreatment can be included as either pH adjustment or a sequestering agent at either water treatment plant if desired by the community.

Future analysis for design will require effluent quality requirements from each of the serviced communities, such as required chlorine residual, water softening requirements, and corrosion control needs. Treatment objectives will also need to consider water chemistry requirements for groundwater injection. The portion of treated water that is injected needs to account for pH, oxidation reduction potential (ORP), salinity, hardness, alkalinity, metals, ionic strengths, ammonia, nitrate, and potentially other parameters. Groundwater quality will need to be monitored via a monitoring and sampling program that informs treatment adjustments, as necessary. A full assessment of injection water quality requirements should be performed prior to treatment design.

## K4.1.2 Pretreatment for Iron and Manganese

Sampling from monitoring wells in close proximity to the proposed extraction wells indicated that iron and manganese concentrations in groundwater could present operational challenges with either GAC, IX, and RO/NF treatment, due to risk of media or membrane fouling. In systems with elevated iron and manganese, removing these constituents prior to the PFAS treatment can extend the life of the PFAS treatment media. Pretreatment options include oxidation of iron and manganese with chlorine, filtration with rapid sand filters and/or GreensandPlus™ (greensand), or cartridge filters. As part of this FS, AECOM's Austin Treatability Laboratory performed a treatability study to evaluate multiple pretreatment options. Results from this treatability study (Appendix H) showed that greensand filters are an effective option for pretreatment. For this reason, greensand filters were used as pretreatment in cost estimates for the evaluated treatment options. While horizontal or vertical vessels can be considered in the design process, this study assumed horizontal pressure vessels with a standard loading rate of 4 gallons per minute per square foot (gpm/sf). The design criteria for the greensand filters are included in Table K.13.

Table K.13: Iron & Manganese Pretreatment Design Criteria.

| Item | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate | gpm | 5150 | 5650 | 3700 | 6150 | 5130 |
| Process Trains | - | 3 | 3 | 2 | 3 | 3 |
| Flow Rate per Train | gpm | 1717 | 1883 | 1850 | 2050 | 1708 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Vessel Length | ft | 36 | 36 | 36 | 36 | 36 |
| Surface Loading Rate (SLR) | gpm/sf | 4.0 | 4.4 | 4.3 | 4.8 | 4.0 |
| Chlorine Dose | mg/L | 2.2 | 5.3 | 2.7 | 2.7 | 2.7 |
| Backwash Frequency | hr | 42 | 15 | 31 | 28 | 33 |

Legend: ft = feet; hr = hour.

The pretreatment options will require backflushing to remove accumulated solids. It is assumed solids-containing backwash water would be discharged to the sanitary sewer for further treatment. The volume of water discharged to sewer was estimated using preliminary design criteria for greensand pretreatment for iron and manganese removal, which would require backwashing an average of every 32-35 hours (hr). Backwash water would be sourced from the treated effluent in the clear well/blending tanks to avoid unintentional discharge of PFAS from the WTP to the sanitary sewer and downstream wastewater treatment plant.

## K4.1.3 Process Operating Principles

### K4.1.3.1 N+1 Redundancy

Operating equipment would be designed with N+1 redundancy to increase system uptime and reliability. N+1 redundancy design allows for maintenance and repairs to occur on a piece of equipment or entire operating unit while maintaining operations at maximum design flow. One additional piece of (redundant) equipment is installed beyond the minimum number ‘N’ required to achieve a design flow. A redundant RO skid is accounted for in the design where applicable as more downtime is required for general operations and maintenance. Redundant GAC and IX trains are not included in the design because in the lead/lag vessel configuration described below, treatment can occur in one of the vessels while the other vessel is out of service for media changeout. Current cost assumptions are built on this N+1 redundancy, though should communities desire N+1 redundancy with a GAC or IX treatment train, this can be added should full-scale design proceed.

### K4.1.3.2 Lead/Lag Pressure Vessels

Lead/lag configuration of pressure vessels is generally assumed as opposed to parallel vessel operation. Parallel operation simply splits the entire flow amongst all vessels; however, a lead/lag configuration utilizes two vessels in series and is more commonly used in PFAS treatment applications. The effluent from the first vessel, the “lead” vessel, discharges into the second vessel, the “lag” vessel (Figure K.28). Treatment takes place predominately in the lead vessel, while the lag vessel removes any residual PFAS remaining. Once the lead vessel is saturated and the media requires changing, the valves are adjusted so the lag vessel becomes the lead vessel while the media in the saturated lead vessel is changed, allowing the system to remain in operation during changeout. The vessel with the new media then becomes the lag vessel and the process repeats. The purpose of this configuration is to reduce the risk of PFAS breakthrough once the bed of the lead vessel has been saturated allowing for the media in the lead vessel to be exhausted prior to change-out.

### K4.1.3.3 NF/RO Membrane Treatment

The use of NF and RO membranes has traditionally been employed for brackish water and seawater desalination, for membrane softening, and for removing other select contaminants including organic compounds. More recently, NF and RO membranes have begun to be used for PFAS treatment.

Understanding the principle of RO starts with a description of “natural” osmosis that occurs when a semipermeable membrane separates, for example, a low total dissolved solids (TDS) solution and a high TDS solution. By osmosis, pure water will flow from the low TDS side of the membrane to the high TDS side, but this flow will stop when the hydrostatic head on the high TDS side of the membrane equals the osmotic pressure of the solution. This process can be reversed when pressure in excess of osmotic pressure is applied, hence the term “reverse osmosis”. Nanofiltration is derived similarly, albeit at slightly lower pressures than RO. For this reason, NF is sometimes referred to as low-pressure RO.

A diagram of membrane separation is provided in Figure K.29. In essence, both NF and RO operate off the same principles of using applied pressure to overcome osmotic pressure and other losses to force water through a semipermeable membrane. As a result of this, treated water moves through the membrane, referred to as the “permeate”, while a certain percentage of the water containing the contaminants are not removed through the membrane, referred to as the “concentrate”, “reject”, or “brine”. The term “concentrate” is most descriptive, because the contaminants are concentrated as the water flows through the membranes, proportional to the flow ratio of permeate to feed water. This flow ratio is called the “recovery”. Depending on the membrane, the rejection of new membranes can be as high as 95% but diminishes over time. Typically, membranes are replaced when rejection drops below 80%.

The main difference between NF and RO is the pore size of the semi-permeable membrane. NF has a larger pore size than RO which means NF is more applicable to water softening and organics removal while RO is more applicable for brackish and seawater treatment. Pore size also impacts the pressures required to generate permeate through a membrane, with the smaller pores of RO membranes requiring higher operating pressures. Operating pressures of NF membranes are generally 70 to 150 pounds per square inch (PSI) while RO membranes may operate anywhere from 150 to 600 psi (AWWA, 2020).

Of the Federally regulated PFAS, the range of molecular weight is from 330.05 g/mol (HFPO-DA) to 500.13 g/mol (PFOS), which means these PFAS are well within the molecular weight cut-off of both NF and RO. To meet the current EPA MCLs, an NF process could be the more appropriate treatment technology for membrane considerations. If, however, PFBA or other short-chain PFAS removal is an objective, an RO system may be more effective than NF depending on the species. Pilot testing would be required to identify and verify the optimal membrane prior to full-scale system design.

### K4.1.4 General Plant Layout Needs

Each treatment plant would be designed to accommodate the selected treatment train. As noted previously, this study assumes that a new facility would be constructed for each scenario. Future planning and design can take into consideration the existing infrastructure at the Oakdale facility that is currently in operation. The new WTP(s) would be designed to house all operating equipment but assumes administrative space would be off-site. Treatment train equipment layout would need to accommodate clearance space and access space for operation, maintenance, and media changeout. Access can be by garage doors, removable walls, removable roof sections, and/or truck ways between trains. Ceiling height would be dependent on height clearances for treatment equipment and should also accommodate maintenance and media changeout needs. Layout space and clearances will also need to accommodate piping, chemical storage and pumping, backwash storage and pumping, and waste storage and pumping. The blending tank and/or clear well and/or final water storage can be built as part of the foundation of the building, thus eliminating the need for above-ground storage.

A designated Electrical Room would house the Motor Control Center, switchgear, transformers, Programmable Logic Controller, and other associated equipment. A Mechanical Room would house HVAC equipment and other building process equipment. An emergency generator would be located outside of the building to provide back-up power.

## K4.2 MBWA Water Treatment Options

### K4.2.1 Option A: GAC Treatment for PFAS

Option A includes GAC media for the treatment of PFAS. Flow from the pretreatment filters would be split between multiple treatment trains of lead/lag GAC vessels with the number depending on the flow rate to each facility. The GAC media would be contained within vertical pressure vessels housed within the WTP building. The pressure vessels are sized to accommodate parallel trains of split flow to maintain a hydraulic loading rate of >6 gpm/sf.

Model 12-40 pressure vessels supplied by Calgon Carbon Corporation (Calgon) were selected as the basis of evaluation for this study. Model 12-40 pressure vessels are 12-foot diameter lead/lag vessels, and each has a GAC media capacity of 40,000 pounds (lbs). This configuration allows for a surface loading rate (SLR) of approximately 6-8 gpm/sf and an empty bed contact time (EBCT) (1) greater than 20 minutes for each train, which is typical for PFAS treatment. An EBCT of 10 minutes for a single vessel (or 20 minutes for a train) was used for RSSCTs in the treatability study; full-scale performance could be slightly improved compared to the treatability studies due to the slightly longer EBCT proposed in full-scale design. A conceptual layout of Option A is provided in Figure K.30. The design criteria for the GAC system for each scenario are summarized in Table K.14.

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(1) Empty Bed Contact Time is calculated by dividing the volume of a treatment vessel by the flow rate through the vessel, giving a theoretical treatment time for liquid that passes through the vessel. It assumes all liquid moves at the same velocity. EBCT provides a comparison between media types for the relative amount of time a liquid must be in contact with a treatment media to reach treatment objectives. A longer EBCT requires a larger vessel. Adsorptive media that requires a shorter EBCT is preferable, as smaller vessels can be purchased, and less building footprint is needed, reducing the cost of projects.

Table K.14: Option A – GAC Design Criteria.

| Item | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all Trains | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 2 | 2 | 2 | 2 | 2 |
| GAC per Vessel | lbs | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per vessel | gpm/sf | 7.6 | 7.1 | 6.5 | 7.8 | 7.6 |
| EBCT per Process Train | min | 20.7 | 22.0 | 24.0 | 20.2 | 20.8 |

Legend: min = minute; sf = square foot.

Pros and cons for Option A are summarized in Table K.15. GAC is effective at removing long-chain PFAS, with high removal of PFOA and PFOS widely reported (AWWA, 2019; ITRC, 2023). GAC used for drinking water treatment can be returned to the vendor where it is then reactivated. Reactivation results in the destruction of PFAS (DiStefano, 2022) and allows for reuse of exhausted media for non-drinking water applications, decreasing the volume of waste sent to the landfill. The spent media would be shipped out of state for reactivation as there are no facilities within Minnesota. Removal of short-chain PFAS such as PFBA is significantly lower than long-chain PFAS removal, and breakthrough is observed for short-chain species much earlier than long-chain species. This would limit the ability of a GAC-only treatment system to meet future standards, should short-chain PFAS species be further regulated.

Table K.15: Option A – Pros and Cons.

| Pros | Cons |
|---|---|
| • GAC is a proven technology that is widely used and available from multiple vendors<br>• PFOA and PFOS removal to below treatment targets achievable<br>• Can be backwashed to reduce pressure drop across the GAC bed<br>• GAC can be sent back to vendor for reactivation which destroys PFAS and significantly reduces solid waste generation<br>• Can remove other contaminants like TOC | • Poor short-chain PFAS removal efficiencies and faster breakthrough of short-chain PFAS<br>• Limited ability to adapt to future regulations should regulatory framework change in the future<br>• GAC requires long residence time for effective treatment<br>• Longer GAC EBCT requires larger vessels and larger footprint than other alternatives<br>• GAC requires more frequent changeouts than IX resin<br>• High pH and arsenic can be a concern during initial GAC startup<br>• Bio-growth can occur if a GAC vessel is idle/stagnant for extended periods of time<br>• Removal of other contaminants can reduce GAC capacity for PFAS |

### K4.2.2 Option B: GAC and NF/RO Parallel Trains

In Option B, drinking water would be treated using a combination of GAC and NF/RO high pressure membranes. Flow would be split between treatment processes, with a portion of water treated with GAC and the balance treated with high pressure membranes. Membrane permeate would be remineralized with caustic soda or lime prior to blending the permeate and treated GAC effluent. Option B presents a treatment alternative where the flow downstream of the pretreatment system is split 50/50 between GAC trains and NF/RO trains. Splitting the flow decreases the amount of GAC vessels required and decreases the volume of media changeouts. Splitting the flow also allows for a reduced number of NF/RO treatment skids to be used, helping to control overall project cost while still meeting the required drinking water standard. Partial treatment by NF/RO would also result in lower PFBA concentrations in the resulting blended water. Water treated by NF/RO would also have lower TDS, decreasing the total hardness in the final blended effluent. A conceptual process train of Option B is provided in Figure K.31.

The use of a membrane technology requires a greater amount of new chemical feeds than the other alternatives evaluated. Upstream of the NF/RO skids, a chemical feed of antiscalant would be needed to reduce scale formation across the membranes and a reducing agent would be recommended to neutralize any free chlorine residual. Pretreatment addition of an acid such as sulfuric acid could also be required to decrease scaling potential. Downstream of the NF/RO skids, post-treatment chemical feeds consisting of caustic soda or lime are usually required for replenishing alkalinity to the water and controlling pH. Additional chemicals may be required for neutralization of the reject.

Clean-in-place (CIP) systems for membrane cleaning would be required as well, consisting of a high pH cleaner (e.g. citric acid and sodium bisulfite) and a low pH cleaner (e.g. caustic soda) batching and recirculation systems. A neutralization tank for spent CIP waste would be also required.

Similar to Option A, the evaluation for Option B assumes 12-foot diameter lead/lag vessels each with 40,000 pounds of GAC media. This configuration allows for a loading rate of approximately 5-8 gpm/sf and an EBCT greater than 20 minutes for each train. The NF/RO trains were sized assuming each skid can treat 500 gpm and includes a redundant skid for each scenario. With redundancy, the RO max flux is approximately 15-16 gallons per square foot per day (gfd) depending on the scenario. The design assumes 90 membrane elements per skid, each element with an area of 400 sf. The design criteria for the GAC system for each scenario is summarized in Table K.16 and the design criteria for the NF/RO system for each scenario is summarized in Table K.17. The design criteria are based on treating the design flow rate; however, an NF or RO system would lose 25% of the feed flow as concentrate, depending on the system recovery of 75%. The treated effluent from both the GAC and NF/RO trains would then combine in a blending tank for chlorination and additional chemical treatment as needed.

Table K.16: Option B – GAC Train Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all GAC Trains | gpm | 2580 | 2830 | 1850 | 3080 | 2570 |
| Flow Rate to each Train | gpm | 860 | 710 | 620 | 770 | 860 |
| Process Trains | - | 3 | 4 | 3 | 4 | 3 |
| Vessels Per Train | - | 2 | 2 | 2 | 2 | 2 |
| GAC per Vessel | lbs | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per Vessel | gpm/sf | 7.6 | 6.2 | 5.5 | 6.8 | 7.6 |
| EBCT per Process Train | min | 20.7 | 25.1 | 28.8 | 23.1 | 20.8 |

Table K.17: Option B – NF/RO Train Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to NF/RO Trains | gpm | 2580 | 2830 | 1850 | 3080 | 2570 |
| Permeate Flow Rate | gpm | 1930 | 2120 | 1390 | 2310 | 1920 |
| No. Skids w/ N+1 | - | 7 | 7 | 5 | 8 | 7 |
| Elements per Skid | - | 90 | 90 | 90 | 90 | 90 |
| Total Elements | - | 630 | 630 | 450 | 720 | 630 |
| Total Membrane Area | sf | 252,000 | 252,000 | 180,000 | 288,000 | 252,000 |
| Total System Flux w/ N+1 | gfd | 15 | 16 | 15 | 15 | 15 |
| Target Recovery | - | 75% | 75% | 75% | 75% | 75% |

Pros and cons for Option B are summarized in Table K.18. The use of membranes for PFAS separation would decrease GAC usage compared to Option A, as only half the total flow would be treated by GAC. NF/RO membranes remove the widest range of contaminants, including short-chain PFAS, which would reduce short-chain PFAS concentrations in drinking water. Additionally, membranes remove dissolved metal ions from water, which would result in softer water for end users.

Use of NF/RO treatment does have consequences though, including significant energy requirements and additional pre- and post-membrane chemical feeds. The significant energy expenditure occurs due to the pumping associated with the process. A large amount of pressure is required to overcome the osmotic pressure and head loss caused by the membrane which is accomplished through additional high-pressure pumping. This additional pumping would increase energy use and electrical costs.

Another major consequence of using an NF/RO membrane process is managing the concentrate from the process. As discussed, the concentrate from the process is a lower volume of flow (depending on the recovery percentage) that contains all the contaminants separated from the bulk flow by the membrane. The concentration of PFAS and other contaminants is therefore much greater in the concentrate than the influent. The concentrate requires design considerations for storage, handling, and disposal. For Option B, the concentrate could be piped to and disposed of at an additional proposed remediation treatment plant for further concentration and destruction. For more details on the proposed treatment plant, see Appendix J (Technology Analysis for Project 1007 Non-Drinking Water Treatment Alternatives). This would, however, require significant investment beyond what is considered in this FS, as the proposed treatment plant in Appendix J is not sized to handle the additional flow of membrane concentrate. Additional piping would also need to be installed to connect the treatment plants as well. Alternatively, a concentrating technology such as foam fractionation could be employed to further concentrate NF/RO concentrate prior to transporting the waste for PFAS destruction. These alternatives would be discussed further based on technology development if the Minnesota Pollution Control Agency (MPCA) and communities determined to pursue this treatment option.

Table K.18: Option B – Pros and Cons.

| Pros | Cons |
|---|---|
| • GAC and NF/RO are both proven technologies that are widely used and available from multiple vendors<br>• Reduced GAC usage as compared to Option A, C, D<br>• PFOA and PFOS removal to below treatment targets achievable<br>• NF/RO membranes remove widest range of contaminants including short-chain PFAS which could aid in meeting potential future regulatory limits<br>• NF/RO membrane use would result in softer water for end users | • Membranes require additional high-pressure pumping (increased energy costs)<br>• Membranes require additional chemical feeds (antiscalant, pH control, reducing agent)<br>• CIP waste streams must be properly neutralized/disposed<br>• Periodic NF/RO membrane replacement will be required, added to cost (every 5-7 years is typical)<br>• Membrane system requires more operator/engineer oversite than a GAC or IX system<br>• GAC requires long residence time for effective treatment<br>• GAC requires more frequent changeouts than IX resin<br>• High pH and arsenic can be a concern during initial GAC startup<br>• Bio-growth can occur if a GAC vessel is idle/stagnant for extended periods of time<br>• Removal of other contaminants can reduce GAC capacity for PFAS<br>• NF/RO concentration factors are only in the range of 4-6x, which would result in a large volume of membrane concentrate requiring further treatment prior to final disposal<br>• Only half of flow treated with membranes, resulting in a higher effluent concentration than if treated solely with NF/RO. |

### K4.2.3 Option C: GAC with NF/RO Polish

Option C provides an alternative NF/RO treatment process. With this process, the influent flows through a lead/lag GAC system and the treated GAC effluent splits between a blending tank and a sidestream NF/RO polish treatment. The preliminary design assumed 50% of the flow would pass through the sidestream NF/RO polish. Full flow treatment was not considered for this appendix as sidestream treatment was able to meet treatment objectives and would reduce overall project cost by reducing the number of NF/RO membrane skids required as well as the total volume of water treated by membranes. It is well documented that GAC is effective in removing long-chain PFAS like PFOA and PFOS. However, short-chain PFAS such as PFBS and PFBA do not adsorb as well on GAC. GAC would serve as the treatment process for removal of long-chain PFAS species as well as providing additional removal for contaminants such as TOC, color, and taste and odor (T&O). The NF/RO side stream process would provide additional polish treatment for PFAS to remove a portion of the remaining PFAS not adsorbed by GAC. The NF/RO permeate would be aerated for pH control and then blended with the GAC effluent potentially reducing the need for added post-treatment chemicals. A conceptual process train of Option C is provided in Figure K.32.

This option requires the same number of GAC trains as Option A, with the same design criteria and likely the same frequency and volume of media changeout. Assuming that the sidestream NF/RO polish treatment system is receiving 50% of the flow, the design criteria for the NF/RO system would be similar to Option B. The GAC design criteria is summarized in Table K.19 and the NF/RO design criteria is summarized in Table K.20.

Table K.19: Option C – GAC Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all Trains | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 2 | 2 | 2 | 2 | 2 |
| GAC per Vessel | lbs | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per vessel | gpm/sf | 7.6 | 7.1 | 6.5 | 7.8 | 7.6 |
| EBCT per Process Train | min | 20.7 | 22.0 | 24.0 | 20.2 | 20.8 |

Table K.20: Option C – NF/RO Sidestream Polish Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to NF/RO Trains | gpm | 2580 | 2830 | 1850 | 3080 | 2570 |
| Permeate Flow Rate | gpm | 1930 | 2120 | 1390 | 2310 | 1920 |
| No. Skids w/ N+1 | - | 7 | 7 | 5 | 8 | 7 |
| Elements per Skid | - | 90 | 90 | 90 | 90 | 90 |
| Total Elements | - | 630 | 630 | 450 | 720 | 630 |
| Total Membrane Area | sf | 252,000 | 252,000 | 180,000 | 288,000 | 252,000 |
| Total System Flux w/ N+1 | gfd | 15 | 16 | 15 | 15 | 15 |
| Target Recovery | - | 75% | 75% | 75% | 75% | 75% |

Pros and cons for Option C are summarized in Table K.21. This treatment option is similar to Option B, thus many of the pros and cons discussed in Section K4.2.2 are relevant here as well, particularly concerning the operational benefits and challenges that come with membrane treatment. The key difference between the treatment options, however, is that the whole flow is treated with GAC with a sidestream RO treatment on the GAC effluent. This could provide benefit for operation of the NF/RO membranes by providing additional pre-filtration ahead of the membranes, reducing the concentrations of potential foulants. There would not be any reduction in GAC use. As an estimated half of the GAC effluent would not be treated by NF/RO membranes, effluent concentrations of long-chain PFAS like PFOA and PFOS would still need to be non-detect to meet treatment objectives in the finished water.

GAC treatment ahead of a membrane process step would also reduce concentrations of long-chain PFAS in the membrane concentrate. Long-chain PFAS species generally have lower discharge limits than short-chain PFAS species, thus removal of long-chain PFAS could increase disposal options for the membrane concentrate. Disposal of the membrane concentrate could still pose a problem and would likely require additional process equipment to treat the concentrate, as previously discussed in Section K4.2.2, particularly if the Metropolitan Council (wastewater authority that would receive sanitary waste) would not allow discharge of the membrane reject to the sanity sewer.

Table K.21: Option C – Pros and Cons.

| Pros | Cons |
|---|---|
| • GAC and NF/RO are both proven technologies that are widely used and available from multiple vendors<br>• GAC ahead of NF/RO membranes may reduce membrane fouling potential<br>• Removal of long-chain PFAS by GAC would reduce long-chain PFAS concentrations in the membrane concentrate<br>• NF/RO reduces the concentration of PFBA in the treated water | • No reduction in GAC changeout frequency as compared to Options A, B, and D<br>• GAC requires long residence time for effective treatment<br>• Longer GAC EBCT requires larger vessels and larger footprint than other alternatives<br>• GAC requires more frequent changeouts than IX resin<br>• High pH and arsenic can be a concern during initial GAC startup<br>• Bio-growth can occur if a GAC vessel is idle/stagnant for extended periods of time<br>• Removal of other contaminants can reduce GAC capacity for PFAS<br>• Membranes require additional high-pressure pumping (increased energy costs)<br>• Membranes require additional chemical feeds (antiscalant, pH control, reducing agent)<br>• CIP waste streams must be properly neutralized/disposed<br>• Periodic NF/RO membrane replacement will be required, added to cost (every 5-7 years is typical)<br>• Membrane system requires more operator/engineer oversite than a GAC or IX system<br>• Only half of flow treated with membranes, resulting in limitations on short-chain PFAS effluent concentrations<br>• No reduction of short-chain PFAS concentrations in the membrane concentrate<br>• NF/RO concentration factors are only in the range of 4-6x, which would result in a large volume of membrane concentrate requiring further treatment prior to final disposal |

## K4.2.4 Option D: GAC Treatment with IX Polish

The fourth treatment alternative is the use of GAC followed by IX resin, as a hybrid treatment approach. This approach combines the treatment benefits of both technologies to provide the maximum range of removal and operational flexibility. The overall approach for the hybrid operation is to utilize GAC followed by IX. The GAC would serve to remove long-chain PFAS compounds such as PFOS and PFOA while also providing additional removal for contaminants such as TOC, color, and T&O. Additionally, GAC is typically less expensive than IX resin and is less prone to fouling due to TOC. By utilizing GAC to remove TOC and long-chain PFAS, the IX vessel life would be extended.

The use of IX downstream of GAC allows for a wider removal of PFAS than what could be removed with GAC alone. Typically, short-chain PFAS, like PFBA, do not adsorb as well with GAC but have improved removal by IX. While many of these PFAS are not currently regulated, this provides flexibility for lower short-chain PFAS effluent concentrations if future regulations lower short-chain PFAS limits. In addition, by utilizing GAC ahead of IX, IX resin bed life will be extended by removing the burden of organics removal (TOC) and long-chain PFAS. Considering the cost of a bed of IX resin, protection of the resin and maximizing longevity should be a priority. Finally, use of GAC to remove long-chain PFAS prior to IX would allow for prioritization of an IX resin that maximizes short-chain PFAS removal instead of needing to prioritize removal of long-chain PFAS species.

GAC vessels would maintain a similar design criteria and number of trains as Option A (GAC treatment). The IX system would consist of a single 12-foot pressure vessel downstream of each GAC lead/lag pair. The target EBCT for each IX system is approximately 3 minutes and the filter SLR is > 6.5 gpm/sf. A conceptual process train for Option D is shown in Figure K.33 and design criteria for both GAC and IX systems are presented in Table K.22 and Table K.23, respectively. Pros and cons for Option D are summarized in Table K.24. Pros and cons of GAC treatment are generally similar to Option A.

Table K.22: Option D – GAC Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all Trains | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 2 | 2 | 2 | 2 | 2 |
| GAC per Vessel | lbs | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per vessel | gpm/sf | 7.6 | 7.1 | 6.5 | 7.8 | 7.6 |
| EBCT per Process Train | min | 20.7 | 22.0 | 24.0 | 20.2 | 20.8 |

Table K.23: Option D – IX Polish Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 1 | 1 | 1 | 1 | 1 |
| IX Bed Depth | ft | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per Vessel | gpm/sf | 7.6 | 7.1 | 6.5 | 7.8 | 7.6 |
| IX Volume | cf | 339 | 339 | 339 | 339 | 339 |
| EBCT per Process Train | min | 3.0 | 3.1 | 3.4 | 2.9 | 3.0 |

Table K.24: Option D – Pros and Cons.

| Pros | Cons |
|---|---|
| • GAC and IX are both proven technologies that are widely used and available from multiple vendors<br>• IX can remove short-chain PFAS compounds to below treatment targets<br>• GAC can be sent back to vendor for reactivation which destroys PFAS and significantly reduces solid waste generation<br>• GAC removal of contaminants like TOC likely would extend IX polish bed life<br>• GAC can be backwashed to reduce pressure drop across the media bed | • No reduction in GAC changeout frequency as compared to Options A, B, and C<br>• GAC requires long residence time for effective treatment<br>• Longer GAC EBCT requires larger vessels and larger footprint than other alternatives<br>• High pH and arsenic can be a concern during initial GAC startup<br>• Bio-growth can occur if a GAC vessel is idle/stagnant for extended periods of time<br>• IX resin is typically landfilled due to cost restrictions<br>• PFAS removed by IX resin unlikely to be destroyed<br>• Removal of other contaminants can reduce GAC capacity for PFAS |

## K4.2.5 Option E: Sacrificial GAC with IX Lead/Lag

Option E provides an alternative IX treatment process. With this process, the influent flows through a single GAC vessel at each train and subsequently through a lead/lag IX system. The single GAC vessel would not provide sufficient EBCT to remove long-chain PFAS species to drinking water standards, but the lead/lag IX system provides removal capacity for PFAS at an EBCT of >5.5 minutes. In this configuration, the GAC vessel acts as a sacrificial adsorbent vessel that removes competing organics such as TOC. GAC would also protect the IX vessels from any residual chlorine present from iron and manganese removal, which utilizes chlorine to oxidize iron and manganese. Chlorine may have a negative effect on IX media, thus breakthrough of chlorine through GAC would likely be the trigger for GAC changeout. A GAC media change out was assumed to be once per year for costing purposes; however, the changeouts may occur less frequently depending on chlorine breakthrough. Additionally, should chlorine be found to have negligible effect on IX media, GAC changeouts could potentially be extended based on TOC removal. A conceptual process train for Option E is shown in Figure K.34. Design criteria for both GAC and IX systems are presented in Table K.25 and Table K.26, respectively.

Table K.25: Option E – GAC Pretreatment Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all Trains | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 1 | 1 | 1 | 1 | 1 |
| GAC per Vessel | lbs | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per Vessel | gpm/sf | 7.6 | 7.1 | 6.5 | 7.8 | 7.6 |
| EBCT per Process Train | min | 10.3 | 11.0 | 12.0 | 10.1 | 10.4 |

Table K.26: Option E – IX Lead/Lag Design Criteria.

| Parameter | Unit | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|---|
| | | Oakdale WTP | Lake Elmo WTP | Oakdale WTP | Lake Elmo WTP | Lake Elmo WTP |
| Flow Rate to all Trains | gpm | 5150 | 5650 | 3700 | 6150 | 5125 |
| Process Trains | - | 6 | 7 | 5 | 7 | 6 |
| Vessels Per Train | - | 2 | 2 | 2 | 2 | 2 |
| IX Bed Depth | ft | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Vessel Diameter | ft | 12 | 12 | 12 | 12 | 12 |
| Surface Area per Vessel | sf | 113 | 113 | 113 | 113 | 113 |
| SLR per Vessel | gpm/sf | 7.6 | 7.1 | 6.6 | 7.8 | 7.6 |
| IX Volume | cf | 339 | 339 | 339 | 339 | 339 |
| EBCT per Process Train | min | 5.9 | 6.3 | 6.9 | 5.8 | 5.9 |

Pros and cons for Option E are summarized in Table K.27. Pros and cons of GAC treatment are similar to Option A and are generally applicable here. The primary benefit of Option E compared to Option D is reduction in GAC usage since GAC changeout is triggered by chlorine breakthrough and not PFAS breakthrough. Use of two IX vessels could also potentially achieve lower effluent short-chain PFAS concentrations should regulatory limits change. Increased use of IX resin could result in additional PFAS loading to landfills though, as IX resin is typically landfilled as opposed to destroyed via incineration or other novel PFAS destruction technology due to the much lower cost of landfilling. However, costs to landfill PFAS have begun to increase and as alternative destruction methods become available, this cost discrepancy is likely to decrease over time.

Table K.27: Option E – Pros and Cons.

| Pros | Cons |
|---|---|
| • Use of GAC as a single sacrificial bed ahead of IX allows for shorter EBCT, decreasing space requirements for GAC vessels<br>• Longer GAC life expected when using GAC to protect IX resin as opposed to targeting PFAS removal<br>• GAC and IX are both proven technologies that are widely used and available from multiple vendors<br>• IX RSSCTs indicated superior performance compared to GAC for both long- and short-chain PFAS<br>• IX removal of short-chain PFAS will help with compliance of MDH HRIs that include non-federally regulated PFAS | • IX resin is typically landfilled as opposed to incinerated or destroyed due to cost differences. Little PFAS destruction would be expected as majority of PFAS would be removed by IX and not GAC |

## K4.3 Comparison of Treatment Options

Treatment options are qualitatively evaluated on six criteria. These criteria are derived from the National Contingency Plan (NCP) nine criteria for evaluating FS remedial alternatives. Criteria, along with a description of each criterion, are described below. Note that cost is not discussed here as it is discussed in this appendix in Section K6.

Short-Term Effectiveness: This criterion evaluates the ability of a treatment option to meet current regulatory standards for drinking water. Current standards include EPA MCLs and MDH HRLs and HBVs. These are described in Section 9 of the FS in greater detail.

Long-Term Effectiveness: Long-term effectiveness considers the ability of a treatment option to meet future regulatory PFAS standards, should regulatory standards be decreased for PFAS that are already regulated, or should additional PFAS be regulated that currently are not regulated. Specific consideration is given to the ability of a treatment train to remove short-chain PFAS, as short-chain species are generally more difficult to remove than long-chain species.

Sustainability – Media Consumption: Expected adsorptive media usage is evaluated by this criterion. Media usage is based on estimates based on the RSSCT bench scale testing. See Section 10 of the FS and Appendix H for the results of this study.

Sustainability – Energy Use: Relative amount of energy use is compared by this criterion. This criterion focuses on process equipment, as building size and heating/cooling requirements are not expected to impact relative energy usage as much as pumping and other process equipment.

Operations and Maintenance Requirements: This criterion evaluates the number of operators/technical staff required to operate and maintain a facility, the relative ease/difficulty of operating a facility, and the expected relative difficulty of maintenance. For example, RO/NF membranes require more oversite than GAC.

Portion of PFAS Destroyed: This criterion compares the relative mass of PFAS that is ultimately destroyed by a given treatment train. Destruction could occur from incineration, reactivation of GAC, or through a novel destruction technology. Further details on PFAS destruction can be found in Section 9 of the FS (Remedial Technology and Action Screening) and Appendix G (PFAS Destruction Technology Bench-Scale Study Summary and Analysis).

Due to relative cost of landfilling versus incineration, it is assumed all single-use ion exchange media will be landfilled. Landfilling is considered to be less desirable, as PFAS is sequestered in a landfill and not ultimately destroyed. Treatment trains that consume less IX media may be candidates for incineration of IX media to destroy PFAS as the volume of media to be incinerated would be lower.

Additional technologies are in development for disposal/re-use of GAC and IX media; however, they are not discussed here as they are not ready for full-scale use. As research and development of PFAS destruction continues, options should be evaluated periodically to reevaluate future options for disposal and destruction of PFAS and adsorptive media.

It must also be noted that, at this time, no destruction or disposal facility exists in the State of Minnesota for destruction of PFAS-impacted waste. Any destruction or disposal of spent media would require transport out of state.

Qualitative scoring of treatment trains is summarized in Table K.28, with descriptions of individual scoring summarized in Table K.30. Qualitative scoring of Low, Moderate, and High are used. Treatment options are compared against each other below as well, with a summary provided in Table K.29.

Table K.28: Qualitative Scoring of Treatment Options.

| **Option** | Short-Term **Effectiveness** | Long-Term **Effectiveness** | Sustainability - Media **Consumption** | Sustainability - Energy Use | O&M | **Portion of** PFAS Destroyed |
|---|---|---|---|---|---|---|
| A | Moderate | Low | High | Low | Moderate | High |
| B | High | Moderate | Moderate | High | High | High |
| C | High | Moderate | High | High | High | High |
| D | High | High | High | Low | Moderate | Moderate |
| E | High | High | Moderate | Low | Low | Low |

## K4.3.1.1 Short-Term Effectiveness

All treatment trains are expected to meet current applicable regulatory standards for finished drinking water, though media required to meet applicable standards will vary by treatment train, as RSSCTs indicated IX resin outperformed GAC. Long-chain PFAS, specifically PFOA, PFOS, and PFHxS, are the primary species that exceed current drinking water standards throughout the Site. The EPA HI is also exceeded due to high PFHxS concentrations, and all MDH HRIs are exceeded as well. Based on RSSCT results, treatment of PFHxS is expected to bring the effluent below the EPA HI limit of 1 for the duration of expected media life. Similarly, based on RSSCTs, the MDH Thyroid HRI (which does not include PFOS or PFOA) is expected to be met for the useful duration of the media life. All other MDH HRIs will be exceeded once PFOA or PFOS are detected in a sample, though as the treatment target for PFOA and PFOS is non-detect, these other HRIs do not have an effect on media changeouts in practice. At this time, no bench-scale or pilot-scale testing is planned for treatment options that would utilize NF/RO, though both treatment options that utilize NF/RO are expected to meet regulatory standards as well.

### K4.3.1.2 Long-Term Effectiveness

Long-term effectiveness of treatment trains is expected to vary significantly due to the relative ability of a treatment train to remove short-chain PFAS. Treatment Option E is expected to have the highest long-term effectiveness, as a lead/lag IX resin system with GAC pretreatment would be expected to allow for the highest level of short-chain PFAS removal of all systems considered. However, it must be noted that IX media usage would correspondingly increase as target effluent concentrations of short-chain PFAS are lowered. Treatment Option D is expected to have a lesser ability to achieve lower short-chain effluent concentrations as there would be only one IX resin vessel in the treatment train as opposed to the two vessels in Option E. This could be partially mitigated if a resin is selected that is highly selective of short-chain PFAS, as the vast majority of long-chain PFAS would be removed by the lead/lag GAC vessels in Option D.

Treatment Options B and C are expected to be the next most effective, with both options expected to have similar ability to lower effluent short-chain PFAS concentration. In Option C, long-chain PFAS would be efficiently removed by GAC for the entire flow. NF/RO polishing of half the flow would effectively remove all remaining PFAS in the NF/RO permeate; however, final effluent concentration of short-chain PFAS would be limited by the effluent concentration from the GAC vessels, which are not expected to be effective at removing short-chain PFAS like PFBA. Dilution from the treated NF/RO permeate would decrease the concentration of short-chain PFAS in the effluent, but there would be a limit to how low of a concentration could be achieved. Option B would function similarly in this regard, though the membranes would also remove long-chain PFAS in addition to short-chain PFAS, as not all water would first be treated by GAC. This is not expected to functionally change the achievable short-chain PFAS concentration though, as the lower limit of achievable concentration will be similar dependent on GAC performance.

Finally, Treatment Option A is expected to have the lowest long-term effectiveness, as a GAC-only system would be ineffective at removing PFBA to similar effluent concentrations as current long-chain regulations (i.e. on the order of 10 ng/L or less). Frequent changeouts of GAC would be likely, making it cost-prohibitive to utilize a GAC-only system to remove PFBA.

### K4.3.1.3 Sustainability – Media Consumption

Option E is expected to have the lowest media usage, as IX media outperformed GAC in RSSCTs, though due to influent concentrations of PFAS, media consumption is still expected to be moderate. This is in contrast to the other Options, all of which are expected to have high media usage. Options B and D are expected to have lower usage rates than Options A and C. Media usage in Option B is decreased through the use of NF/RO membranes, which would reduce the amount of GAC needed compared to Options A and C. Option D, which incorporates IX resin polishing, may have slightly reduced media usage compared to Options A and C due to the improved performance of IX resin, but usage would still be high.

Options A and C would have the highest usage rates, as GAC is the only adsorbent media used to remove PFAS in both options. Though Option C does include an NF/RO polish, which would decrease the effluent short-chain PFAS concentration, minimal decrease in GAC usage would be expected due to the extremely low effluent standards for PFOS and PFOA. While membranes would remove any remaining PFOA and PFOS in the GAC effluent in Option C, this would only be true for the portion of the flow that is treated by NF/RO. The portion of GAC effluent that would not be treated by membranes would still need to meet all applicable standards. Due to the low concentrations of PFOA and PFOS allowed by the EPA MCLs and the MDH HRIs, functionally there would be no reduction in GAC usage between Options A and C, with both options using a significant amount of GAC to meet effluent standards.

Media usage rates for Option A, and to a lesser extent Options B and C would be expected to increase drastically if short-chain PFAS effluent targets or regulatory limits decrease, as GAC is ineffective at removing short-chain PFAS. GAC usage increases in Options B and C would be lower due to the incorporation of NF/RO; however, as the entire flow is not treated by NF/RO, if short-chain PFAS limits were lowered to limits similar to current long-chain PFAS standards, treating only half the flow with NF/RO would be insufficient to meet those limits. Media usage would also increase for Options D and E if short-chain PFAS effluent requirements decreased as additional IX media changeouts would be required to meet lower effluents limits. The relative increase in media usage would be significantly lower for IX options though, due to the improved ability of IX resin to remove short-chain PFAS compared to GAC.

### K4.3.1.4 Sustainability – Energy Use

Energy use would be expected to vary widely based on whether or not a treatment system utilizes NF/RO membranes. Functionally, energy usage is not expected to vary widely for general systems as all considered treatment options include pretreatment for iron and manganese removal and other general process equipment like chemical dosing. Treatment Option A is expected to have the lowest energy usage as it does not utilize NF/RO membranes and only utilizes two GAC pressure vessels per treatment train. Treatment Options D and E are expected to have similar energy usage to Option A, though the additional of a third pressure vessel in each treatment option could increase energy use slightly. Building energy use may be slightly higher for Option D as it would require a larger footprint than Treatment Options A or E, but this is not expected to be significant. Overall, energy use is expected to broadly be very similar or Treatment Options A, D, and E.

Conversely, Treatment Options B and C are expected to have the highest energy use due to their utilization of NF/RO membranes. Membranes systems can operate at pressures up to 600 psi, which requires a significant amount of energy. Energy use is expected to be higher for Treatment Option C compared to Treatment Option B even though they have the same sized membrane system. The full flow in Option C receives GAC treatment while only half the flow in Option B would go through GAC treatment, which would be expected to reduce the pumping energy needed. This reduction would be minimal though compared to the overall energy usage of the membrane systems.

### K4.3.1.5 Operations and Maintenance

Similar to energy use, operation and maintenance (O&M) requirements are expected to vary widely dependent on whether or not a system utilizes NF/RO membranes. Treatment Options A, D, and E are expected to have the lower O&M requirements than Options B and C as they do not utilize a membrane system. Option E expected the lower O&M requirements due to the lowest number of expected media changeouts per year. Options A and D, which would have frequent GAC media changeouts, would correspondingly have more O&M requirements to facilitate the frequent media changeouts.

Treatment Options B and C are expected to have significantly higher O&M requirements due to the incorporation of NF/RO membranes. Membrane systems require additional pumps, chemical addition, and system cleanings than the GAC- and IX-only systems. Additional daily/weekly sampling would also be required, along with additional operator/engineer/supervisor oversite of treatment plant operations. Option C could have slightly lower O&M requirements compared to Option B as all water is treated by GAC prior to use of membranes in Option C, which may improve feed water quality compared to Option B. However, this difference is likely minimal, as prefilters would still be required ahead of the membrane system in Option B.

### K4.3.1.6 Portion of PFAS Destroyed

Portion of PFAS destroyed is evaluated based on three primary assumptions: 1) that IX resin is landfilled, 2) that NF/RO concentrate is sent to a separate treatment plant for further processing and destruction, and 3) that all GAC is returned to the generator for reactivation and reuse in a non-drinking water application. Under these assumptions, Options B and C would have the highest portion of PFAS destroyed, as PFAS removed by GAC would be destroyed during reactivation and PFAS removed by membranes would be destroyed at a separate treatment plant. These would be followed by Options A and D. In Option A, PFAS removed by GAC would similarly be destroyed upon reactivation, but without the use of membranes, there would be higher concentrations of short-chain PFAS expected and thus less PFAS would be destroyed overall. In Option D, while the IX resin would remove additional short-chain PFAS and prevent its distribution through the drinking water system, it would not be destroyed and would instead be sequestered in a landfill. Finally, Option E would be expected to have the lowest portion of PFAS destroyed, as the majority of PFAS removed would occur using IX resin and would thus result in higher mass of PFAS sequestered in landfills relative to other treatment options.

These rankings would change if any assumptions made prove wrong, particularly that IX resin is landfilled and NF/RO concentrate is destroyed at a separate treatment plant. If PFAS removed by IX resin can be destroyed cost effectively, then Treatment Options D and E would be ranked higher. Conversely, if NF/RO concentrate cannot be destroyed at a separate treatment plant, then Options B and C would be ranked lower.

Table K.29: Relative Rankings of Treatment Options.

| Criteria | **Treatment Option** Rankings |
|---|---|
| Short-Term Effectiveness | Most able to meet current regulatory PFAS limits to least able<br>B = C = D = E > A |
| Long-Term Effectiveness (1) | Most able to meet potential future regulatory PFAS limits (e.g. lower short-chain PFAS limits) to least able<br>E > D > B = C > A |
| Sustainability - Media Consumption | Least adsorptive media use to highest adsorptive media use<br>E < B < D < A =C |
| Sustainability - Energy Use | Lowest energy use to highest energy use<br>A < D = E < B < C |
| Operations and Maintenance Requirements | Least demanding O&M to most demanding<br>W < A = D < C < B |
| Portion of PFAS Destroyed (2) | Highest percentage of PFAS destroyed to lowest percentage of PFAS Destroyed<br>B = C > A = D > E |

Note: =: equal to; <: less than; >: greater than.

(1) Assumes short-chain PFAS regulatory limits significantly decrease in the future, with particular regard to PFBA.

(2) Assumes IX media is landfilled as opposed to incinerated due to cost, that PFAS in NF/RO concentrate is destroyed, and that GAC is reactivated.

Table K.30: Comparison of Treatment Options.

| Option | Treatment Technology | Evaluation Criteria | | | | | |
|---|---|---|---|---|---|---|---|
| | | Short -Term Effectiveness | Long -Term Effectiveness (1) | Sustainability - Media Consumption | Sustainability - Energy Use | Operations and Maintenance Requirements | Portion of PFAS Destroyed (2) |
| A | GAC Only | Moderate - Current regulatory drinking water standards could be met with this treatment option, but frequent media changeouts would be required. | Low - should regulatory limits be dropped significantly on PFBA, a GAC-only system would struggle to meet low short-chain effluent limits. | High - A GAC-only system would be expected to have the highest media usage of any treatment options considered. Significant increases in usage would be expected if short-chain PFAS regulatory standards are decreased. | Low - A GAC-only system would have the lowest expected energy use of treatment system. | Moderate - A GAC-only treatment plant would generally not be expected to have significant O&M requirements, but frequent media changeouts would increase O&M tasks and relative difficulty of operations. | High - The vast majority of PFAS removed by GAC would be destroyed upon GAC reactivation. However, this does not account for short-chain PFAS that is not removed by GAC. |
| B | GAC and RO (3) Parallel Trains | High - Current regulatory drinking water standards would be met with this treatment option. | Moderate - RO would effectively remove all short chain PFAS, though only the portion of flow that goes through RO would see significant removal. Short-chain PFAS would be expected to breakthrough the portion of flow that is only treated by GAC, limiting the achievable effluent concentrations. | Moderate - Use of RO membranes on half the influent flow would decrease GAC usage, as only half of the influent water would be treated with adsorptive media. | High - RO membranes require significant energy input to force water through semi-permeable membranes. Systems utilizing RO will have significantly higher energy demand than other treatment alternatives. | High - Use of RO membranes would require significantly more operator and engineer/supervisor oversite of treatment systems as well as more frequent maintenance tasks like membrane cleanings. | High - PFAS removed by GAC would be destroyed during GAC reactivation, and RO concentrate is expected to be destroyed with additional treatment. However, if destruction is not an option, this ranking drops to moderate. |
| C | GAC Treatment with RO Polish | High - Current regulatory drinking water standards would be met with this treatment option. | Moderate - RO would effectively remove all short chain PFAS, though only the portion of flow that goes through RO would see significant removal. Short-chain PFAS would be expected to breakthrough the portion of flow that is only treated by GAC, limiting the achievable effluent concentrations. | High - Use of RO polish would help to remove additional short-chain PFAS, however, as not all water would be treated with RO, GAC treatment would need to meet current regulatory limits for long-chain PFAS. Minimal reduction in adsorptive media use compared to GAC only would be expected based on current PFAS regulations. | High - RO membranes require significant energy input to force water through semi-permeable membranes. Systems utilizing RO will have significantly higher energy demand than other treatment alternatives. | High - Use of RO membranes would require significantly more operator and engineer/supervisor oversite of treatment systems as well as more frequent maintenance tasks like membrane cleanings. | High - PFAS removed by GAC would be destroyed during GAC reactivation, and RO concentrate is expected to be destroyed with additional treatment. However, if destruction is not an option, this ranking drops to moderate. |
| D | GAC Treatment with IX Polish | High - Current regulatory drinking water standards would be met with this treatment option. | High - IX could remove short-chain PFAS, though more frequent resin change outs would be expected. | High - Overall media usage is expected to be high with this treatment option, though use of an IX polish would be expected to decrease GAC changeout frequency due to IX resins improved performance with short-chain PFAS. | Low - Energy use of GAC with IX polish is expected to be similar to a GAC-only system and significantly lower than a treatment system utilizing membranes. | Moderate - A GAC-only treatment plant would generally not be expected to have significant O&M requirements, but frequent media changeouts would increase O&M tasks and relative difficulty of operations. Use of GAC, however, decreases the risk of IX media fouling. | Moderate - PFAS removed by GAC would be destroyed during reactivation while PFAS removed by the IX polish would not be destroyed. Should destruction or regeneration of IX resin become more cost competitive in the future, this ranking would change to high. |
| E | GAC Pretreatment with IX Lead/Lag Treatment | High - Current regulatory drinking water standards would be met with this treatment option. | High - IX could remove short-chain PFAS, though more frequent resin change outs would be expected. | Moderate - Use of IX resin to remove the majority of PFAS is expected to decrease media usage compared to a GAC-only system. Additionally, GAC pretreatment is expected to increase the life of IX resin. | Low - Energy use of GAC pretreatment ahead of IX resin is expected to be similar to a GAC-only system and significantly lower than a treatment system utilizing membranes. | Low - While IX resin can be susceptible to fouling, use of a sacrificial GAC bed ahead of the lead/lag IX vessels would help to protect the resin and significant additional maintenance tasks compared to a GAC-only system are not expected. | Low - Only PFAS removed by GAC would be destroyed when the GAC is reactivated. Should destruction or regeneration of IX resin become more cost competitive in the future, this ranking would change to high. |

(1) Assumes short-chain PFAS regulatory limits significantly decrease in the future, with particular regard to PFBA.

(2) Assumes IX media is landfilled as opposed to incinerated due to cost and that PFAS in RO Concentrate is destroyed.

(3) While both NF and RO membranes are considered in this FS, for simplicity, membranes are referred to as RO in this table. Both NF and RO membrane systems are expected to have similar scoring.

# K5 Pipe Network

Pipe alignments for each scenario were created connecting each well configuration to one or two water treatment plants. These alignments were generated by following existing roadways whenever possible, minimizing impacts to natural spaces, and reducing total pipe length. Once established, they were constructed in an InfoWater Pro hydraulic model, which was used to determine pipe diameters and ensure the drinking water system could operate properly. Cost allocation to pipes and wells was determined for this assessment.

Using the optimal pipe alignments established, the hydraulic model was used to evaluate the conditions within these scenarios. Several key assumptions were utilized throughout this analysis to form the foundation of this hydraulic assessment. These included maintaining a maximum velocity of 5 feet per second (ft/s) for both treated and raw water lines, ensuring the maximum head loss per 1000 ft remained below 10 ft for these lines, and enforcing a system pressure range between 40 psi and 100 psi. This model also assumed that Class 52 ductile iron was the material used for pipes of all diameters, and a roughness value of 125 was applied to all pipes. This could change if directional drilling is utilized as opposed to open cut. Extraction and injection rates were applied to each of the wells in the model, and the resulting flows were used to appropriately size the pipes in the system while following the guidelines mentioned above.

Each scenario modeled has a few locations that either exceed or fall below the pressure requirements, typically found at the high and low points of the system. In this evaluation, we made the assumption that all injection and extraction wells were operating at maximum capacity simultaneously. This was done to calculate pipe sizes in a conservative manner. However, for future simulations, it is advisable to model the wells in this system with a range of operational conditions. Additionally, upcoming assessments may also consider equipment to mitigate these pressure deviations such as pressure relief valves, since these analyses extend beyond the scope of this report.

The details of configurations of the extraction wells, injection wells, and associated pipelines are presented in Table K.31. The piping configurations for each Scenario are shown in Figure K.1 (Scenario 1), Figure K.2 (Scenario 2), and Figure K.3 (Scenario 3).

Table K.31: Scenario Extraction Wells, Injection Wells, and Pipelines.

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Number of extraction (includes new vs. repurposed) | 13 new wells, 2 existing Oakdale supply wells | 10 new wells, 2 existing Oakdale supply wells | 8 new wells |
| Number of injection (includes new vs. repurposed) | 6 new wells, 3 existing Oakdale supply wells | 4 new wells, 3 existing Oakdale supply wells | 5 new wells |
| Total Pipe Length (ft) | 182,800 | 127,200 | 81,800 |
| Maximum Extraction Rate (gpm) | 10,800 | 9,850 | 5,130 |
| Maximum Injection Rate (gpm) (1) | 7,000 | 6,000 | 3,500 |

(1) Maximum Injection Rate is calculated using average daily demand. When demand exceeds the average daily demand, injection rates would be lower. During low demand periods, injection rates could be higher, though field injection studies are required to verify maximum practical injection rate.

Scenario 1 has wells located in Oakdale, Lake Elmo, and West Lakeland. It contains a total of 9 injection wells (6 new and 3 repurposed supply wells), 15 extraction wells (13 new and 2 repurposed supply wells), and 2 water treatment plants (1 new Oakdale facility and 1 new Lake Elmo facility). This is the most extensive of the three scenarios with a total extraction of 10,800 gpm and a total injection of 7,000 gpm. The complete system consists of 182,80 feet of pipe.

Spanning Oakdale and Lake Elmo, Scenario 2 is similar to the setup of Scenario 1 with the exclusion of wells in West Lakeland. This scenario contains a total of 7 injection wells (4 new and 3 repurposed supply wells), 12 extraction wells (10 new and 2 repurposed supply wells), and 2 water treatment plants (1 upgraded and 1 new). The extraction is a total of 9,850 gpm and the injection totals 6,000 gpm. This configuration spans a total pipe length of 127,200 feet and also includes a flow control valve to assist in meeting demands across the system.

Scenario 3 is exclusive to Lake Elmo. It incorporates a total of 5 new injection wells, 8 new extraction wells, and a single new water treatment plant. This scenario has a total extraction rate of 5,130 gpm and a total injection rate of 3,500 gpm. The pipe length in this scenario totals 81,800 feet.

# K6 Costs Summary

The following summarizes the unit costs developed for the MBWA system, including new drinking water treatment facilities equipped with pretreatment process equipment, PFAS removal process equipment, a new building, pumps, chemical treatment, and ancillary equipment and storage. Other cost elements include pipe installation cost per linear foot, installation of new pumps, and new well sites. This appendix assumes reuse of existing storage facilities (water towers) but would not utilize other existing treatment infrastructure. The unit cost estimate reflects the opinion of AECOM of probable construction costs utilizing information available at the time the document was prepared.

AECOM has no control over future costs of construction labor, materials, equipment, nor of contractors' methods of determining prices, nor of competitive construction industry market conditions. The accuracy of the estimates is not guaranteed, and they are not intended to predict the outcome of the construction bidding.

AECOM has based the unit costs in accordance with the Association for the Advancement of Cost Estimating International (AACE) Class V estimating guidance. This opinion of probable costs is based on conceptual design and the basis of estimate summarized in this report. All costs were developed in November 2024 dollars based on the Engineering News-Record’s (ENR) Building Cost Index (BCI) for Minneapolis. All project descriptions and cost estimates in this report represent planning-level accuracy and opinions of costs (-50%, +100%,).

The unit costs have been developed based on cost estimating resources including:

- Local vendor estimates for specialized materials and equipment;
- Construction and installation costs from similar AECOM projects;
- Historical data and prices for similar facilities designed and/or constructed by AECOM;
- Where applicable, historic costs have been inflated based on Engineering News Record construction indices.

The estimated unit cost includes the sum of materials, labor, and equipment of reasonably identified features of a project. The estimated total project cost is the sum of construction costs with additional allowances for direct and indirect costs and contingencies. The engineering costs include design and surveying. This section presents the opinion of probable costs for the following major elements:

- Pipelines
- Injection and Extraction Pumps
- Injection and Extraction Well Sites

- Water Treatment Plant Installation and Upgrades
- Additional Costs: Direct Cost, Indirect Costs, and Contingencies

The following additional direct and indirect costs and contingencies were included while developing costs:

### Direct:

- Mobilization and Site Setup (5%)
- Bonding and Insurance (3%)

### Indirect:

- Contractor Overhead and Profit (15%)
- Engineering and Construction Contingency (45%)

## K6.1 Pipelines

Water pipeline unit costs have been developed based on diameter, project location category, and pipe material costs and are assumed to be constructed within public right-of-way.

The project location will have a significant impact on pipeline installation costs, based on construction complexity, site access, and installation rates. For example, installing pipe in a dense urban area will be costlier than an undeveloped, wide-open field. Unit costs were developed for both developed and undeveloped areas.

- Developed – reflects pipe construction in dense urban areas where roadway rehabilitation and/or concrete replacement will be required; includes major cost components.
- Undeveloped – reflects new pipe construction or replacement of existing pipes in undeveloped areas with minimal constructability barriers; neglecting roadway replacement and utility crossing.

Each pipe segment was reviewed based on the site plan and engineering judgment was used to identify the pipe segment as either developed or undeveloped to account for the constructability and cost implications based on the selected location. The estimated unit cost for pipelines includes the following reasonably identified features:

- Piping, fittings, valves, and water service connections
- Excavation
- Waste of material associated with trenching
- Imported bedding and zone material
- Native backfill
- Testing and disinfection
- Surface restoration
- Dewatering groundwater
- Contractor overhead and profit

The original cost estimate for water distribution mains, as specified in the 2021 WSP Proposal for the MBWA system, was $552 per foot (Wood, 2021). To reflect current market conditions and ensure an accurate representation in today’s market, this figure underwent adjustment using (ENR) BCI for

Minneapolis. BCI was used rather than Construction Cost Index (CCI) because it provides a more conservative modification of costs. Further refinement involved scaling this adjusted value for each pipe diameter, drawing insights from comparative data extracted from a similar project conducted in Denver, CO in 2021. This multi-step process not only accommodates for inflationary changes but also accounts for specific regional and size-based cost variations, resulting in a more accurate and contextually relevant cost estimation for the proposed pipe infrastructure. The costs presented here are preliminary and based on a conceptual analysis of pipelines. Water distribution pipeline sizing would likely change to accommodate standard sizing with final design.

Pipeline unit costs are presented in Table K.32. Project Cost includes direct and indirect costs.

Table K.32: Water Pipeline Unit Costs.

| Pipe Diameter (in) | Construction Cost ($/ft) | | Project Cost ($/ft) | |
|---|---|---|---|---|
| | Developed | Undeveloped | Developed | Undeveloped |
| 10 | $475 | $320 | $760 | $515 |
| 12 | $535 | $365 | $850 | $580 |
| 16 | $690 | $425 | $1,100 | $675 |
| 20 | $750 | $485 | $1,205 | $775 |
| 24 | $875 | $545 | $1,400 | $870 |

An additional factor influencing the pricing of pipe installation pertains to highway crossings. These crossings were deemed necessary whenever the pipe alignment intersected a roadway with more than three lanes in total. Each highway crossing price represents costs necessary to span a crossing of 300 linear feet. The costs associated with highway crossings for different pipe diameters were derived from a comparable project conducted in the Denver Metro area in 2016. These costs were adjusted to align with current market conditions using ENR's BCI for Minneapolis and are presented in Table K.33.

Table K.33: Highway Crossing Unit Costs.

| Diameter (in) | Construction Cost ($/ft) | Project Cost ($/ft) |
|---|---|---|
| 10 | $1,225 | $1,960 |
| 12 | $1,250 | $2,000 |
| 16 | $1,255 | $2,010 |
| 20 | $1,525 | $2,440 |
| 24 | $1,795 | $2,870 |

As an alternative to open-cut installation of water pipeline, horizontal directional drilling (HDD) unit costs were also considered for costing (Table K.34). Final selection would be dependent, in part, on city and county roadwork plans, as open-cut cost estimates assume removal and reinstallation of roadways. If road replacement is already planned, the costs to install piping with an open-cut may be more competitive with HDD. Final selection may include a combination of both installation methods if either HDD or open-cut cannot be used in certain areas.

Table K.34: Horizontal Directional Drilling Unit Costs.

| Diameter (in) | **Construction Cost ($/ft)** | Project Cost **($/ft)** |
|---|---|---|
| 10 | $140 | $230 |
| 12 | $160 | $260 |
| 16 | $220 | $360 |
| 20 | $277 | $450 |
| 24 | $347 | $560 |

The total project costs for open-cut and HDD water pipeline installation as well as highway crossings are presented in Table K.35.

Table K.35: Total Project Costs for Piping.

| Scenario | Piping (Open Cut) | Piping (HDD) | Highway Crossings |
|---|---|---|---|
| 1 | $176,144,000 | $59,141,000 | $13,193,000 |
| 2 | $110,938,000 | $36,311,000 | $11,825,000 |
| 3 | $68,974,000 | $22,862,000 | $7,721,000 |

## K6.2 Pumps and Wells

The cost estimates for well pumps, well motors, and well construction as presented in this section were obtained from a local vendor's estimates, ensuring that they reflect current market conditions and localized pricing. Estimates were obtained for pumps and motors of various horsepower, including 75HP, 125HP, 150HP, 175HP, and 200HP. Horsepower for each pump motor was calculated based on the flow rate and head, and an appropriate capacity value was then selected for cost estimation. Detailed costs estimates by Scenario are provided in Table K.36 (Scenario 1), Table K.37 (Scenario 2), and Table K.38 (Scenario 3).

Table K.36: Scenario 1 Pump and Well Costs.

| Item | **Quantity** | Price per Unit ($) | Total Cost ($) |
|---|---|---|---|
| New well install (extraction) | 13 | $500,000 | $6,500,000 |
| 125 HP extraction pump | 6 | $185,000 | $1,110,000 |
| 150 HP extraction pump | 2 | $200,000 | $400,000 |
| 175 HP extraction pump | 5 | $225,000 | $1,125,000 |
| 200 HP extraction pump | 2 | $250,000 | $500,000 |
|  |  | **Subtotal Extraction** | $9,635,000 |
| New well install (injection) | 6 | $500,000 | $3,000,000 |
| Remove extraction, convert to injection | 3 | $25,000 | $75,000 |
| 2000 gpm of injection | 3.5 | $100,000 | $350,000 |
|  |  | **Subtotal Injection** | $3,425,000 |
| Solids IDW Cost | - | - | $2,000,000 |
|  |  | TOTAL | $15,060,000 |

Legend: IDW = Investigation Derived Waste.

Table K.37: Scenario 2 Pump and Well Costs.

| Item | Quantity | Price per Unit ($) | Total Cost ($) |
|---|---|---|---|
| New well install (extraction) | 10 | $500,000 | $5,000,000 |
| 75 HP extraction pump | 2 | $150,000 | $300,000 |
| 125 HP extraction pump | 3 | $185,000 | $555,000 |
| 150 HP extraction pump | 1 | $200,000 | $200,000 |
| 175 HP extraction pump | 3 | $225,000 | $675,000 |
| 200 HP extraction pump | 3 | $250,000 | $750,000 |
| | | **Subtotal Extraction** | $7,480,000 |
| New well install (injection) | 4 | $500,000 | $2,000,000 |
| Remove extraction, convert to injection | 3 | $25,000 | $75,000 |
| 2000 gpm of injection | 2.5 | $100,000 | $250,000 |
| | | **Subtotal Injection** | $2,325,000 |
| Solids IDW Cost | - | - | $1,600,000 |
| | | TOTAL | $11,405,000 |

Table K.38: Scenario 3 Pump and Well Costs.

| Item | Quantity | Price per Unit ($) | Total Cost ($) |
|---|---|---|---|
| New well install (extraction) | 8 | $500,000 | $4,000,000 |
| 75 HP extraction pump | 2 | $150,000 | $300,000 |
| 125 HP extraction pump | 3 | $185,000 | $555,000 |
| 150 HP extraction pump | 3 | $200,000 | $600,000 |
| | | **Subtotal Extraction** | $5,455,000 |
| New well install (injection) | 5 | $500,000 | $2,500,000 |
| 2000 gpm of injection | 1.75 | $100,000 | $175,000 |
| | | **Subtotal Injection** | $2,675,000 |
| Solids IDW Cost | - | - | $1,400,000 |
| | | TOTAL | $9,530,000 |

## K6.3 Water Treatment Facilities

The cost estimates presented in this section include the capital expenditure (CAPEX) and operation and maintenance costs, or operating expenditure (OPEX) associated with each treatment option for each of the three scenarios. CAPEX costs considered the process equipment and associated ancillary equipment, backwash storage, pumping, piping and valving, chemical feed and storage, and building footprint based on 2024 RS Means unit cost (inclusive of Electrical, Plumbing, HVAC, and Architectural). The CAPEX costs are inclusive of direct and indirect costs and are presented for each Scenario and treatment option in Table K.39. A more detailed cost breakdown for CAPEX and OPEX for each option with each scenario is presented in Section 9 of the FS.

Table K.39: WTP CAPEX by Scenario.

| **Treatment Options** | Oakdale WTP | Lake Elmo WTP |
|---|---|---|
| Scenario 1 | | |
| Option A: GAC Treatment for PFAS | $52,938,000 | $58,039,000 |
| Option B: GAC and NF/RO Parallel Trains | $56,694,000 | $61,794,000 |
| Option C: GAC with NF/RO Polish | $67,138,000 | $72,238,000 |
| Option D: GAC Treatment with IX Polish | $60,759,000 | $67,121,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | $59,703,000 | $65,889,000 |
| Scenario 2 | | |
| Option A: GAC Treatment for PFAS | $40,860,000 | $59,658,000 |
| Option B: GAC and NF/RO Parallel Trains | $44,040,000 | $65,442,000 |
| Option C: GAC with NF/RO Polish | $51,002,000 | $75,886,000 |
| Option D: GAC Treatment with IX Polish | $47,419,000 | $68,740,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | $46,539,000 | $67,508,000 |
| Scenario 3 | | |
| Option A: GAC Treatment for PFAS | - | $52,857,000 |
| Option B: GAC and NF/RO Parallel Trains | - | $56,613,000 |
| Option C: GAC with NF/RO Polish | - | $67,057,000 |
| Option D: GAC Treatment with IX Polish | - | $60,678,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | - | $59,622,000 |

The following summarizes the methodology used to develop the OPEX costs for the treatment trains considered in this appendix, including estimated media usage, chemical usage, process testing, labor costs, electrical use, and replacement parts/operational equipment. AECOM has no control over future costs of construction labor, materials, equipment, nor of vendors' methods of determining prices, nor of competitive construction industry market conditions. The accuracy of the estimates is not guaranteed. Assumptions made for each category of costs are detailed in Table K.40.

Table K.40: Operating Expenditure (OPEX) Cost Estimating General Assumptions.

| Parameter | Assumptions |
|---|---|
| PFAS Testing | • $700/sample for rapid testing<br>• Weekly influent and effluent testing for all treatment trains<br>• Mid-bed and post samples for adsorptive media (GAC/IX) |
| Process / NPDES Testing | • $1000 per week |
| Electrical Costs | • $0.10 / kilowatt hour (kWh)<br>• RO System (where applicable): 24/7 operations @ 90% uptime (7884 hours per year)<br>• 80% efficiency for pumps |
| Labor Costs | • $65 / hour for operators<br>• $150 / hour for engineer or supervisor |
| Replacement Parts & Operations Equipment | • 2% of total process equipment CAPEX cost |
| Sewer Cost | • Discharge to sanitary sewer<br>• Yearly permit at $10,325 from the Metropolitan Council<br>• Cost of $2.31 per 1000 gal of discharge |
| GAC Media Costs | • GAC quoted at $2.25 per pound with shipping |
| IX Media Costs | • IX quoted at $439 per cubic foot |
| GAC and IX Disposal Costs | • All GAC and IX media would be landfilled<br>• Landfilling cost of $12,000 per trip 15 tons of material |
| Chemical Dosing | • Chlorine dose based on Iron and Manganese concentrations in measured background water quality |

Vendor budgetary estimates were used for virgin GAC and IX resin. GAC was quoted at $2.25 per pound delivered to Lake Elmo, MN. IX resin was quoted at $439 per cubic foot. Media changeout frequencies were estimated based on the results from the RSSCTs. The results for the RSSCT are provided in Appendix H and summarized in Section 10 of this FS. Results indicated improved PFAS removal with IX resin over GAC media. Overall GAC media changeout frequency (for the lead vessel) for Options A, B, C, and D is estimated to be approximately every 15 to 25 days and is 65%-80% of the annual OPEX. IX will likely require fewer changeouts than GAC and for Options D and E is 111% and 40% of the OPEX, respectively. Final selection of a treatment train should not be completed until additional bench- and pilot-scale testing is performed to validate design assumptions made in this appendix.

Landfilling costs were estimated from a similar project within the Midwest at approximately $12,000 per 15 tons of material; as PFAS disposal regulations change, this cost may increase in the future. Sewer costs were estimated based on discharge rates published by the Metropolitan Council of $2.31 per 1000 gal for industrial users (MCES, 2024). The volume of water discharged to sewer was estimated using preliminary design criteria for greensand pretreatment for iron and manganese removal, which would require backwashing every 32-35 hr. Two backwash volumes of the greensand filter were assumed to accommodate all backwash volume needs.

The storage and disposal of NF/RO concentrate was lumped into the total cost estimate for the NF/RO systems. The cost of the NF/RO membrane replacement was assumed to be 20% of the total membrane elements annually.

Replacement parts and operations equipment was estimated to be 2% of the total equipment cost. Electrical costs were assumed at $0.10/kWh and based on the assumed pump sizes required for backwash, final finished water pumping, and NF/RO (where applicable).

The labor rate for treatment plant operators was estimated at $65/hr for two full time operators. This rate assumes direct hire of treatment plant operators. Labor rates for an engineer/supervisor was estimated at $150/hr for a half-time staffed position. Direct hire of an engineer or supervisor or outsourcing of treatment plant operators would likely result in a change to the yearly salary estimates.

The OPEX costs for each Scenario and treatment option are presented in Table K.41.

Table K.41: WTP OPEX by Scenario.

| **Treatment Options** | Oakdale WTP | Lake Elmo WTP |
|---|---|---|
| Scenario 1 | | |
| Option A: GAC Treatment for PFAS | $16,278,000 | $17,810,000 |
| Option B: GAC and NF/RO Parallel Trains | $9,464,000 | $10,269,000 |
| Option C: GAC with NF/RO Polish | $17,122,000 | $18,654,000 |
| Option D: GAC Treatment with IX Polish | $13,678,000 | $14,951,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | $4,012,000 | $4,352,000 |
| Scenario 2 | | |
| Option A: GAC Treatment for PFAS | $11,859,000 | $19,237,000 |
| Option B: GAC and NF/RO Parallel Trains | $6,975,000 | $11,099,000 |
| Option C: GAC with NF/RO Polish | $12,469,000 | $20,213,000 |
| Option D: GAC Treatment with IX Polish | $10,001,000 | $16,140,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | $3,066,000 | $4,594,000 |
| Scenario 3 | | |
| Option A: GAC Treatment for PFAS | - | $16,199,000 |
| Option B: GAC and NF/RO Parallel Trains | - | $9,430,000 |
| Option C: GAC with NF/RO Polish | - | $17,053,000 |
| Option D: GAC Treatment with IX Polish | - | $13,618,000 |
| Option E: Sacrificial GAC with IX Lead/Lag | - | $3,999,000 |

## K6.4 Total Project Costs

Total project costs are presented in Table K.42 as the lowest and highest costs for each scenario. The low-range piping costs correspond to the costs previously presented for horizontal directional drilling, as these costs are estimated to be less than open cut methods. The high range costs presented for piping are the estimates for open cut piping methods. Highway crossings and pumps and wells are presented as a single cost estimate. The water treatment plant high and low costs assume that a single water treatment option is selected for the water treatment plant(s). For example, for Scenario 1, the low range is presented as the lowest cost for both Oakdale and Lake Elmo facilities, which happens to be the Option A – GAC treatment train. The high range for Scenario 1 is the highest sum of costs for Oakdale and Lake Elmo facilities with Option C – GAC with NF/RO Polish selected. Option A is the cheapest option for all three scenarios, and Option C is the most expensive for all three scenarios.

Table K.42: Total Project Costs by Scenario.

| Cost Element | Scenario 1 | | Scenario 2 | | Scenario 3 | |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | Low | High |
| Piping | $59,141,000 | $176,144,000 | $36,311,000 | $110,938,000 | $22,862,000 | $66,974,000 |
| Highway Crossings | $13,193,000 | $13,193,000 | $11,825,000 | $11,825,000 | $7,721,000 | $7,721,000 |
| Pumps & Wells | $15,060,000 | $15,060,000 | $11,405,000 | $11,405,000 | $9,530,000 | $9,530,000 |
| WTP | $110,977,000 | $139,376,000 | $100,518,000 | $126,888,000 | $52,857,000 | $67,057,000 |
| Total | $198,371,000 | $343,773,000 | $160,059,000 | $261,056,000 | $92,970,000 | $151,282,000 |

# K7 Recommendation for MBWA

The three MBWA Scenarios were all evaluated considering five water treatment options. All options include GAC as either treatment for PFAS removal or for removal of chlorine and competing organics such as TOC. Two options include NF/RO for PFAS removal to be blended with GAC effluent, and two options included IX for PFAS removal. Based on the evaluation of treatment options, which includes comparisons of treatment effectiveness, sustainability, O&M requirements, and cost, Option E – Sacrificial GAC with IX Lead/Lag is recommend for treatment across all three Scenarios. The results of the RSSCT indicate that IX resin is significantly more effective at removing long-chain and short-chain PFAS and has a longer estimated bed life than GAC media. The estimated GAC media changeout frequency for other alternatives is likely to be cost prohibitive when GAC is used for PFAS removal and would be a O&M challenge to facilitate frequent media changeouts. While membrane systems would be effective at generating a permeate stream with lower short-chain PFAS in the distributed water, treatment of the membrane concentrate stream is not included in this analysis. As CAPEX costs for a membrane system are either similar or exceed that of Option E and OPEX costs for a membrane system exceed that of Option E without even considering the additional cost of membrane concentrate treatment, a membrane-based system is also not recommended at this time due to the higher costs. Thus, Option E is recommended for treatment across all Scenarios.

The overall recommendation of the Project 1007 FS (see Section 14) is Alternative 8, which would utilize Scenario 1. Secondary recommendations are Alternative 6 (which would utilize Scenario 3) and Alternative 4, which would not utilize a MBWA. Alternative 8 could be implemented as a multiphase project as depicted in Figure K.35. In a phased approach, WTPs in the Cities of Lake Elmo and Oakdale would be constructed as part of Phase 1 and Phase 2, respectively, to prioritize provision of clean drinking water to communities. Subsequent phases would expand the system capacity with additional extraction and injection wells and associated pipelines located in Lake Elmo, Oakdale, Woodbury, and West Lakeland. Phasing could be staggered such that the design phase for subsequent phases could begin during the construction phase of each preceding phase. Completion of all five phases could occur over the duration of 10 years.

With the multi-phase implementation of Alternative 8, capital costs could be distributed over a 10-year duration. Table K.43 shows the costs of each individual phase for Alternative 8. Phasing costs should consider escalation to the mid-point of construction for each phase. For the purpose of this feasibility study, the annual escalation rate was assumed to be 3.5%.

Table K.43: Alternative 8 MBWA Implementation Phases.

| Phase | **Construction Year Mid-Point** | Project Cost per Phase **(No Escalation)** | Project Cost per Phase **(3.5% Escalation)** |
|---|---|---|---|
| 1 | 3 | $100,996,000 | $111,976,000 |
| 2 | 4 | $86,773,000 | $102,220,000 |
| 3 | 6 | $50,801,000 | $62,448,000 |
| 4 | 8 | $20,701,000 | $27,259,000 |
| 5 | 9 | $70,720,000 | $96,384,000 |
| Total | - | $329,991,000 | $400,287,000 |

Alternative 6 is secondary recommendation of this FS. This could also be constructed in a phased approach as shown in Figure K.36.

# K8 Next Steps

This appendix presents three conceptual MBWAs that could be used to provide drinking water and gradient control of PFAS-impacted groundwater in the East Metro. Pursuit of a MBWA is recommended as a component of the overall remedial action. Specifically, based on the improved plume control and provision of drinking water to multiple communities, Section 14 of the Project 1007 FS recommends Remedial Alternative 8, which incorporates Scenario 1 of the MBWA, as the preferred remedial alternative. Additionally, Alternative 6, which incorporates Scenario 3, is the secondary recommendation in Section 14. The conceptual scenarios discussed in this appendix are not indicative of a final design. Additional work is needed prior to selection of a PFAS treatment train and configuration of a final MBWA. Next steps for selecting a treatment option are summarized in Figure K.37, as well as next steps for implementation and incorporation into community drinking water plans. As both recommended alternatives incorporate a version of the MBWA, next steps are applicable to both recommendations.

Pilot-scale and treatability (bench-scale) studies are the first step towards selecting a treatment option. RSSCTs to compare GAC and IX were conducted as part of this FS, with results demonstrating that IX had superior performance to GAC. However, only one type of GAC and one type of IX resin were evaluated. Additional testing is recommended to evaluate additional IX media to select the optimal IX media for this application. Breakthrough was not observed in all IX RSSCT, thus longer analysis is also recommended to ensure media breakthrough occurs to provide a better estimate of media life. In addition to more bench-testing, an IX pilot study is recommended to further evaluate IX treatment at a larger scale. A pilot study could compare IX media with and without GAC prefiltration to determine if GAC prefilters are indeed required for long-term operations of IX resin. If GAC is not required, CAPEX costs would be decreased. While bench- and pilot-scale testing can be a significant investment, it is essential to ensure the final treatment option selection and ensuing treatment plant design will provide clean drinking water to communities for decades to come in a cost-effective manner. The bench and pilot-scale testing plan should be completed with feedback from MDH to confirm all necessary regulatory data is collected as part of the testing process.

Bedrock aquifer injection pilot studies are also needed prior to implementation of a MBWA. Prior to full-scale design, it is imperative to know and understand the groundwater chemistry, geological formations, and variation in geology between the various extraction well and injection well sites. Considerations for design of extraction wells also include additional borings and modeling as necessary, hydrogeological evaluations, sizing and flow rates, frequency of operation, maintenance considerations and monitoring requirements. Pumping tests are recommended to understand the impacts on groundwater transmissivity and potential for mounding. Injection is not a common practice in Minnesota; while the findings from injection studies will be key for design considerations, they will also be important in demonstrating injection to State regulators ahead of permit approvals.

Stakeholder engagement is needed for selecting the final treatment option as well as for incorporating a MBWA into the planned improvements for communities. As previously discussed, much of the community water treatment system information was sourced from the CDWSP, which was published in 2021. Updates to community plans may not be reflected in the conceptual MBWA scenarios presented in this appendix. Community input and participation is needed to tailor the selected remedial alternative to work for their communities as a long-term, holistic solution. Specifically, this will likely include:

- Updating community water treatment information from CDWSP;
- Aligning community 2050 demand with MBWA scenarios;
- Tailoring MBWA to meet community needs and to integrate with current and planned updates to community water treatment plants.

The final MBWA may not match any of the three conceptual scenarios evaluated in this appendix. Fundamentally, this FS is recommending the pursuit of a system that combines remediation and control of the PFAS groundwater plume in the East Metro drinking water aquifers with provision of drinking waters to the affected communities. Community engagement is critical to tailor a system to fit the needs of both groundwater gradient control and drinking water supply.

State engagement is also needed to guarantee all stakeholders are in-agreement as to the best course of action. Specific engagement with the Minnesota Department of Natural Resources (MDNR), MDH, and MPCA is expected. Engagement with State stakeholders may help to facilitate permitting; more information on expected permitting required is given in Section 14 of the FS. Additionally, stakeholder engagement will be needed to confirm projected 2050 demands.

After selection of a drinking water treatment technology and finalization of a MBWA configuration, evaluation and selection of a destruction technology is then recommended. Drinking water treatment technologies considered in this appendix are all separation technologies which remove PFAS from the bulk liquid phase and concentrate the PFAS onto an adsorbent media (GAC and IX) or in a concentrate stream (NF/RO). Ultimate destruction of the PFAS removed by treatment, while outside the scope of this appendix to evaluate, would require one or more additional treatment technologies. This is particularly crucial if IX is selected as there are currently limited disposal options for IX media. Bench-scale studies were conducted on Site-specific SAFF® concentrate as part of this FS (see Appendix G). Further evaluation is needed once a drinking water treatment technology is selected, as destruction technology effectiveness varies depending on the waste input. As mentioned previously, these efforts may overlap with remediation efforts at WCL, offering the opportunity to potentially combine treatment and reduce overall project costs.

Implementation of a MBWA offers the ability to provide clean drinking water to residents in currently impacted communities, slow the migration of PFAS throughout drinking water aquifers in the East Metro, and protect downgradient communities that are currently minimally impacted or unimpacted. The aforementioned next steps are critical for successful design and implementation of a MBWA and will help to protect East Metro residents from exposure to PFAS in drinking water.

# K9 References

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# K10 Figures

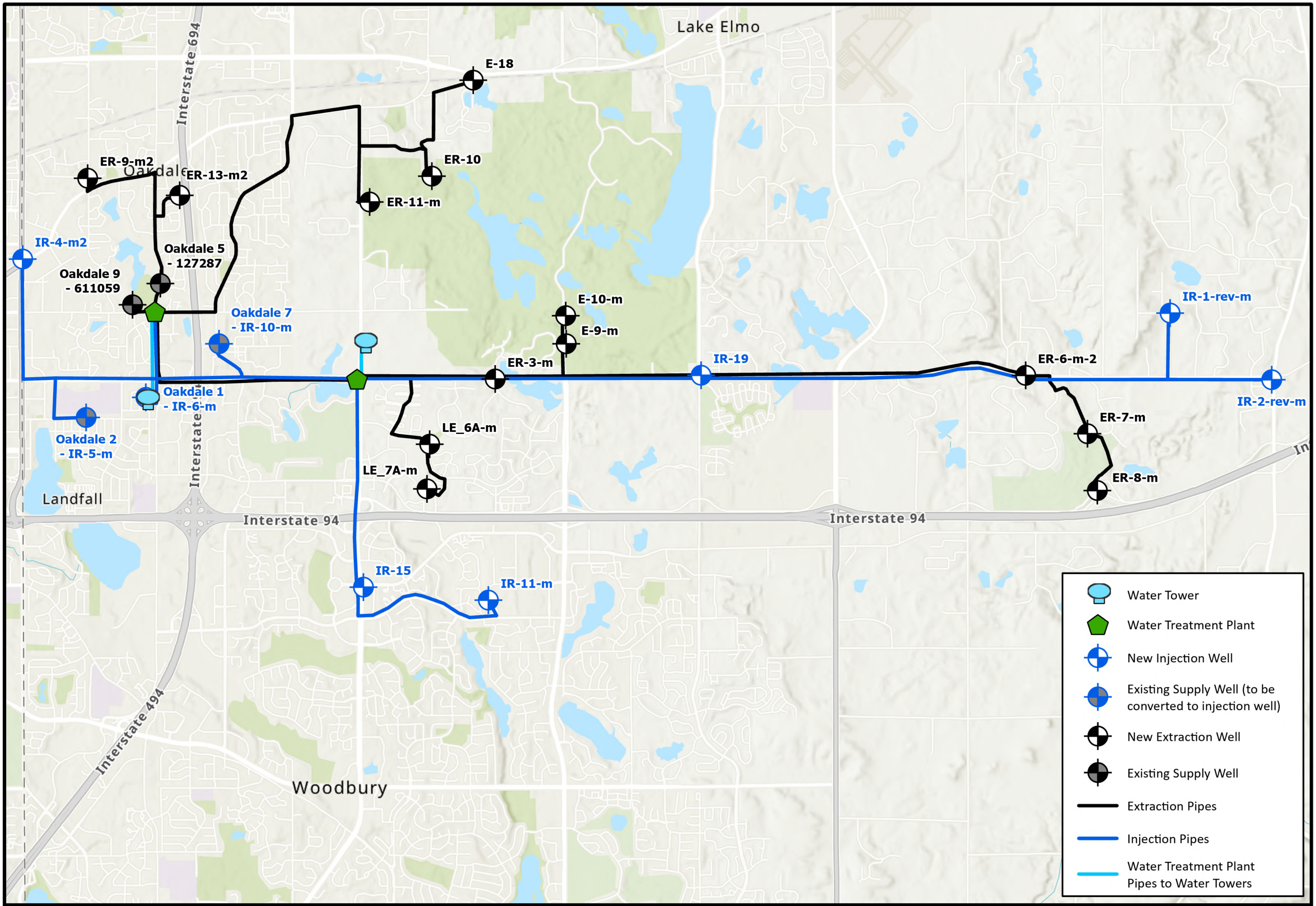

**Figure K.1: Scenario 1 Multi-Benefit Well Array Piping Configuration Project 1007 Feasibility Study**

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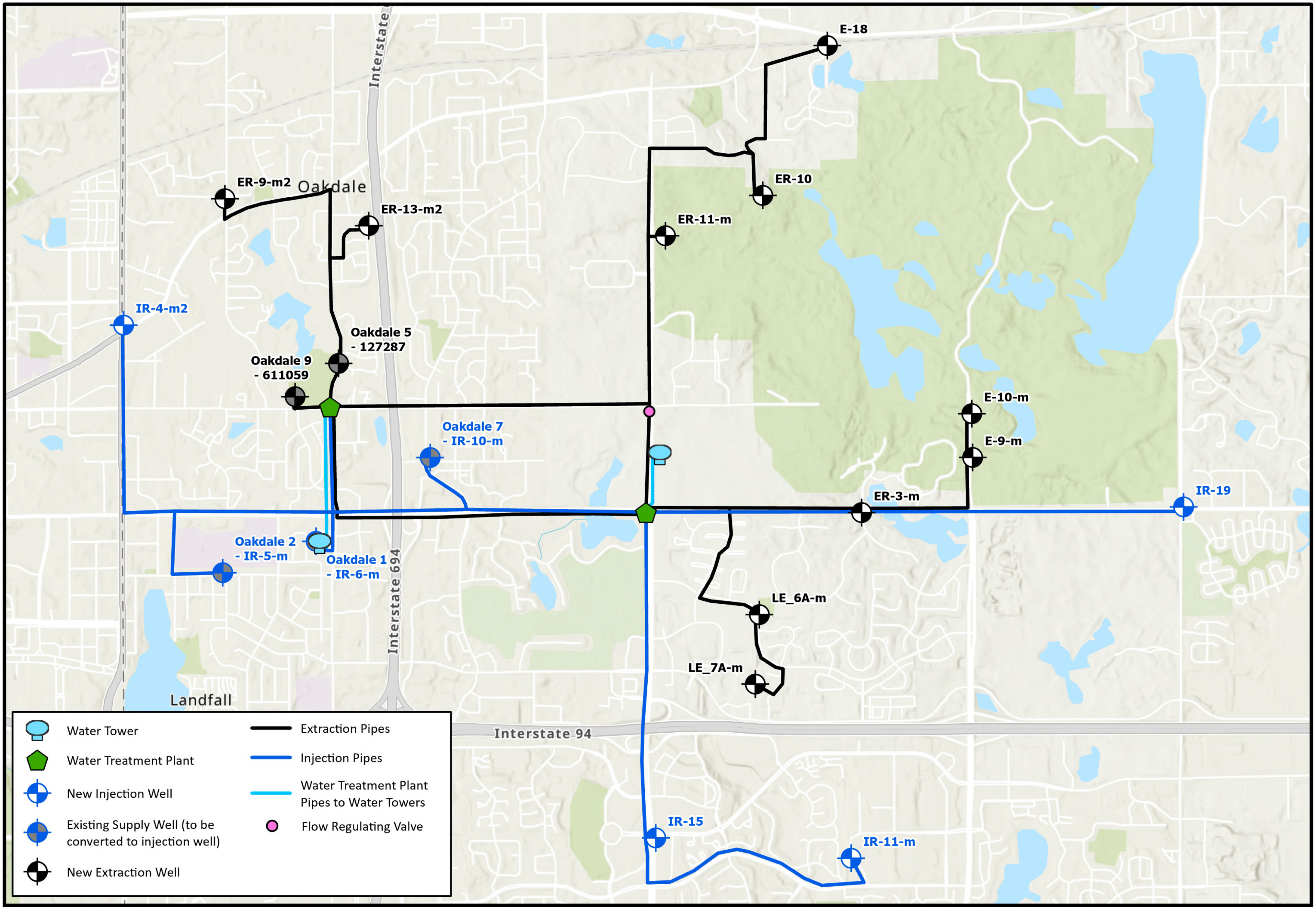

**Figure K.2: Scenario 2 Multi-Benefit Well Array Piping Configuration Project 1007 Feasibility Study**

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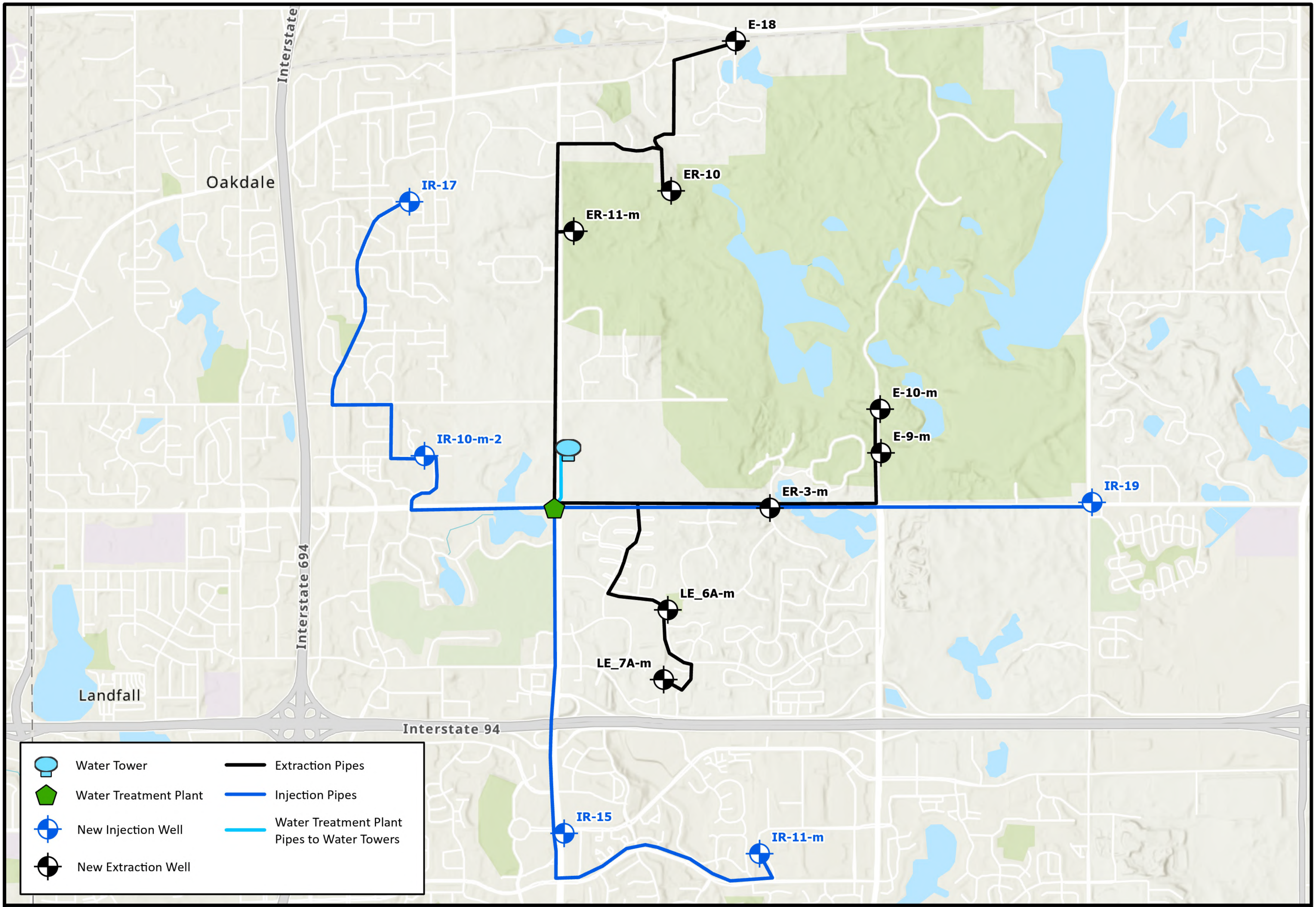

**Figure K.3: Scenario 3 Multi-Benefit Well Array Piping Configuration**
**Project 1007 Feasibility Study**

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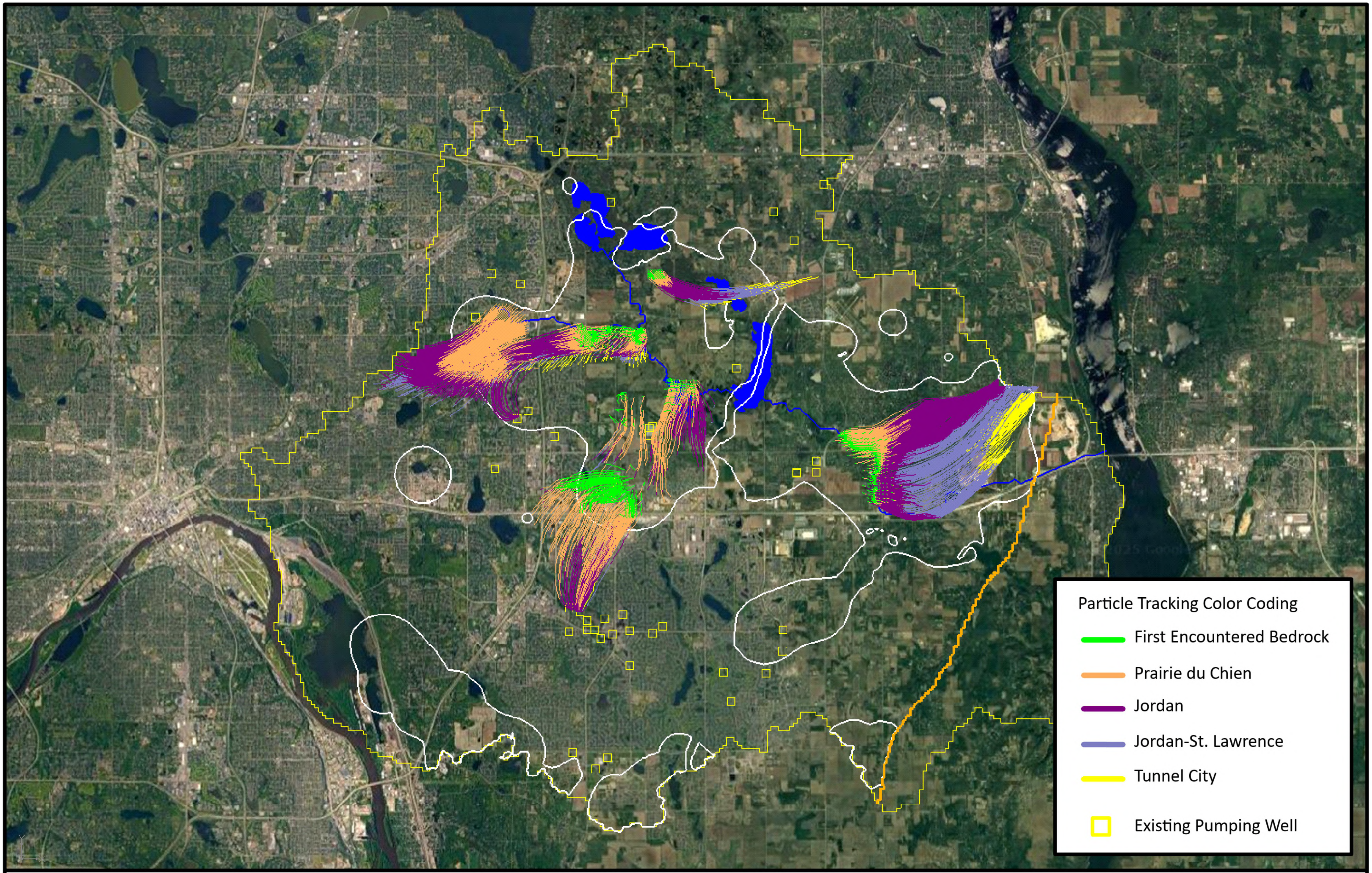

**Figure K.4: Current Pumping Conditions Particle Tracking**
**First Encountered Bedrock and Prairie du Chien Release**
**Project 1007 Feasibility Study**

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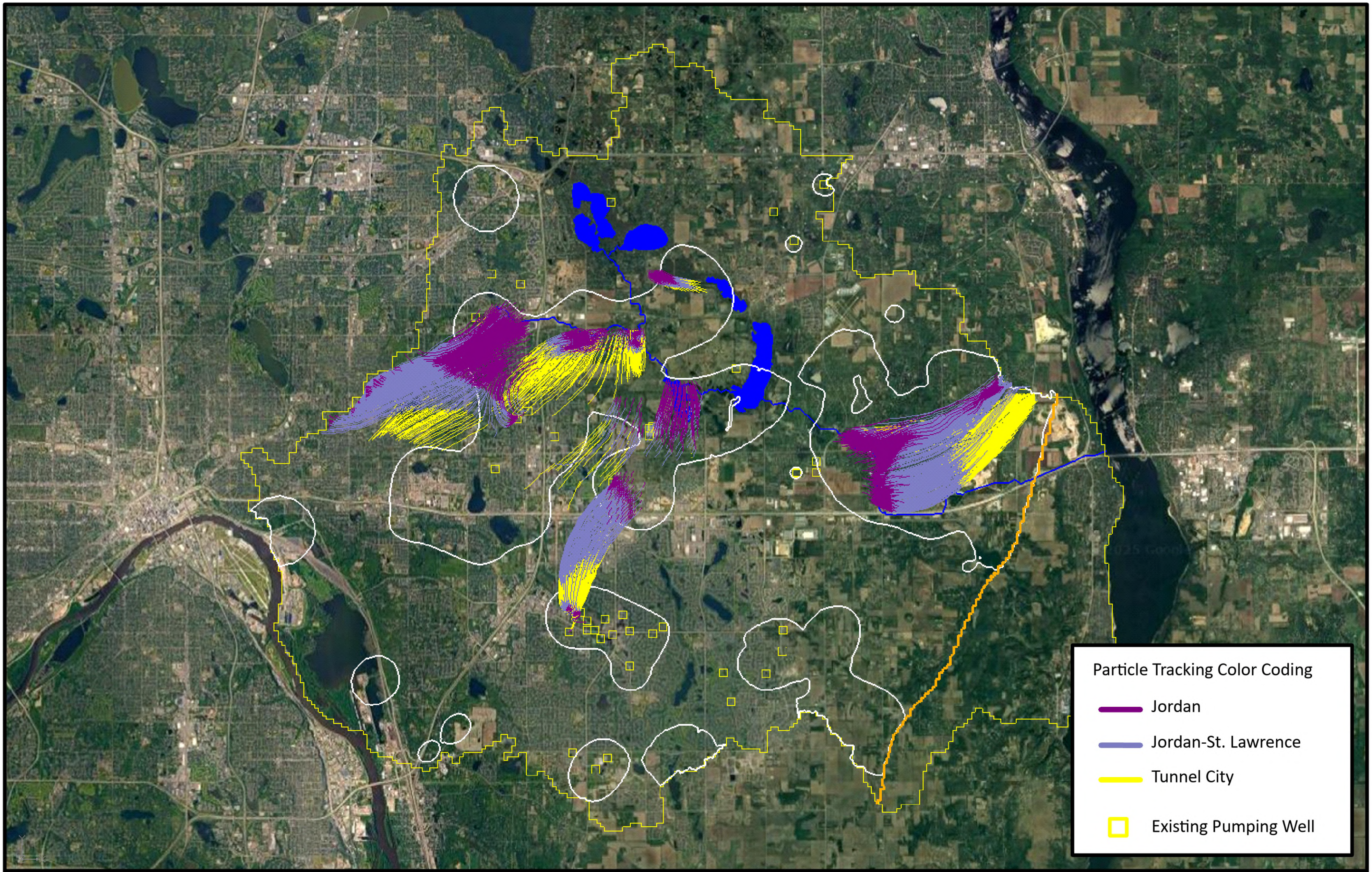

**Figure K.5: Current Pumping Conditions Particle Tracking**
**Jordan Release**
**Project 1007 Feasibility Study**

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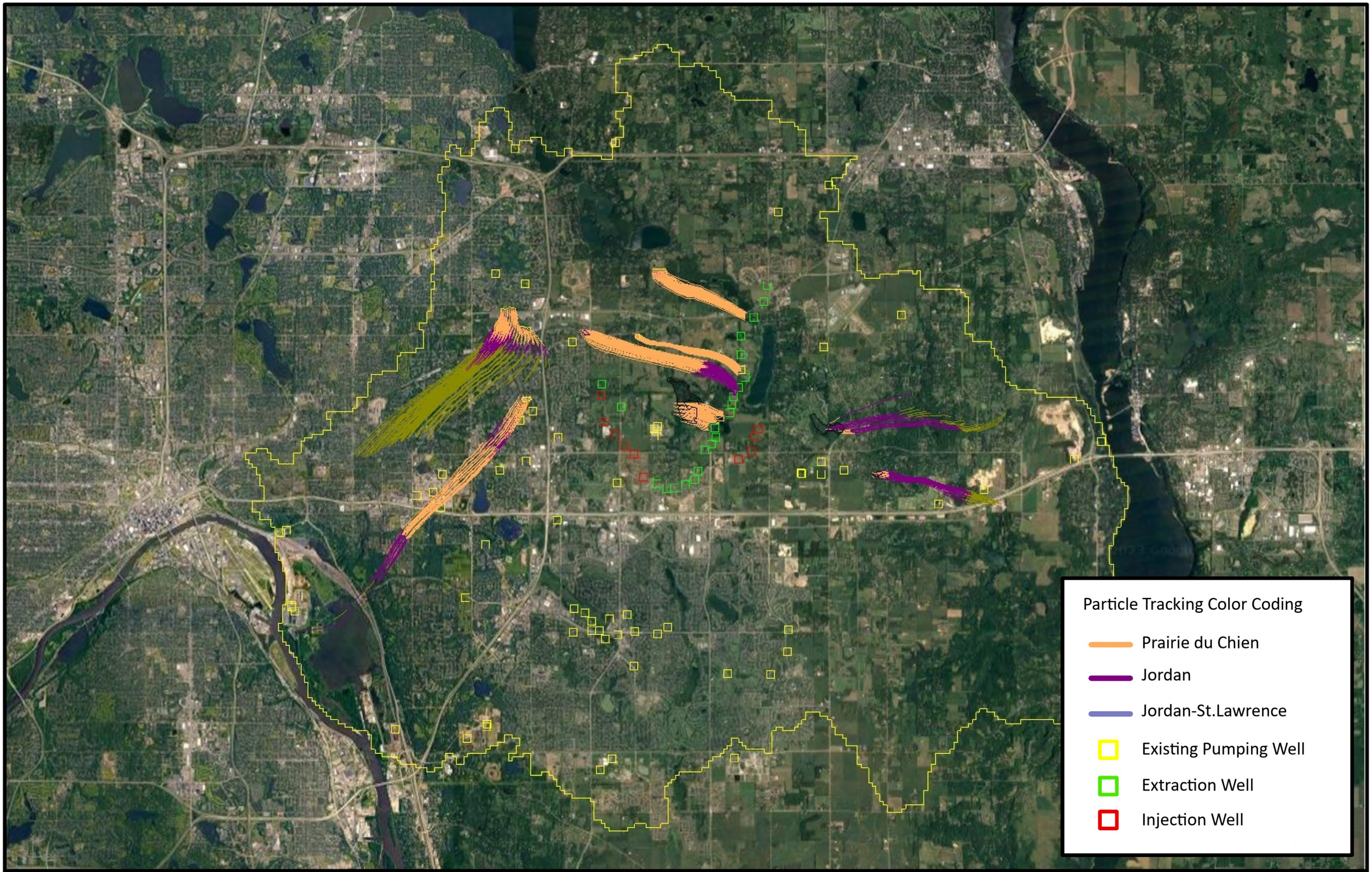

**Figure K.6: Wood Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

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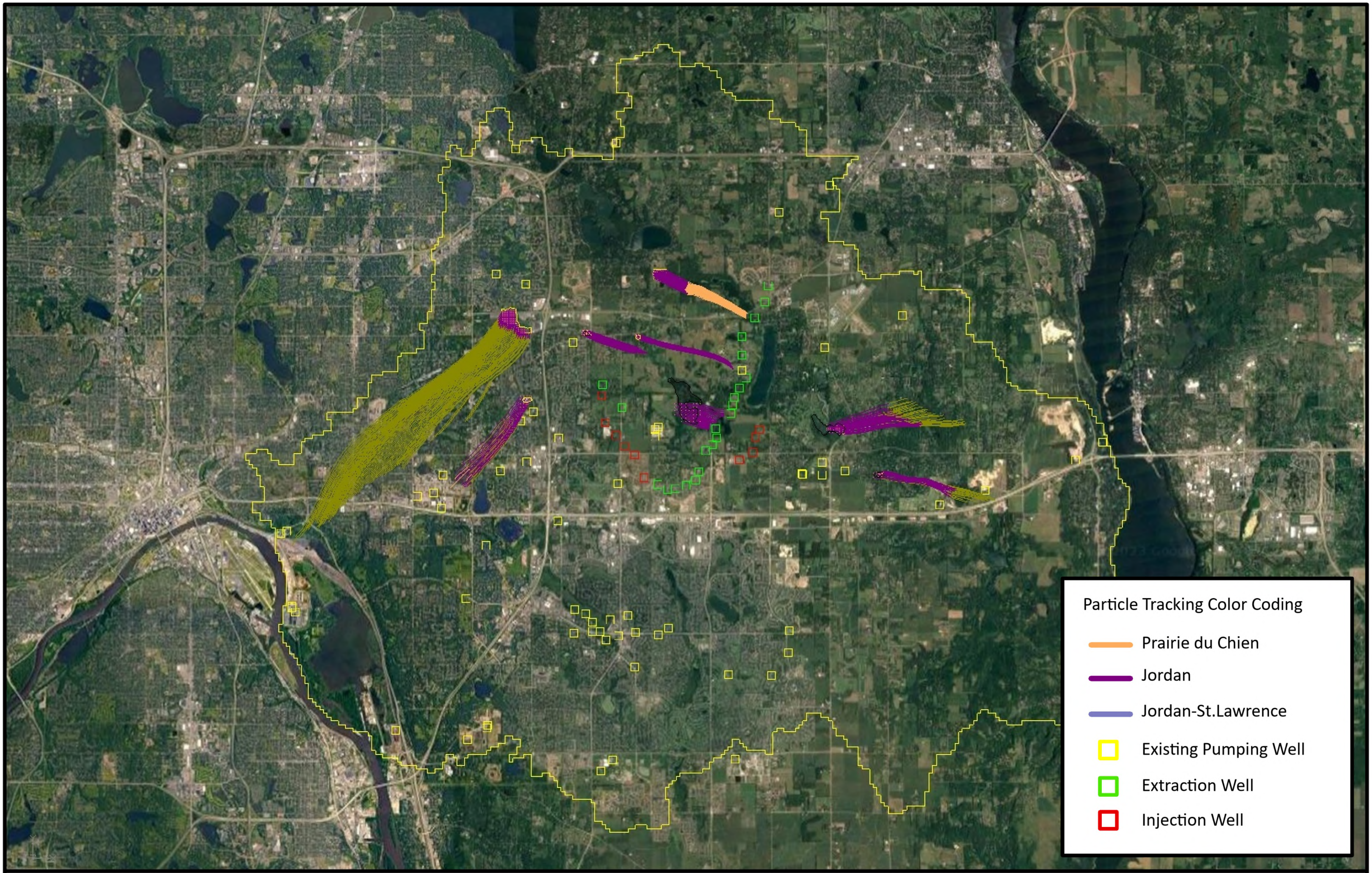

**Figure K.7: Wood Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

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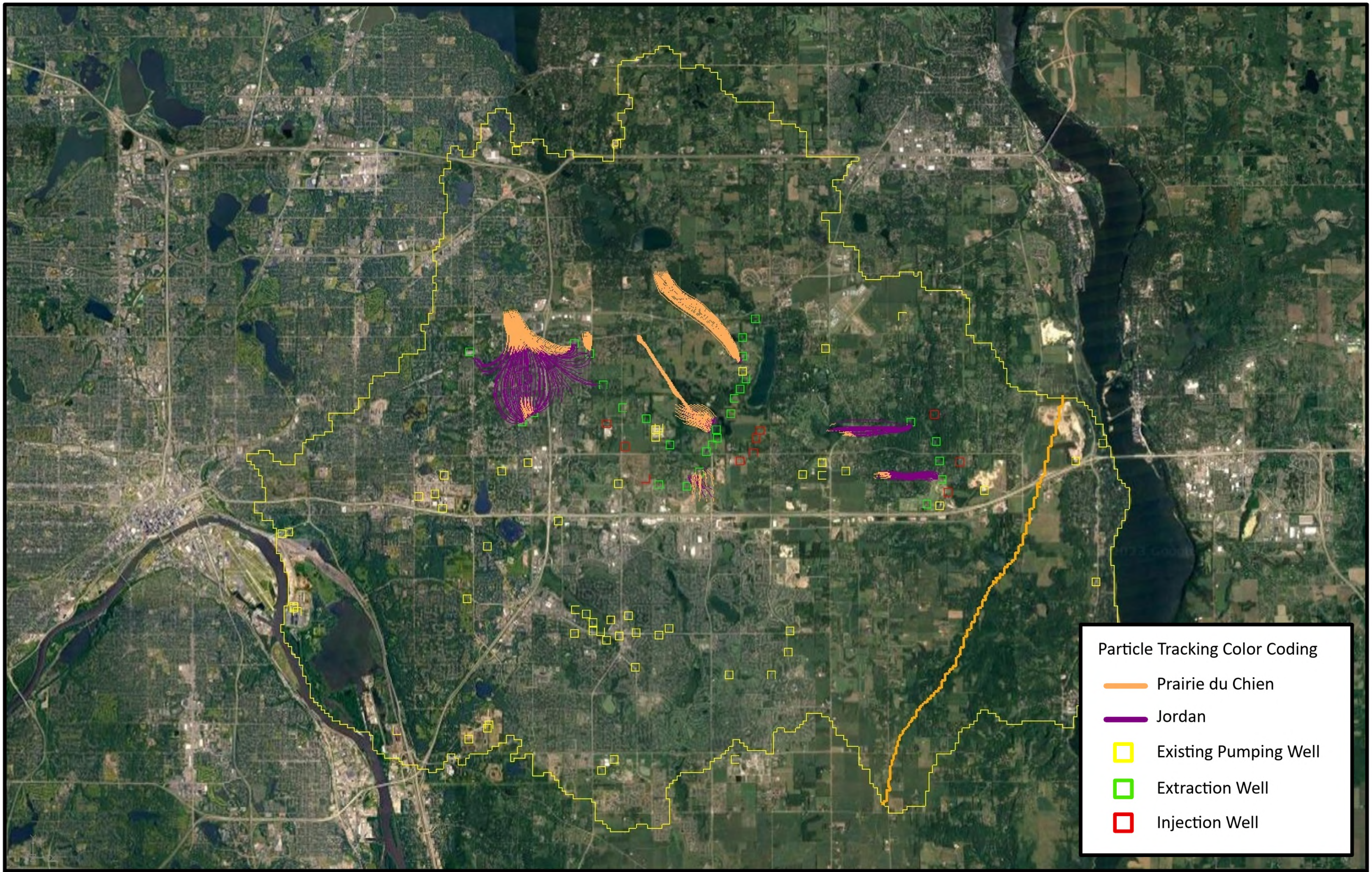

Figure K.8: AECOM 1 Particle Tracking Configuration
Prairie du Chien Release
Project 1007 Feasibility Study

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

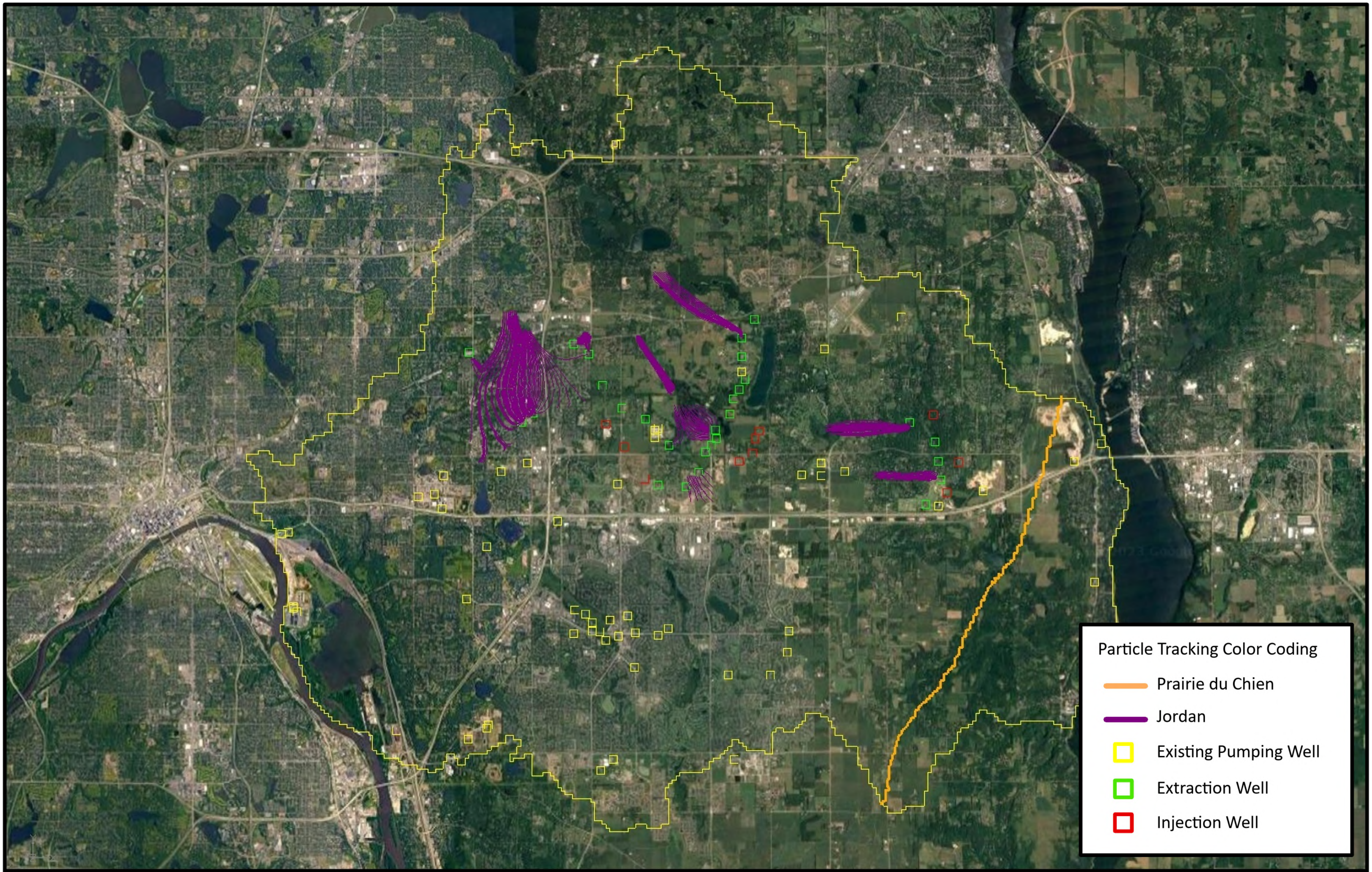

**Figure K.9: AECOM 1 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

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AECOM

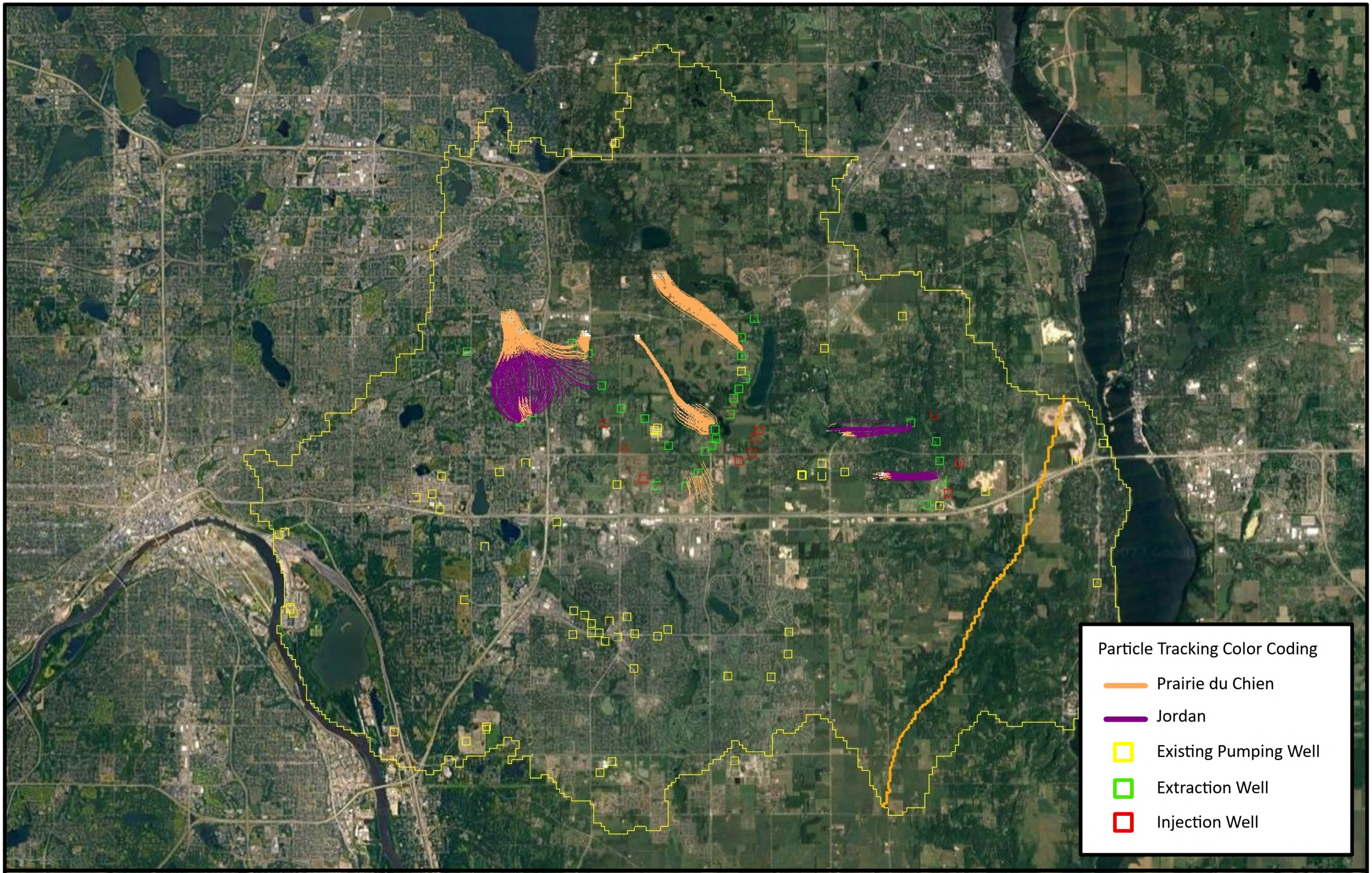

**Figure K.10: AECOM 2 Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

N

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

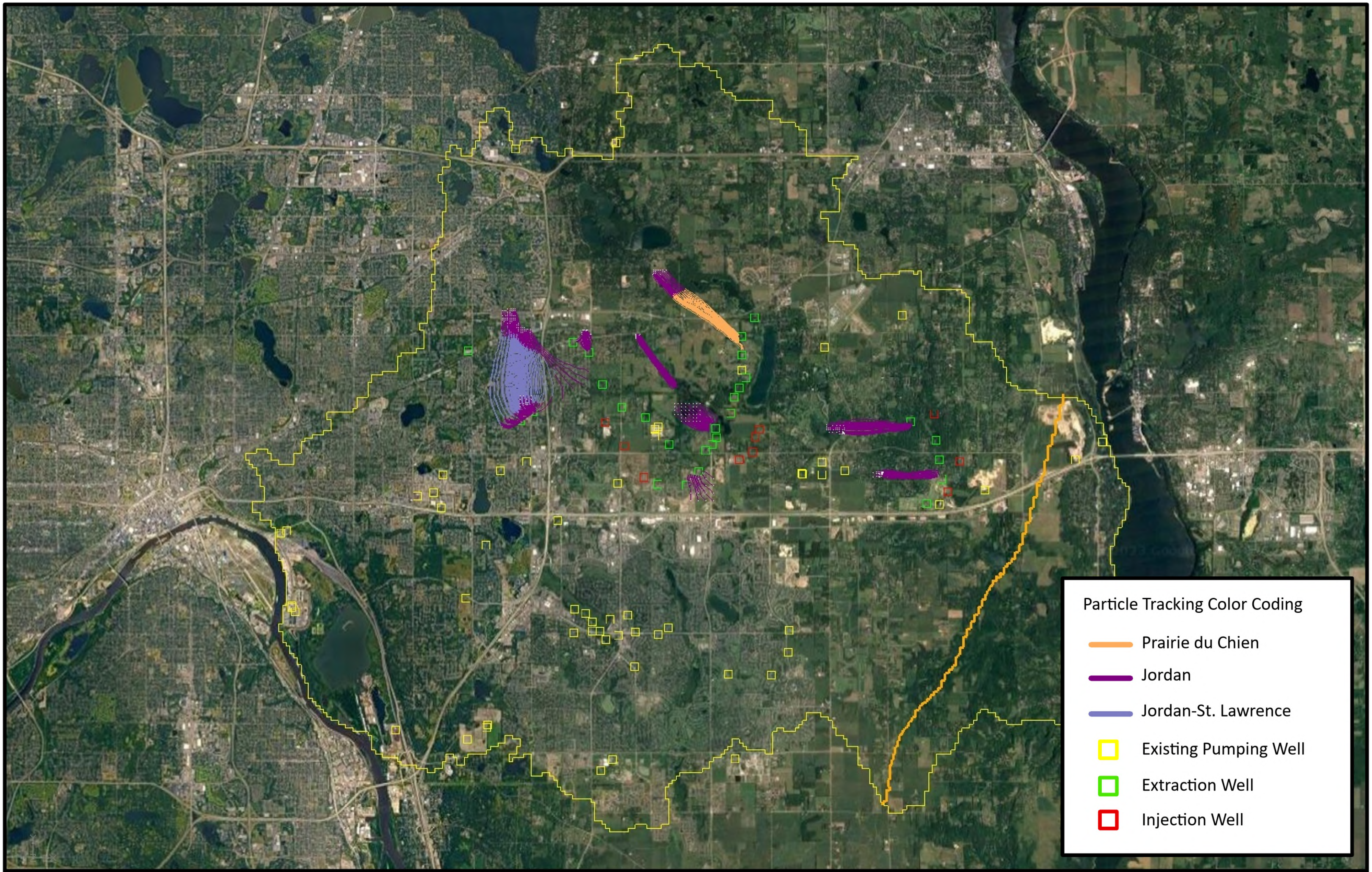

**Figure K.11: AECOM 2 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

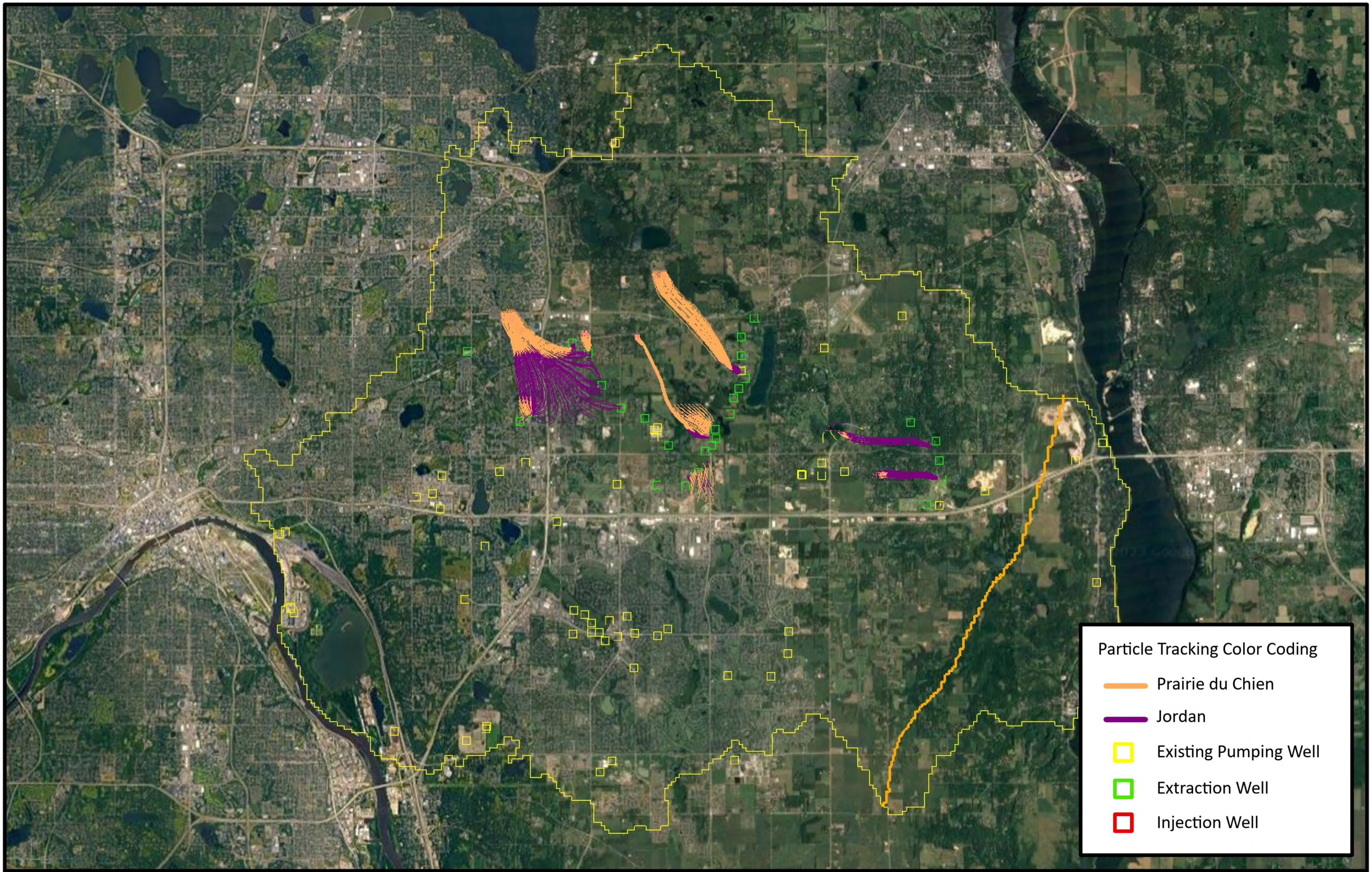

**Figure K.12: AECOM 3 Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

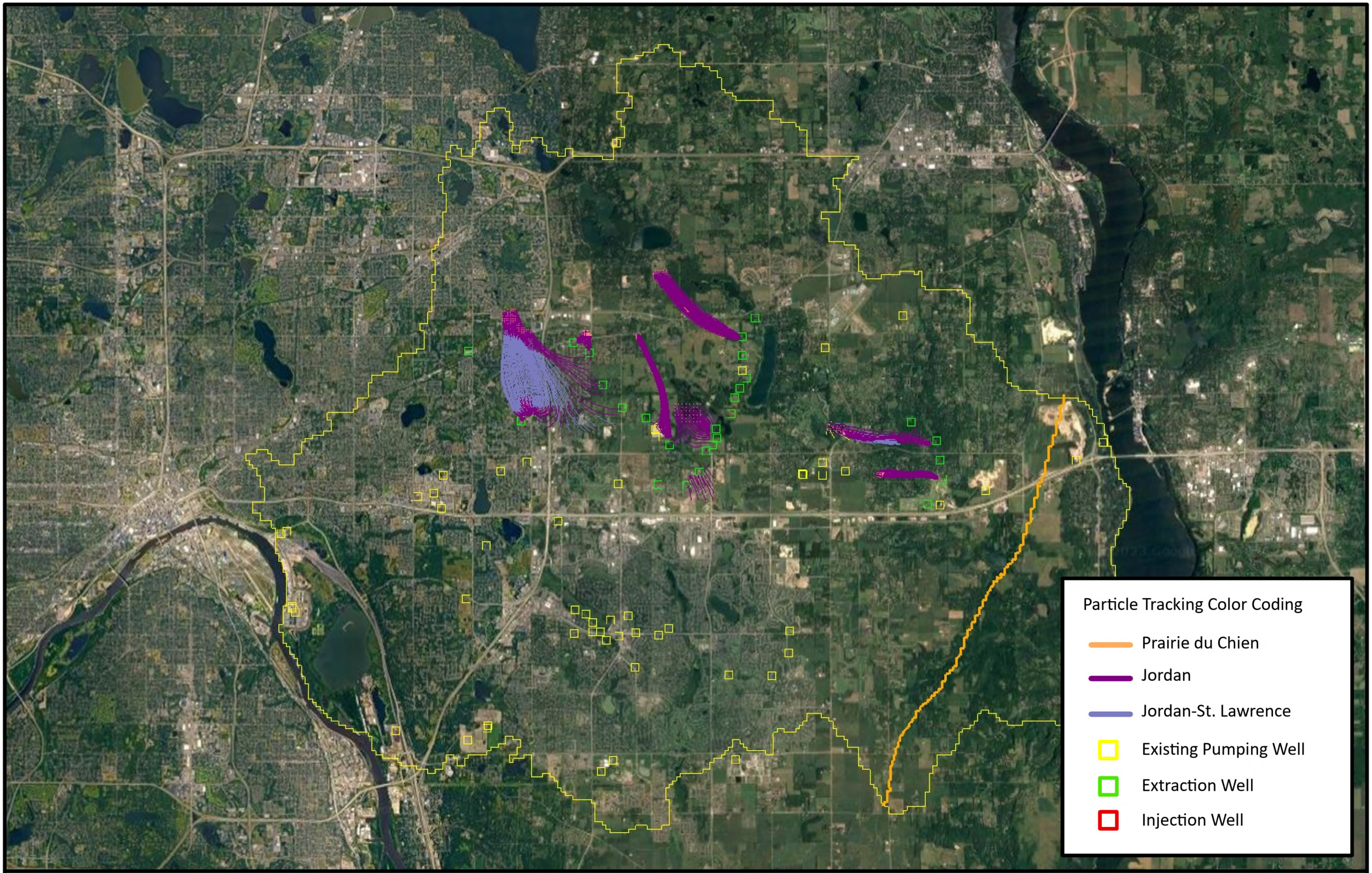

**Figure K.13: AECOM 3 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

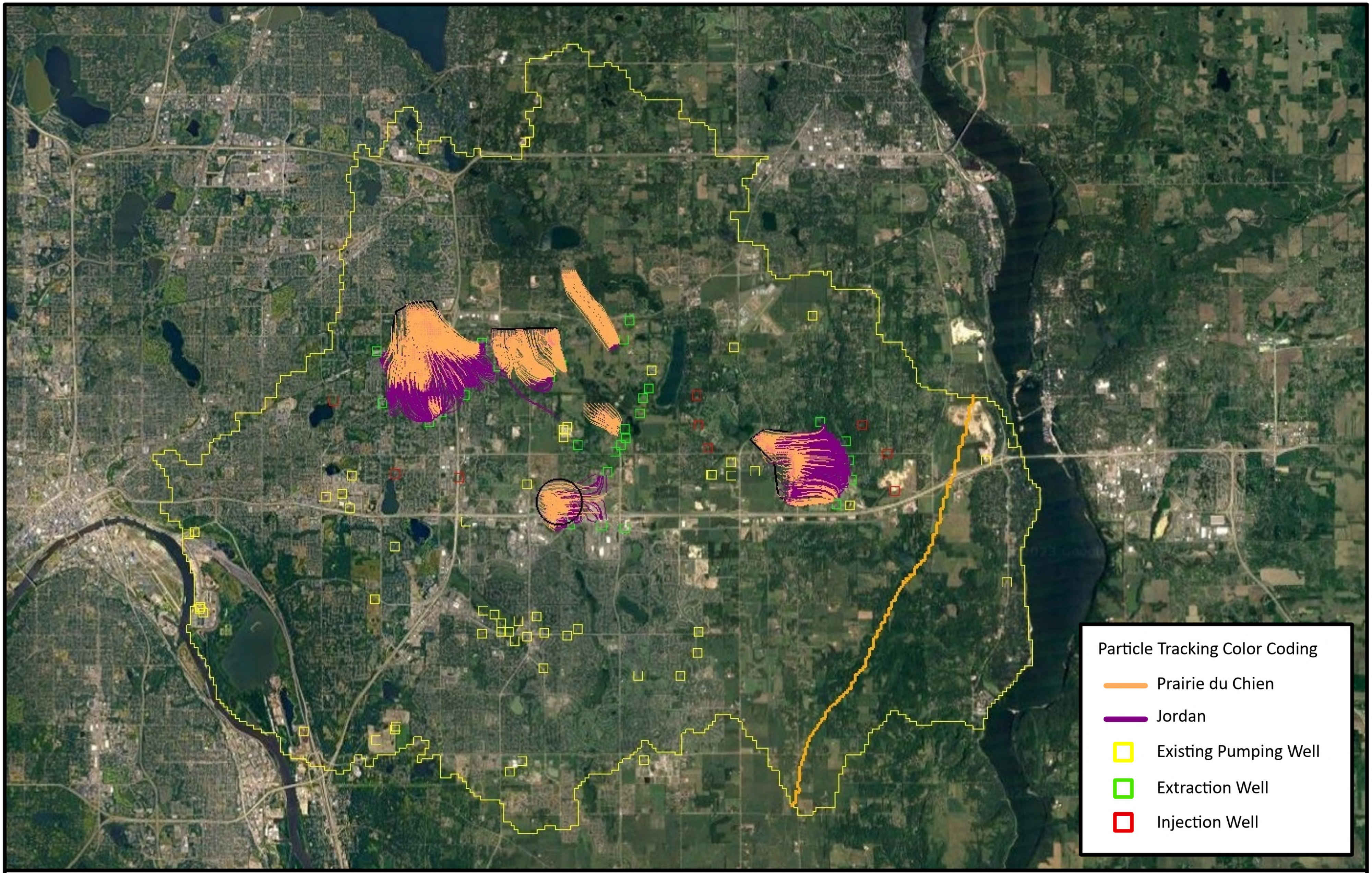

**Figure K.14: AECOM 4 Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

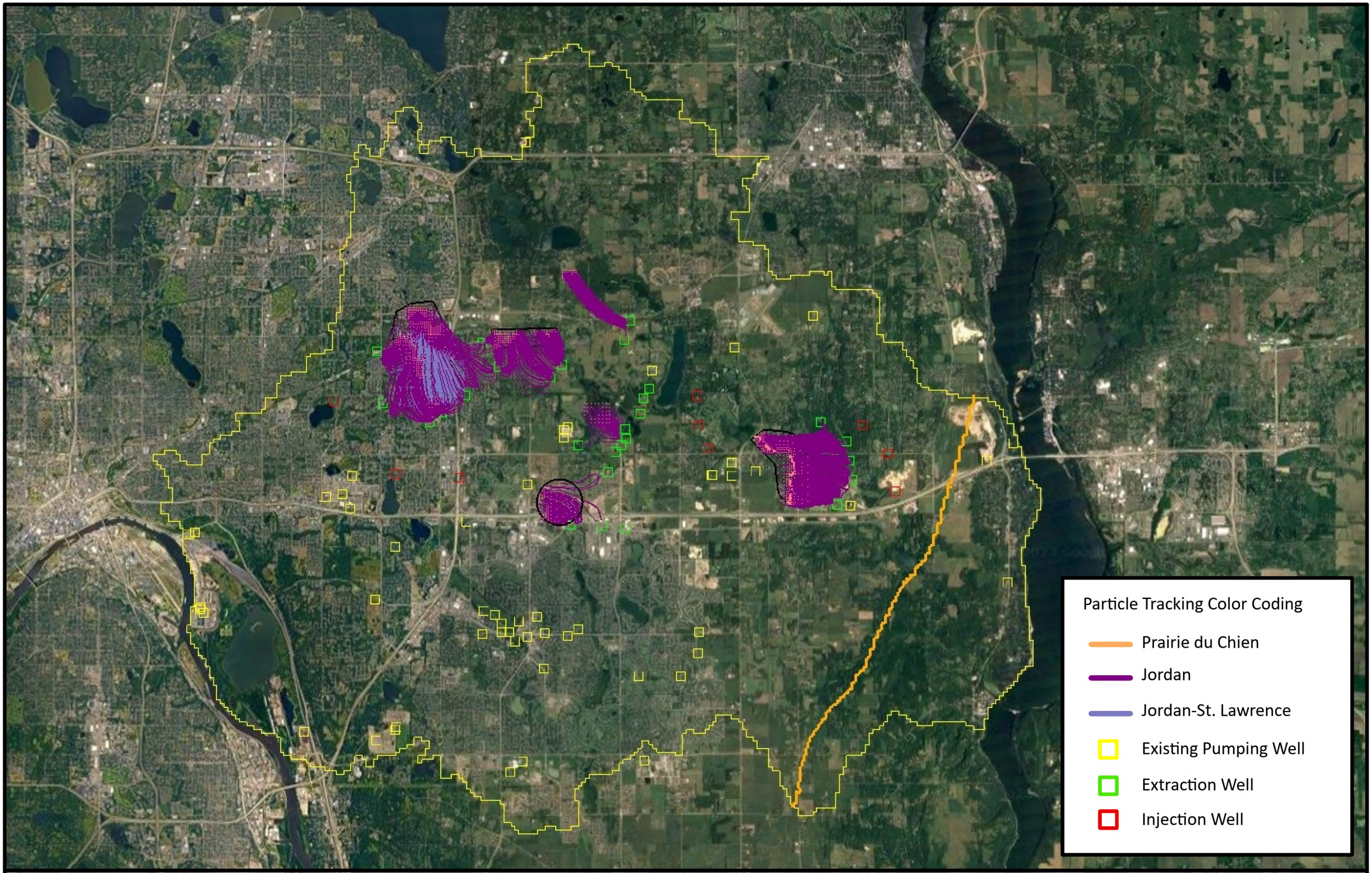

**Figure K.15: AECOM 4 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

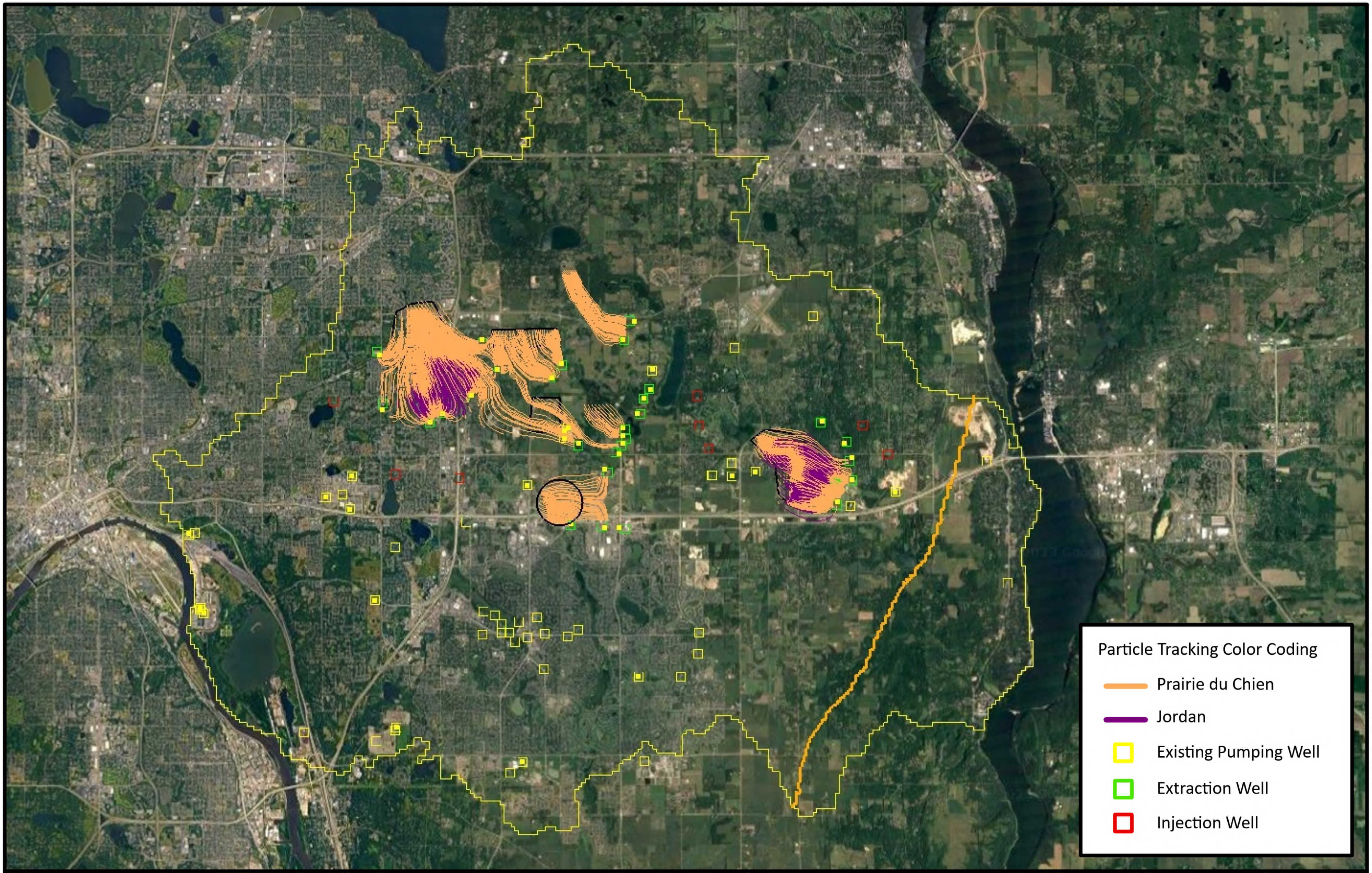

**Figure K.16: AECOM 5 Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

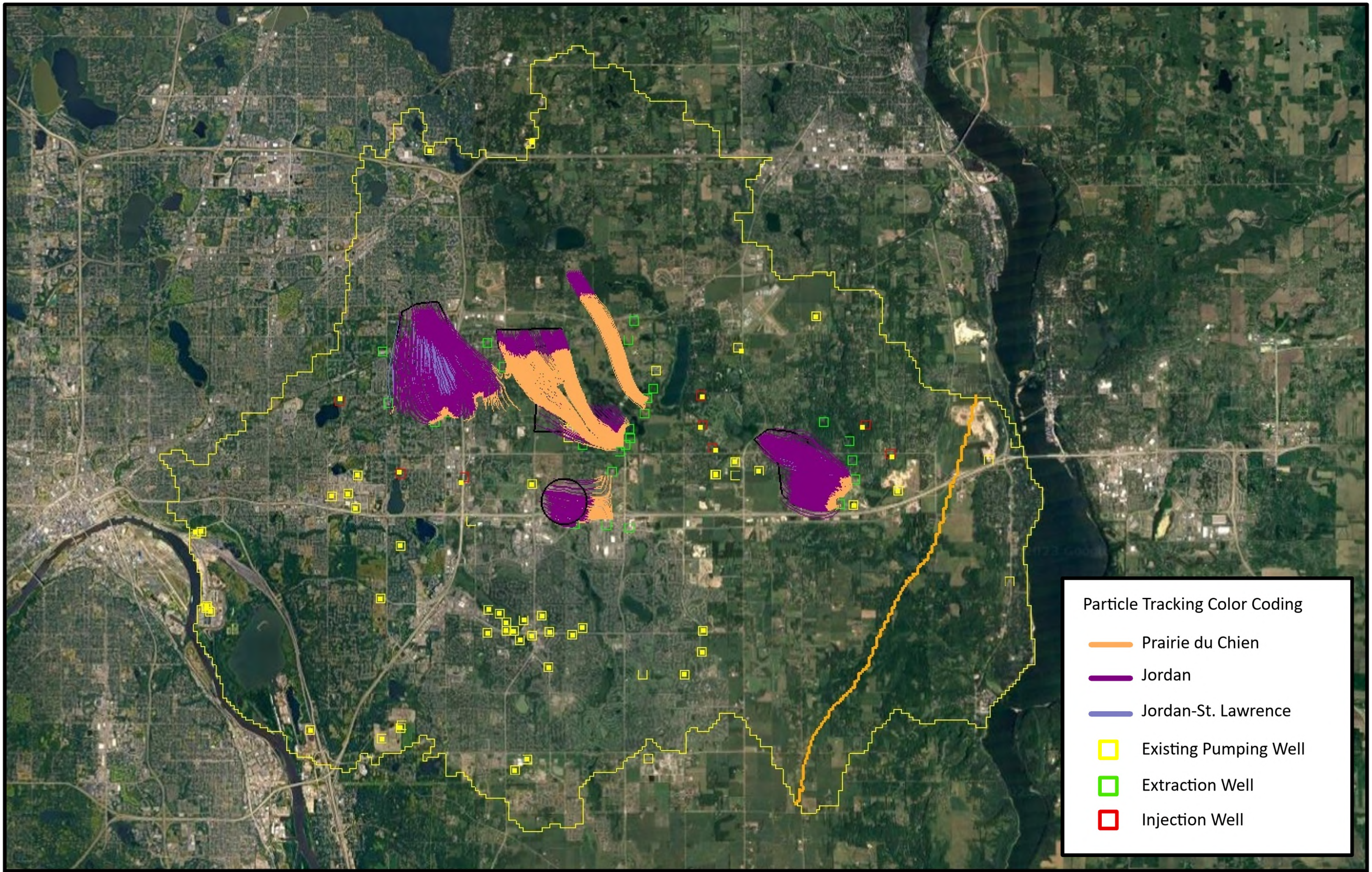

**Figure K.17: AECOM 5 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

N

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

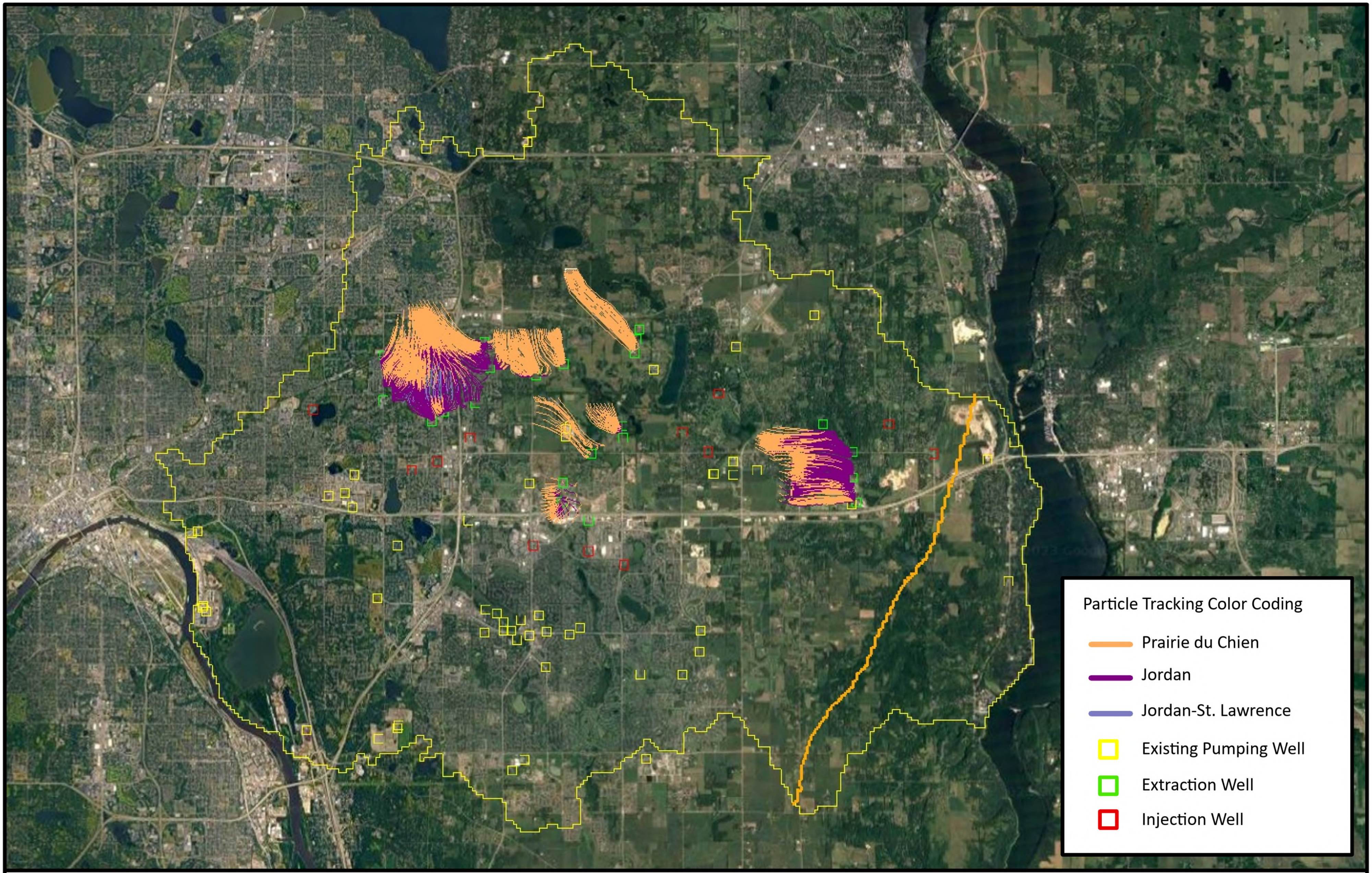

**Figure K.18: AECOM 6 Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

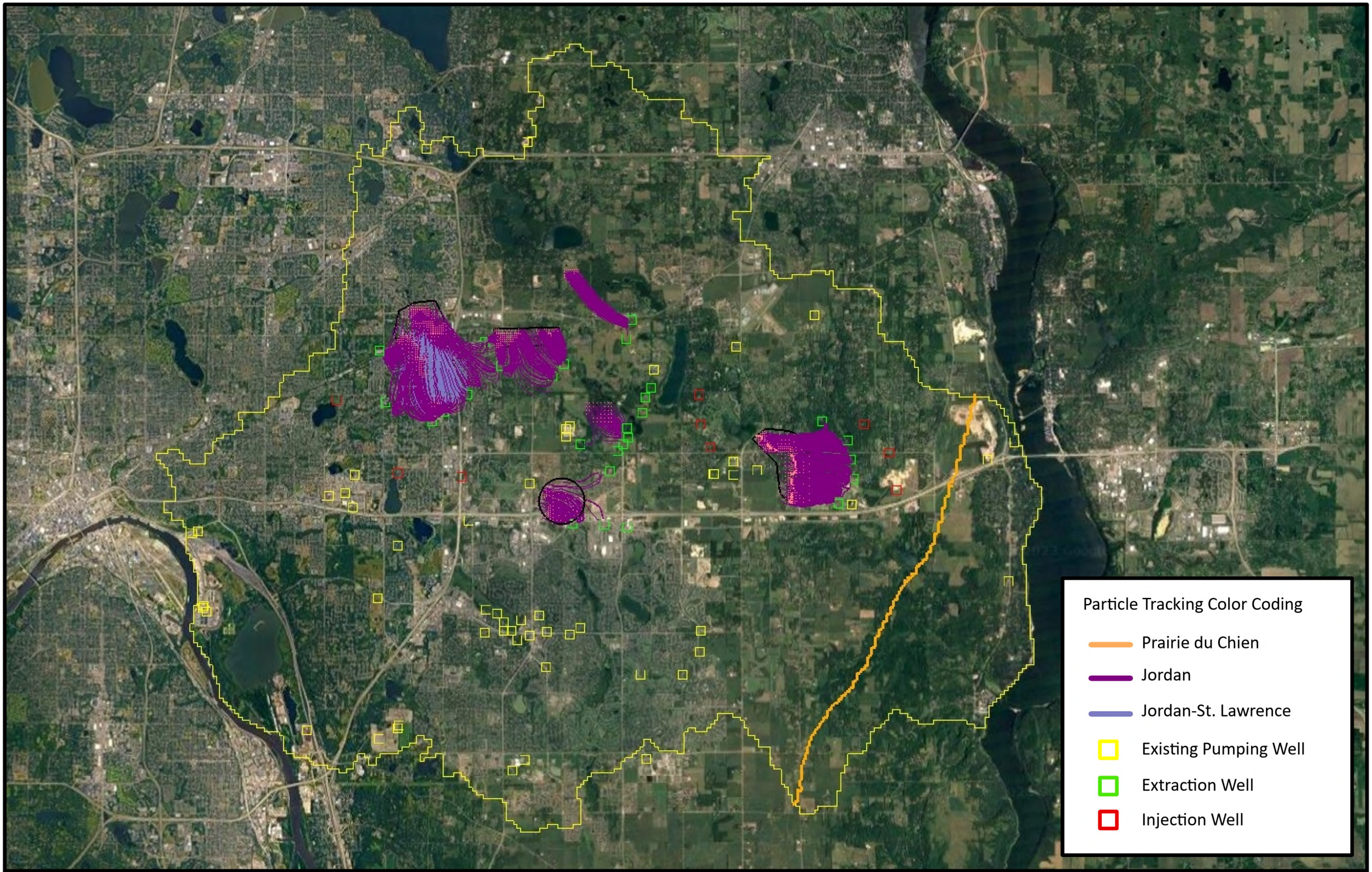

**Figure K.19: AECOM 6 Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

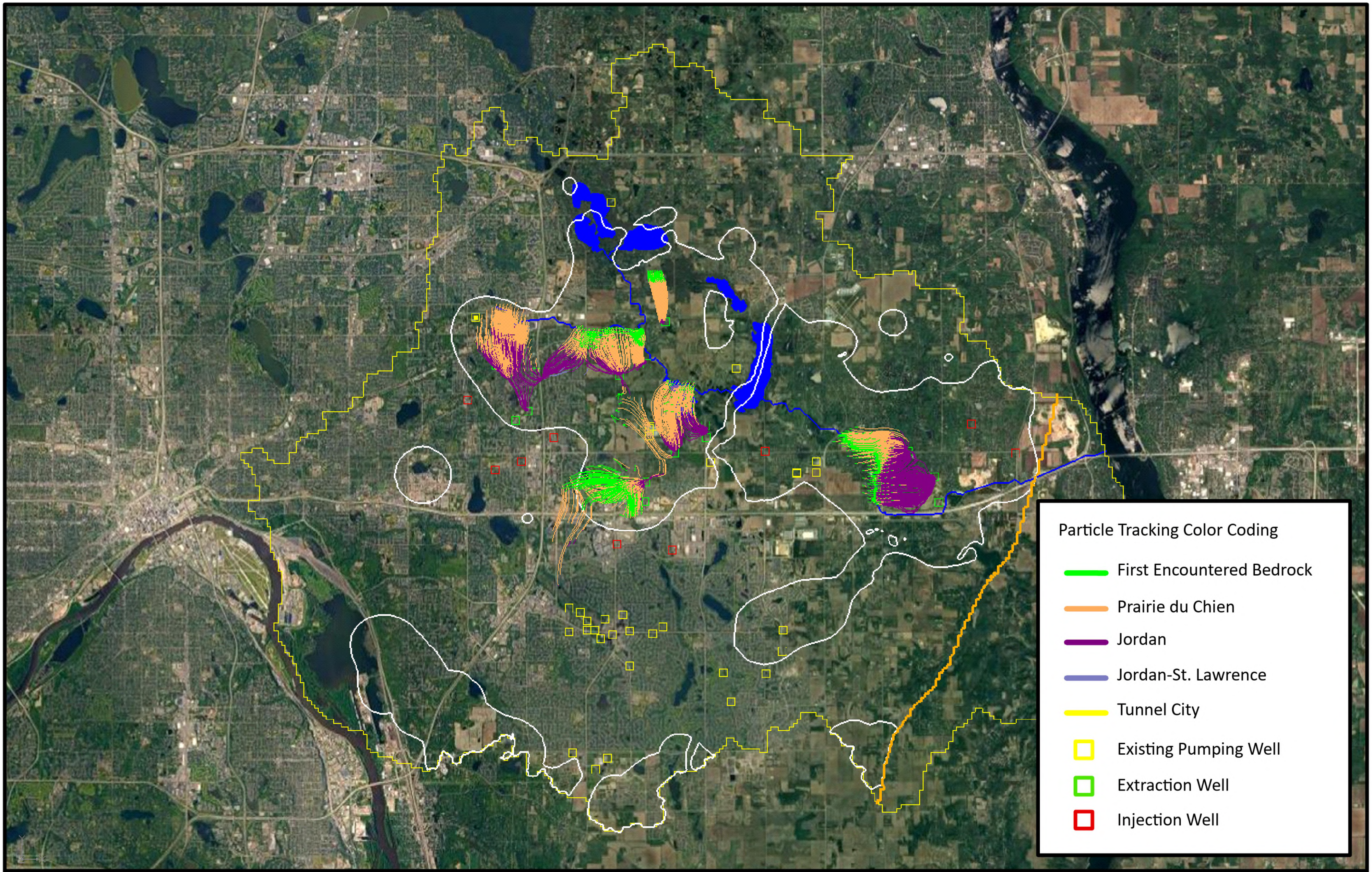

**Figure K.20: Scenario 1 (Alternative 8) Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

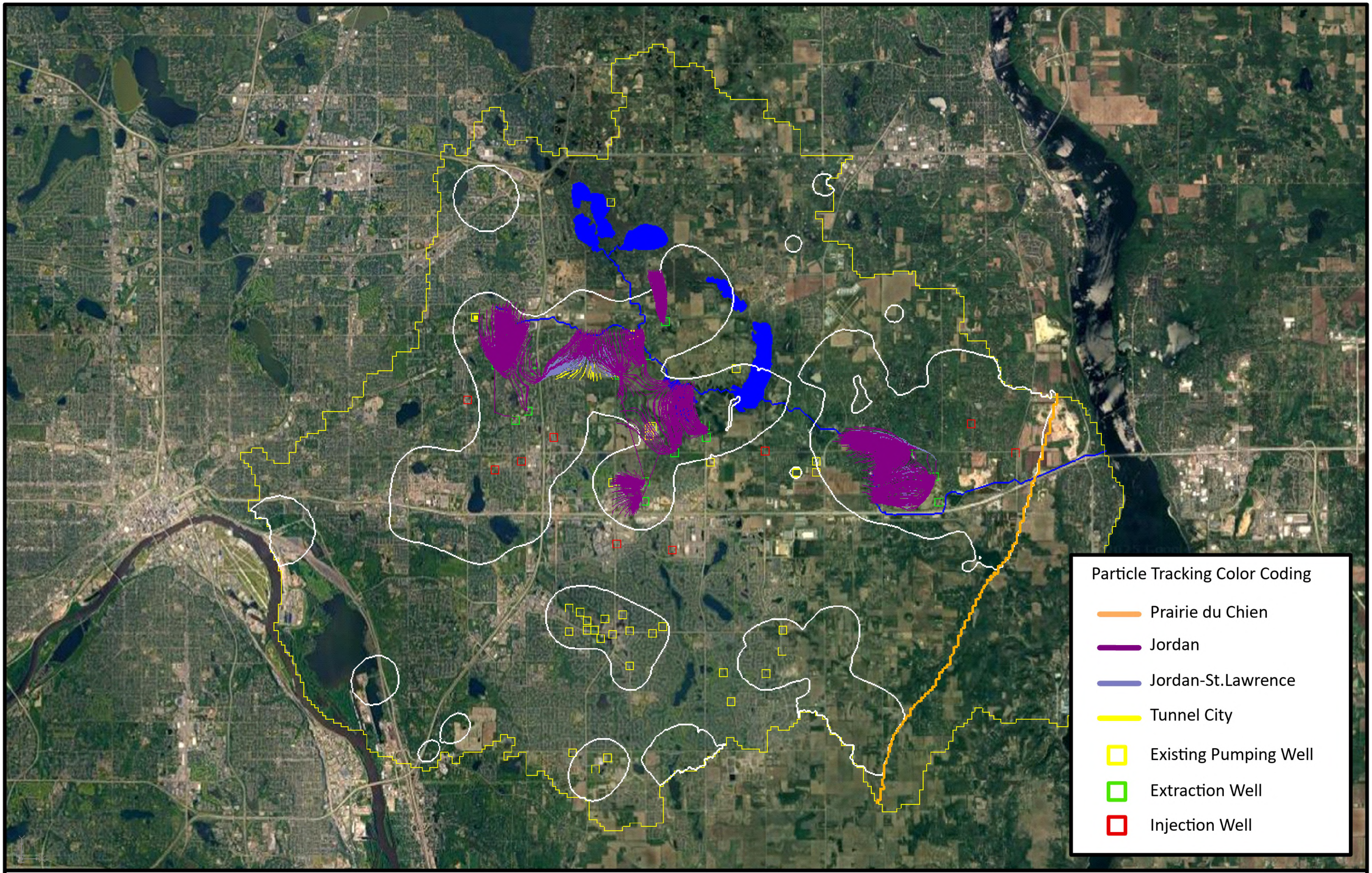

**Figure K.21: Scenario 1 (Alternative 8) Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

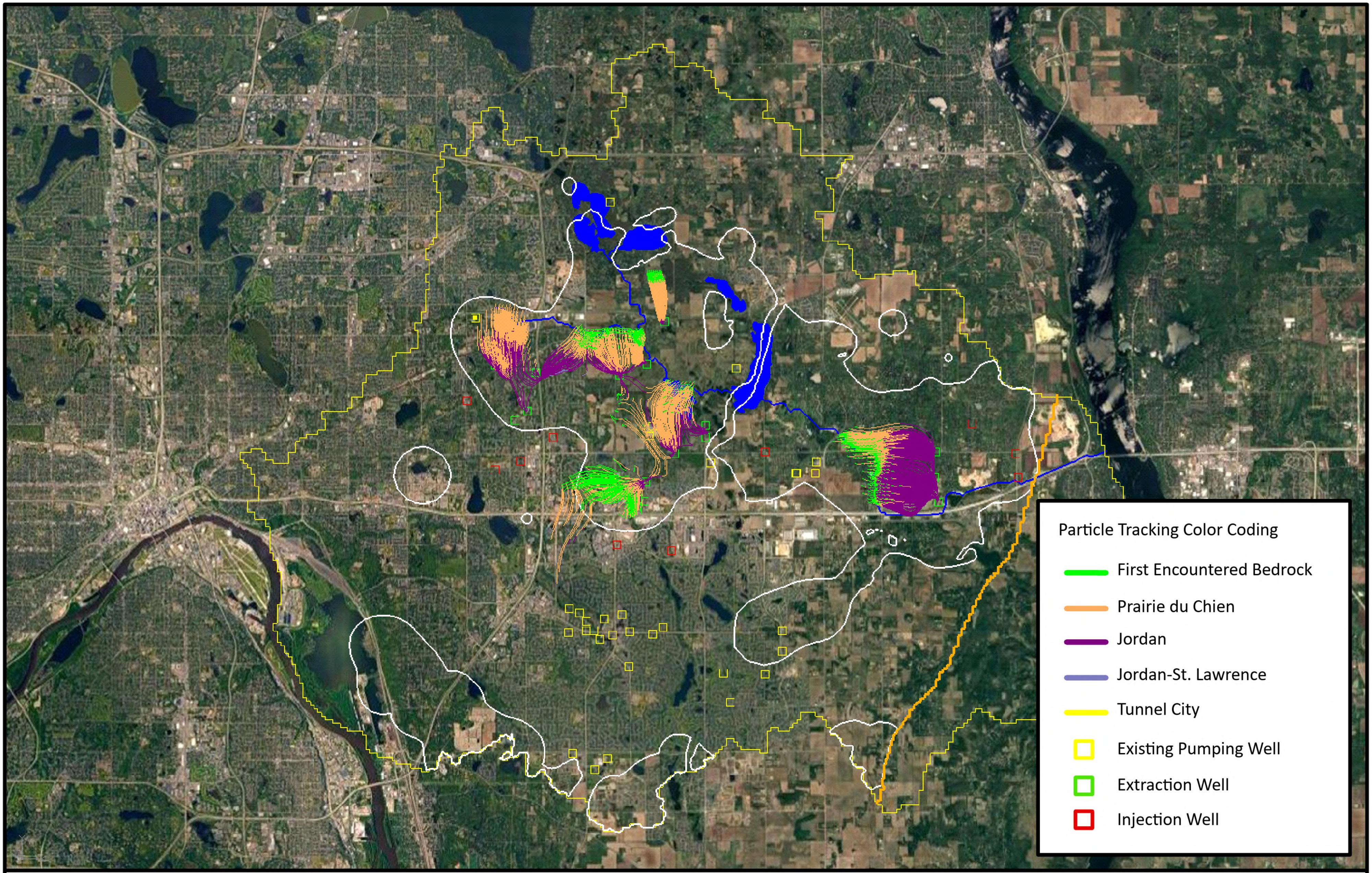

**Figure K.22: Scenario 2 (Alternative 7) Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

Note: Capture in West Lakeland is associated with the separate pump and treat system proposed in Alternative 7.

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

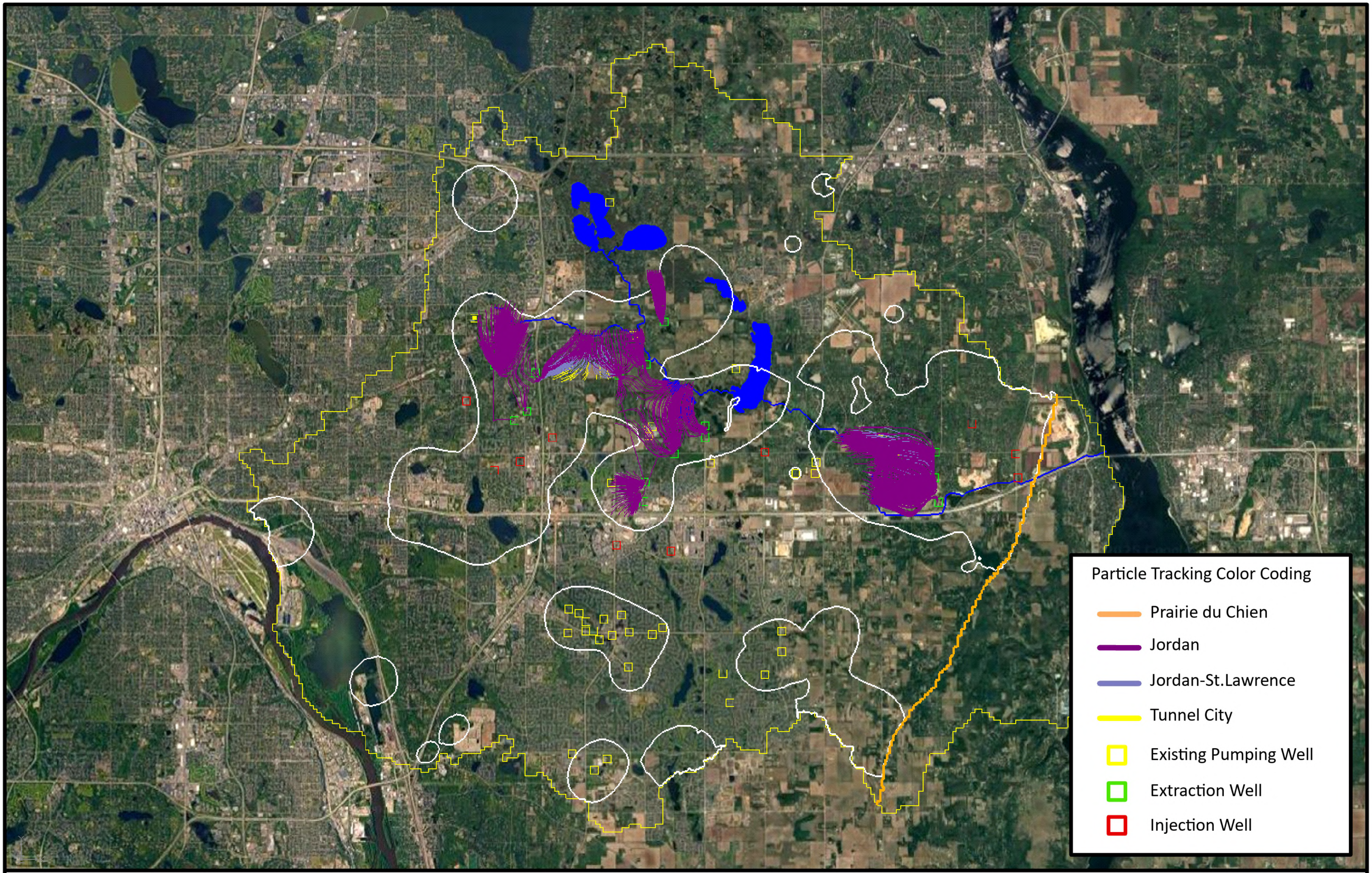

**Figure K.23: Scenario 2 (Alternative 7) Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

Note: Capture in West Lakeland is associated with the separate pump and treat system proposed in Alternative 7.

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MINNESOTA POLLUTION
CONTROL AGENCY

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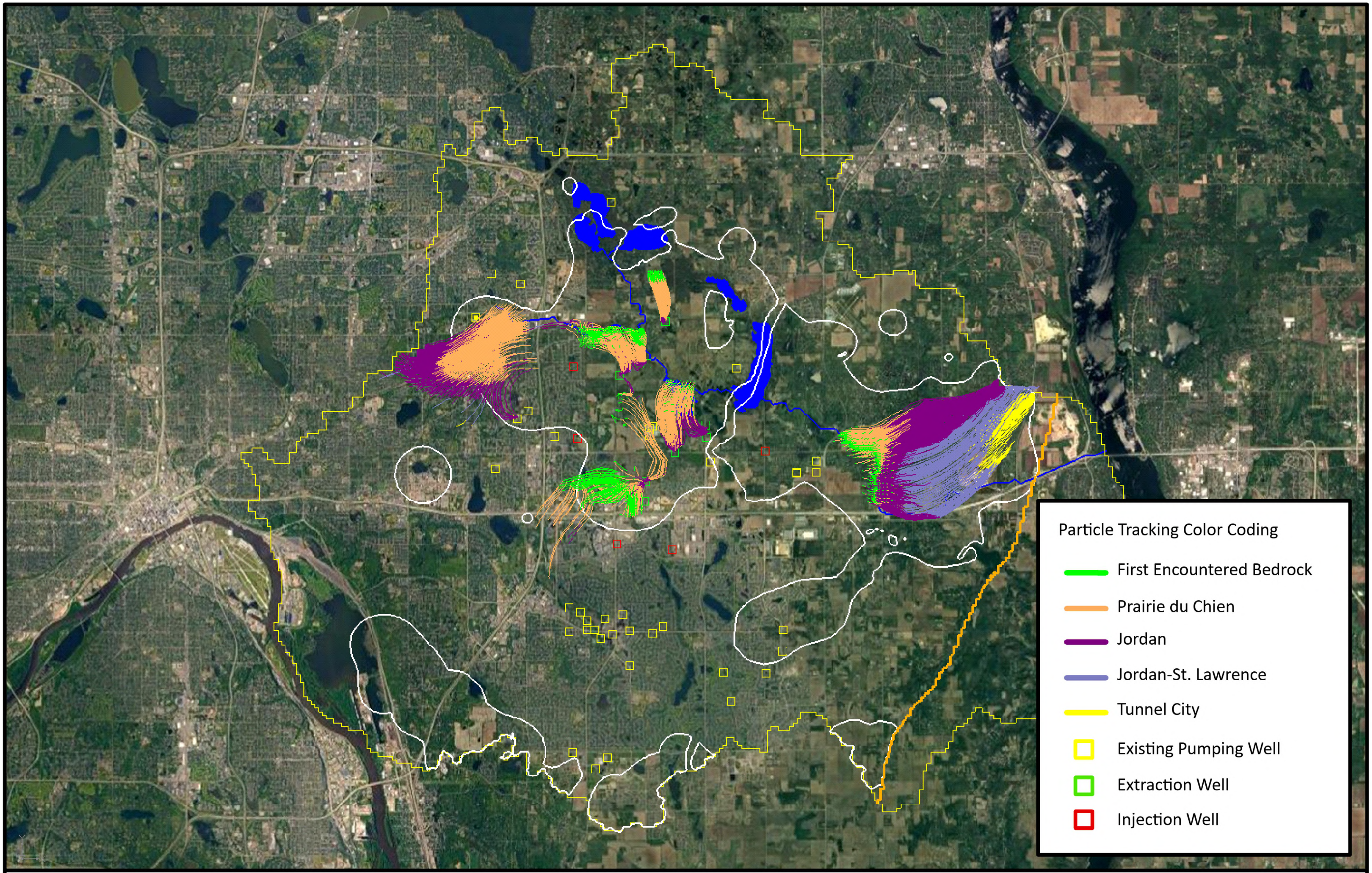

**Figure K.24: Scenario 3 (Alternative 5) Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

Note: The Lake Elmo Multi-Benefit Well Array proposed in Scenario 3 is identical for Alternatives 5 and 6. The proposed West Lakeland pump and treat system is absent in Alternative 5 and present in Alternative 6.

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

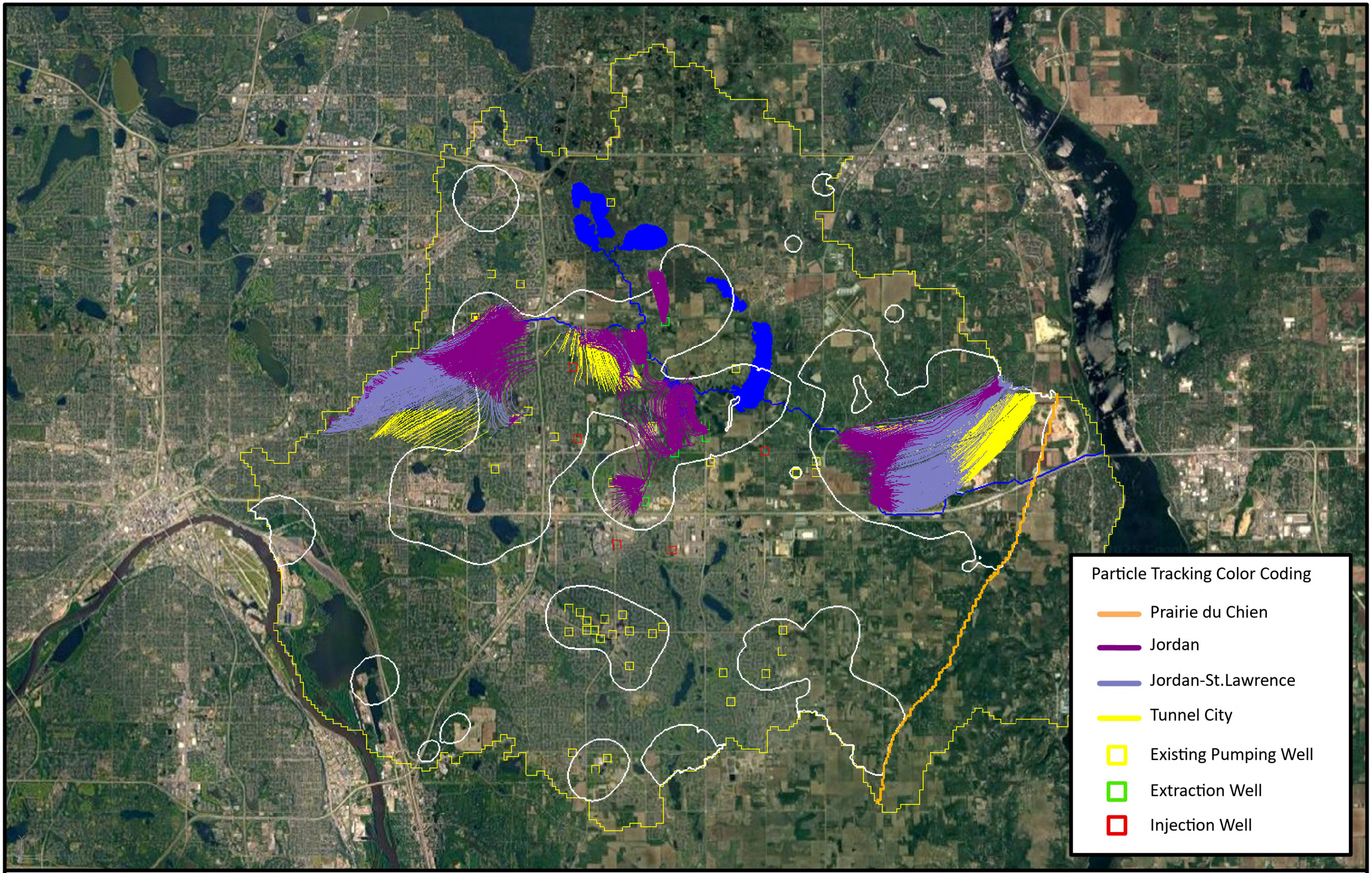

**Figure K.25: Scenario 3 (Alternative 5) Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

Note: The Lake Elmo Multi-Benefit Well Array proposed in Scenario 3 is identical for Alternatives 5 and 6. The proposed West Lakeland pump and treat system is absent in Alternative 5 and present in Alternative 6.

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MINNESOTA POLLUTION CONTROL AGENCY

AECOM

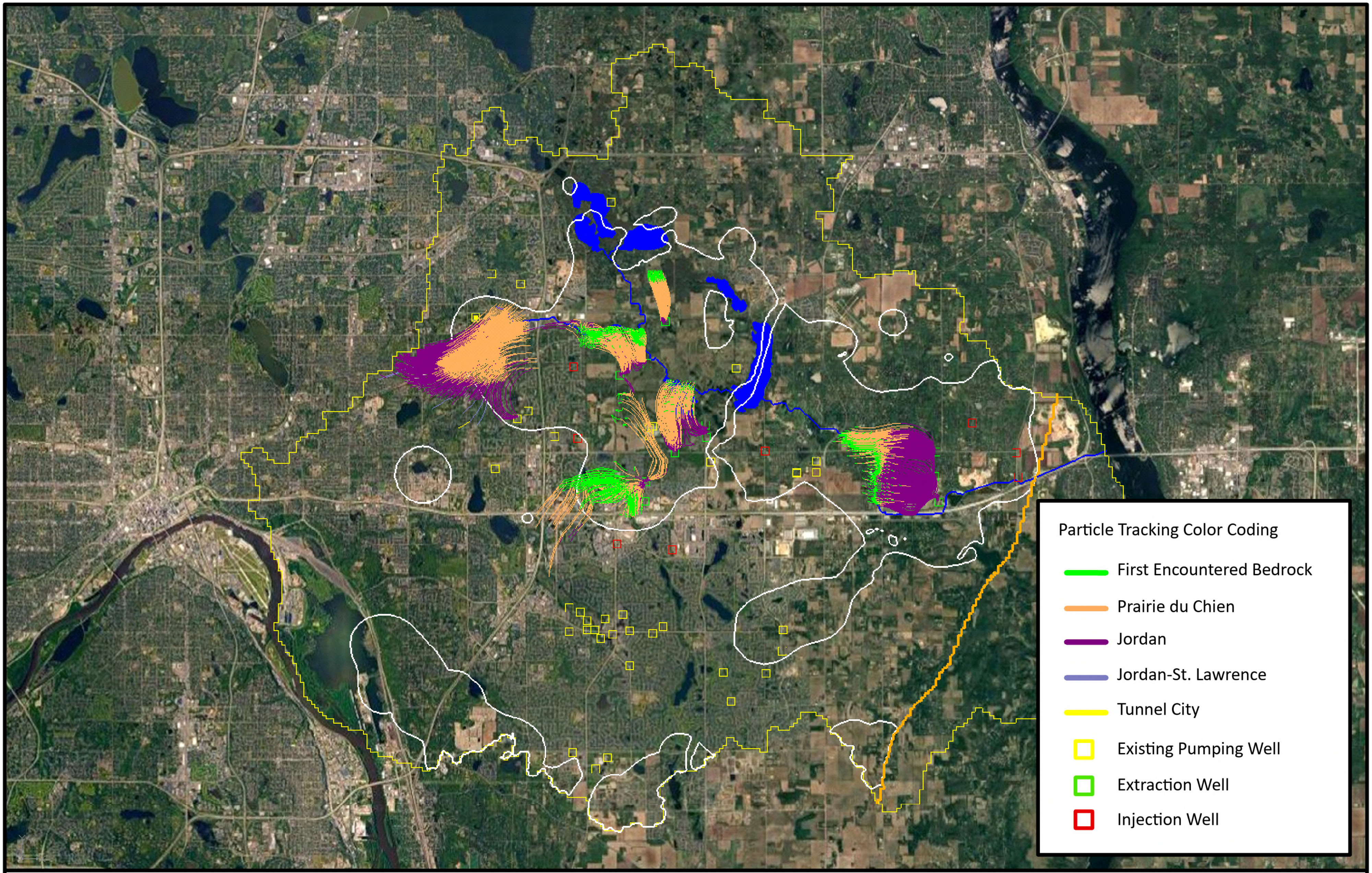


**Figure K.26: Scenario 3 (Alternative 6) Particle Tracking Configuration**
**Prairie du Chien Release**
**Project 1007 Feasibility Study**

Note: The Lake Elmo Multi-Benefit Well Array proposed in Scenario 3 is identical for Alternatives 5 and 6. The proposed West Lakeland pump and treat system is absent in Alternative 5 and present in Alternative 6.

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

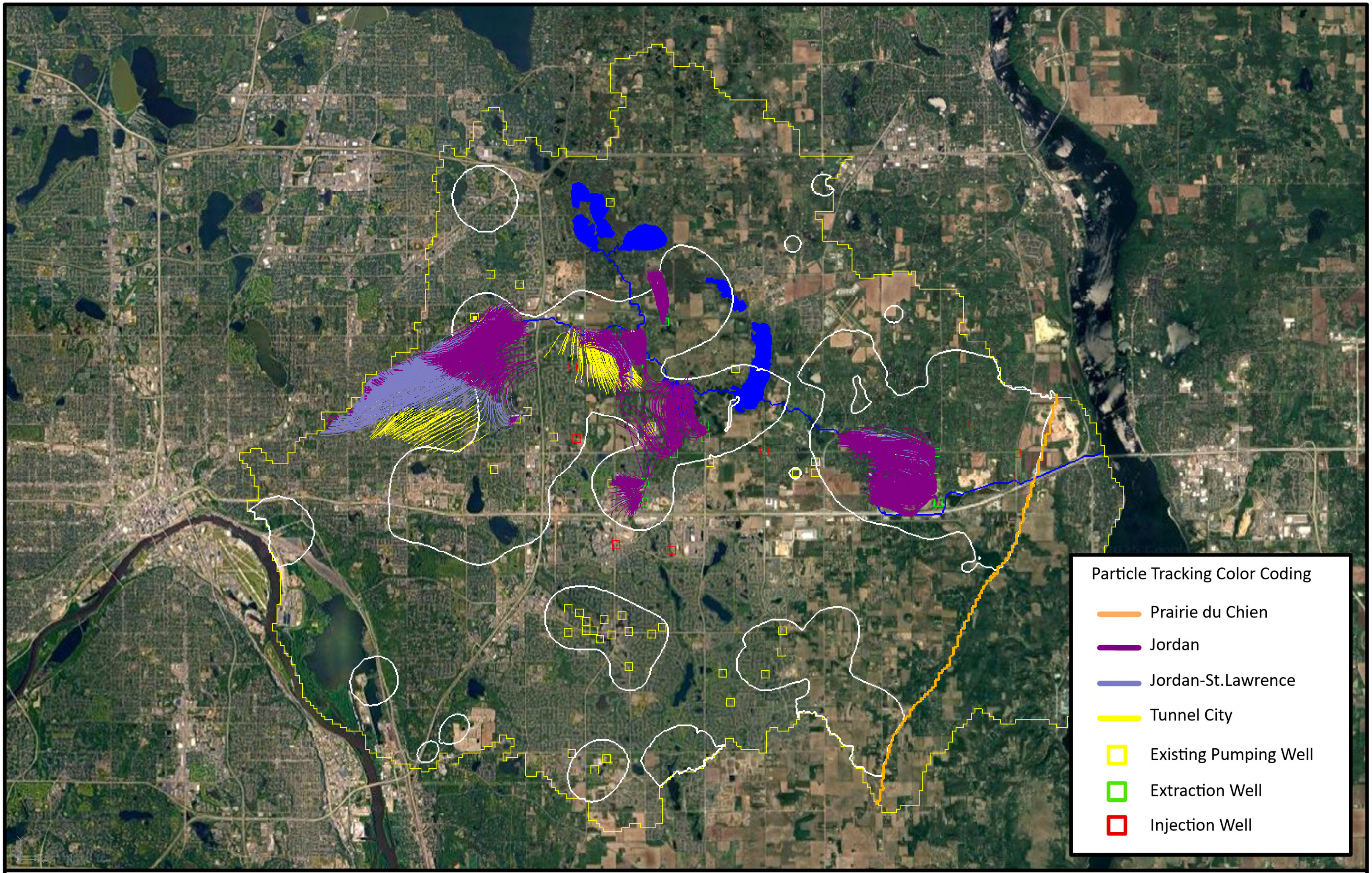


**Figure K.27: Scenario 3 (Alternative 6) Particle Tracking Configuration**
**Jordan Release**
**Project 1007 Feasibility Study**

Note: The Lake Elmo Multi-Benefit Well Array proposed in Scenario 3 is identical for Alternatives 5 and 6. The proposed West Lakeland pump and treat system is absent in Alternative 5 and present in Alternative 6.

MINNESOTA POLLUTION CONTROL AGENCY

AECOM

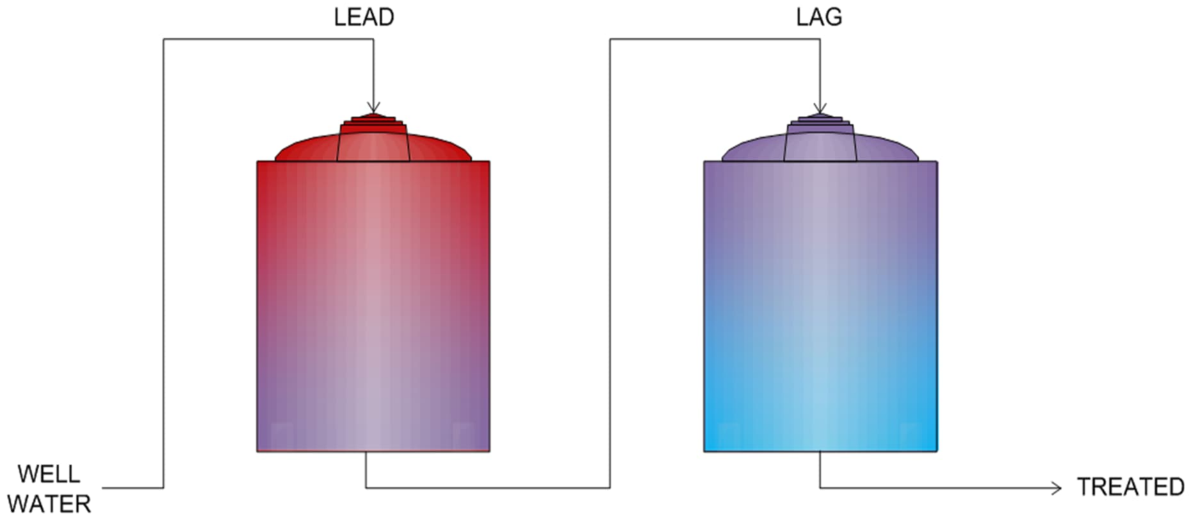


Figure K.28: GAC Lead/Lag Configuration. Influent well water (groundwater) passes through a primary (lead) vessel which removes the bulk of the contamination while the secondary (lag) vessel removes any residual PFAS, meeting treatment objectives.

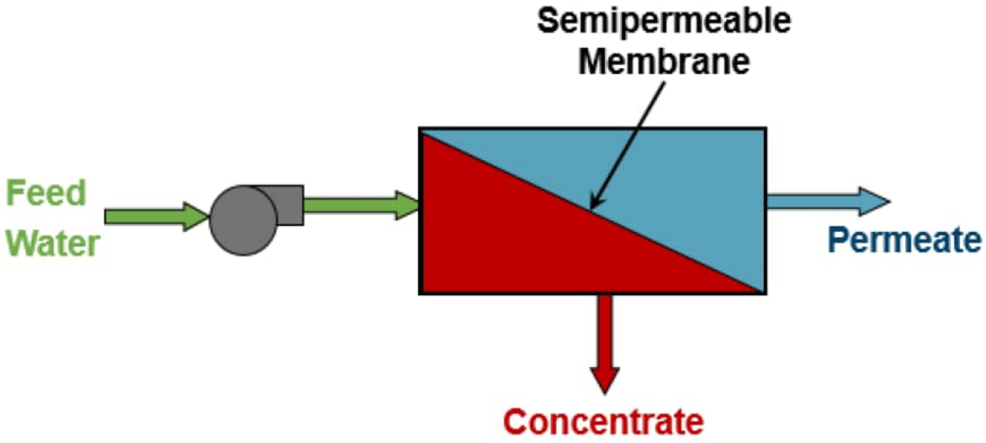


Figure K.29: Membrane Separation Schematic, From AWWA Drinking Water Treatment for PFAS Selection Guide (2020).

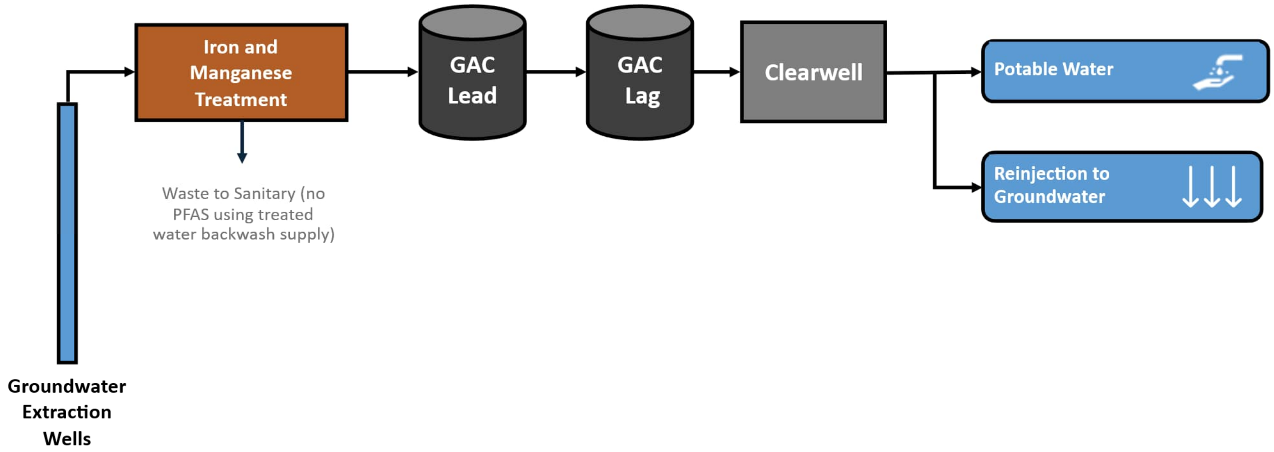


Figure K.30: Option A Process Train – GAC Treatment.

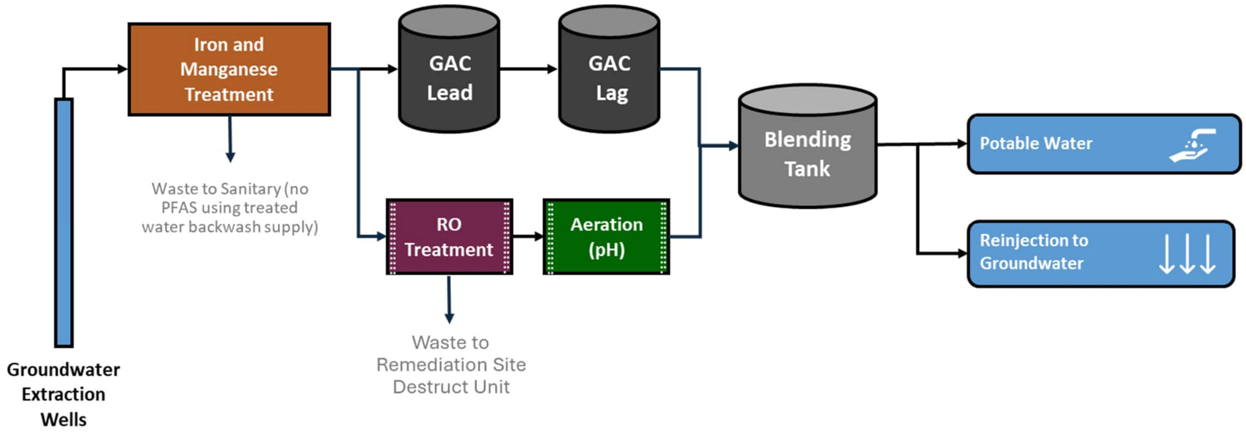


Figure K.31: Option B Process Train – GAC and NF/RO Parallel Treatment.

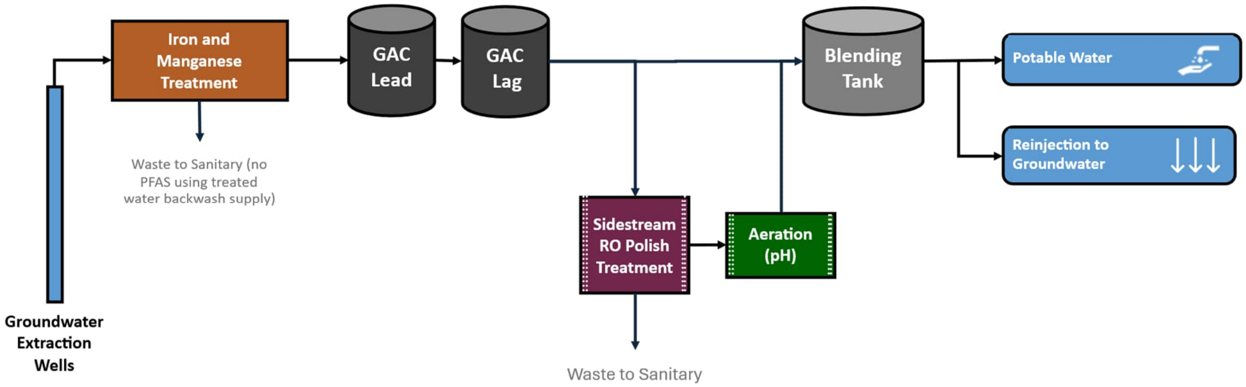


Figure K.32: Option C Process Train – GAC with NF/RO Sidestream (Polish) Treatment.

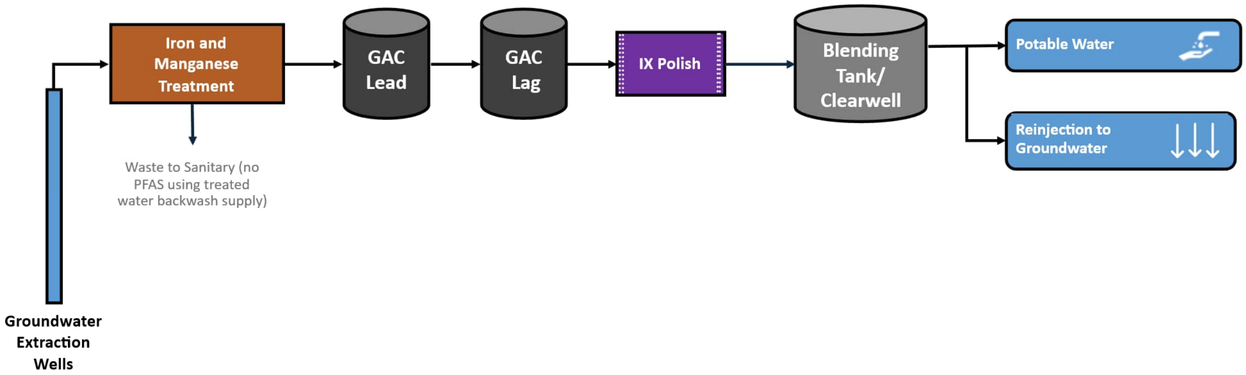


Figure K.33: Option D Process Train – GAC with IX Polish Treatment.

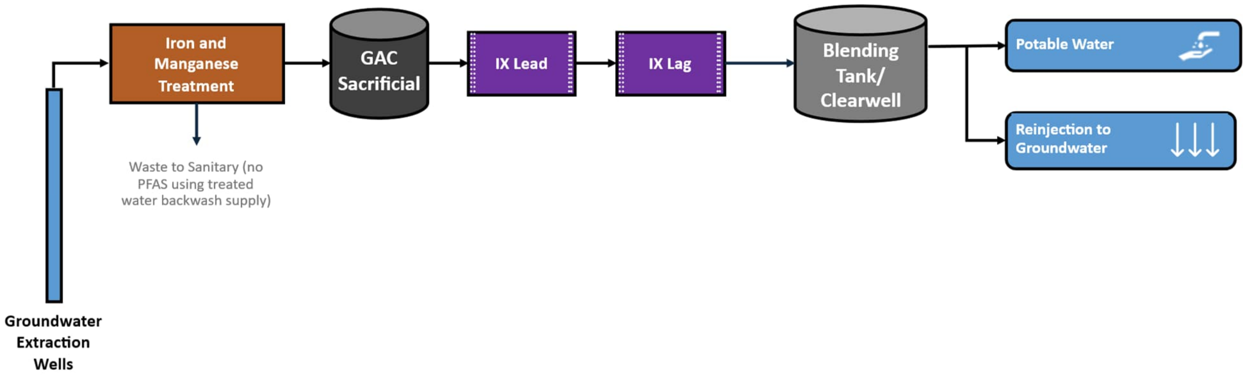
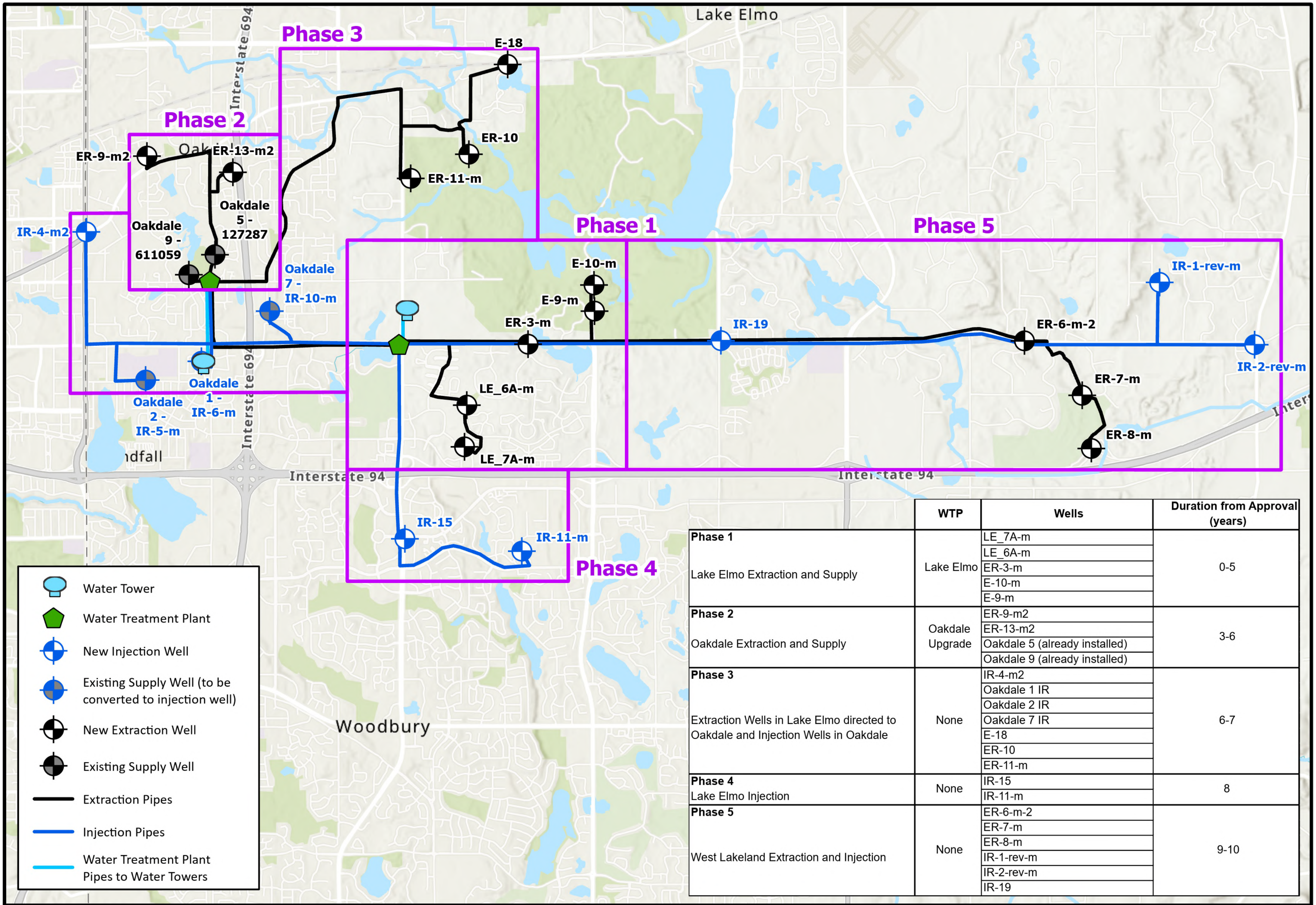


Figure K.34: Option E Process Train – GAC Pretreatment with IX Lead/Lag.



| | WTP | Wells | Duration from Approval (years) |
|---|---|---|---|
| **Phase 1**<br>Lake Elmo Extraction and Supply | Lake Elmo | LE_7A-m | 0-5 |
| | | LE_6A-m | |
| | | ER-3-m | |
| | | E-10-m | |
| | | E-9-m | |
| **Phase 2**<br>Oakdale Extraction and Supply | Oakdale Upgrade | ER-9-m2 | 3-6 |
| | | ER-13-m2 | |
| | | Oakdale 5 (already installed) | |
| | | Oakdale 9 (already installed) | |
| **Phase 3**<br>Extraction Wells in Lake Elmo directed to Oakdale and Injection Wells in Oakdale | None | IR-4-m2 | 6-7 |
| | | Oakdale 1 IR | |
| | | Oakdale 2 IR | |
| | | Oakdale 7 IR | |
| | | E-18 | |
| | | ER-10 | |
| | | ER-11-m | |
| **Phase 4**<br>Lake Elmo Injection | None | IR-15 | 8 |
| | | IR-11-m | |
| **Phase 5**<br>West Lakeland Extraction and Injection | None | ER-6-m-2 | 9-10 |
| | | ER-7-m | |
| | | ER-8-m | |
| | | IR-1-rev-m | |
| | | IR-2-rev-m | |
| | | IR-19 | |

**Figure K.35: Alternative 8 Multi-Benefit Well Array Implementation Phases**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

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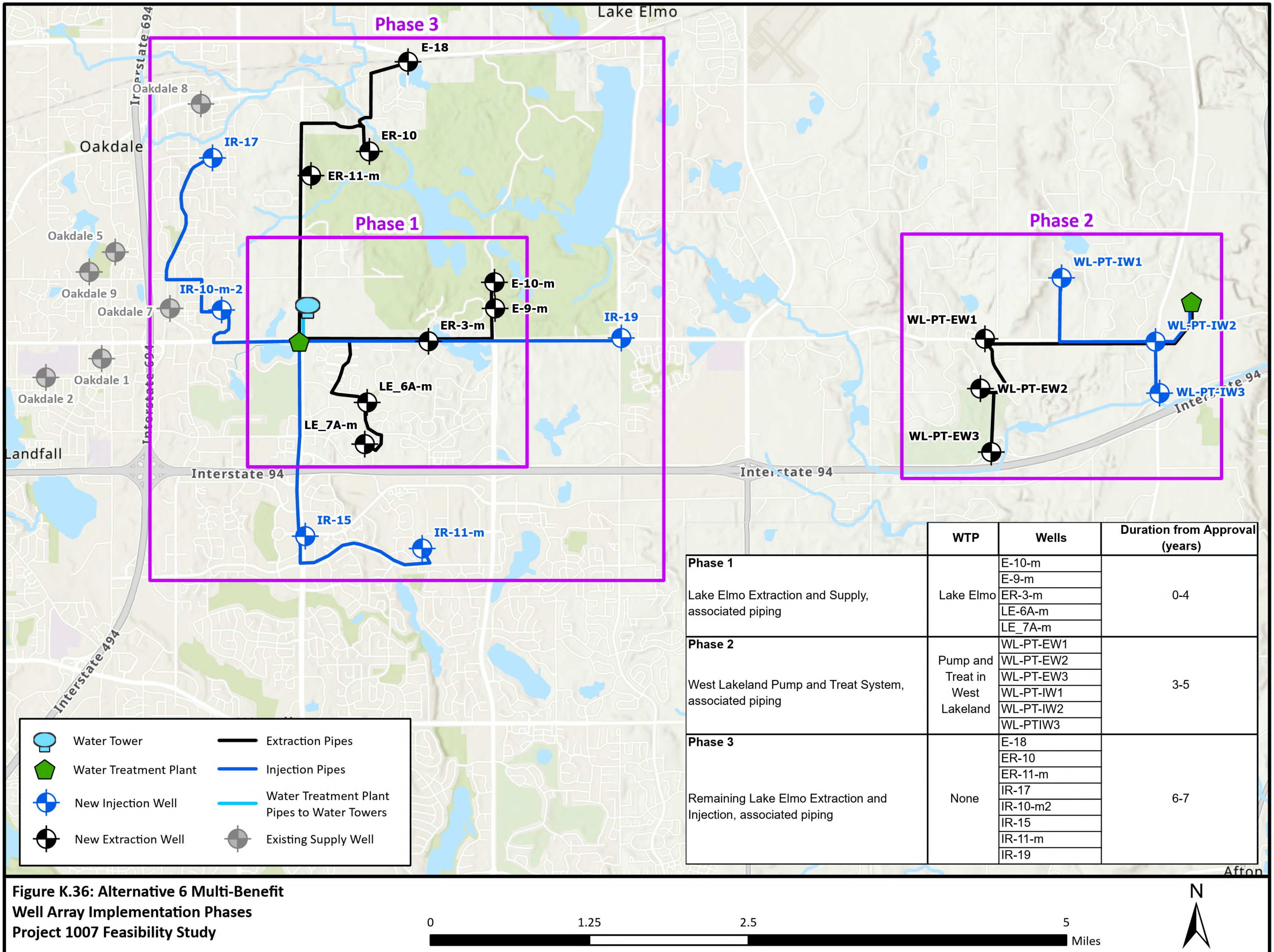
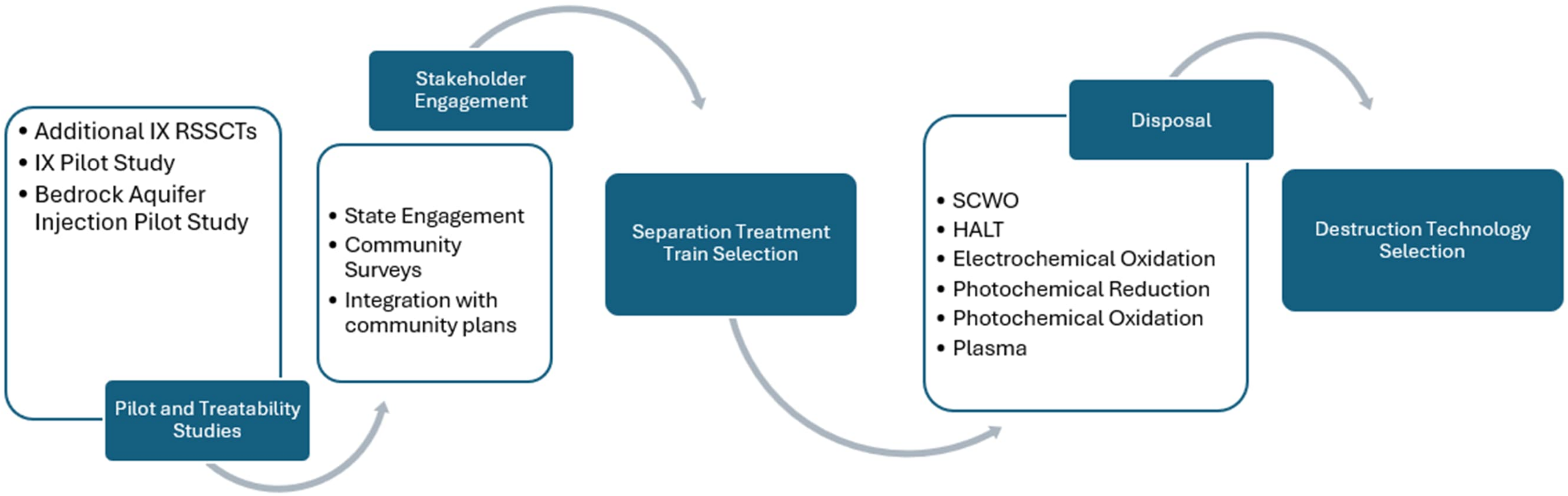


| | WTP | Wells | Duration from Approval (years) |
|---|---|---|---|
| **Phase 1**<br>Lake Elmo Extraction and Supply, associated piping | Lake Elmo | E-10-m<br>E-9-m<br>ER-3-m<br>LE-6A-m<br>LE_7A-m | 0-4 |
| **Phase 2**<br>West Lakeland Pump and Treat System, associated piping | Pump and Treat in West Lakeland | WL-PT-EW1<br>WL-PT-EW2<br>WL-PT-EW3<br>WL-PT-IW1<br>WL-PT-IW2<br>WL-PTIW3 | 3-5 |
| **Phase 3**<br>Remaining Lake Elmo Extraction and Injection, associated piping | None | E-18<br>ER-10<br>ER-11-m<br>IR-17<br>IR-10-m2<br>IR-15<br>IR-11-m<br>IR-19 | 6-7 |

**Figure K.36: Alternative 6 Multi-Benefit Well Array Implementation Phases**
**Project 1007 Feasibility Study**

MINNESOTA POLLUTION CONTROL AGENCY

AECOM



Legend: HALT = Hydrothermal Alkaline Treatment; SCWO = Supercritical Water Oxidation.

Figure K.37: Proposed next steps for MBWA.

# K11 Additional Tables: Detailed Cost Tables

Table K.44: Option A GAC Treatment for PFAS – Detailed CAPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| Greensand Filters (Equipment, Media, Installation) | $3,888,000 | $3,888,000 | $2,592,000 | $3,888,000 | $3,888,000 |
| GAC Skids (Equipment, Media, Installation) | $4,881,600 | $5,695,200 | $4,068,000 | $5,695,200 | $4,881,600 |
| Greensand Filter/GAC Backwash Storage and Pumps | $919,872 | $919,872 | $819,872 | $919,872 | $919,872 |
| Chemical Tanks & Chemical Feed Skids | $1,430,500 | $1,565,500 | $1,039,000 | $1,700,500 | $1,423,750 |
| Finished Water Pumping | $556,200 | $610,200 | $399,600 | $664,200 | $553,500 |
| Process Piping | $148,320 | $162,720 | $106,560 | $177,120 | $147,600 |
| Valves and Flow Control | $436,000 | $482,000 | $354,000 | $482,000 | $436,000 |
| Building (Architecture, Plumbing, Electrical, HVAC) | $19,250,176 | $21,223,136 | $14,942,048 | $21,983,456 | $19,212,160 |
| SUBTOTAL | $31,510,668 | $34,546,628 | $24,321,080 | $35,510,348 | $31,462,482 |
| *Mobilization & Site Setup (5%)* | $1,575,533 | $1,727,331 | $1,216,054 | $1,775,517 | $1,573,124 |
| *Bonding & Insurance (3%)* | $945,320.04 | $1,036,398.84 | $729,632.40 | $1,065,310.44 | $943,874.46 |
| *Contractor Overhead and Profit (15%)* | $4,726,600 | $5,181,994 | $3,648,162 | $5,326,552 | $4,719,372 |
| *Engineering & Construction Contingency (45%)* | $14,179,801 | $15,545,983 | $10,944,486 | $15,979,657 | $14,158,117 |
| TOTAL (2025 – Rounded to nearest $1000) | $52,938,000 | $58,039,000 | $40,860,000 | $59,658,000 | $52,857,000 |

Table K.45: Option B GAC and NF/RO Parallel Trains – Detailed CAPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| Greensand Filters (Equipment, Media, Installation) | $3,888,000 | $3,888,000 | $2,592,000 | $3,888,000 | $3,888,000 |
| GAC Skids (Equipment, Media, Installation) | $2,440,800 | $3,254,400 | $2,440,800 | $3,254,400 | $2,440,800 |
| Greensand Filter/GAC Backwash Storage and Pumps | $919,872 | $919,872 | $819,872 | $919,872 | $919,872 |
| NF/RO System (Equipment, Installation) | $5,076,400 | $5,076,400 | $3,626,000 | $5,801,600 | $5,076,400 |
| Chemical Tanks & Chemical Feed Skids | $1,430,500 | $1,565,500 | $1,039,000 | $1,700,500 | $1,423,750 |
| Finished Water Pumping | $556,200 | $610,200 | $399,600 | $664,200 | $553,500 |
| Process Piping | $148,320 | $162,720 | $106,560 | $177,120 | $147,600 |
| Valves and Flow Control | $298,000 | $344,000 | $262,000 | $344,000 | $298,000 |
| Building (Architecture, Plumbing, Electrical, HVAC) | $18,987,936 | $20,960,896 | $14,927,968 | $22,203,456 | $18,949,920 |
| SUBTOTAL | $33,746,028 | $36,781,988 | $26,213,800 | $38,953,148 | $33,697,842 |
| *Mobilization & Site Setup (5%)* | $1,687,301 | $1,839,099 | $1,310,690 | $1,947,657 | $1,684,892 |
| *Bonding & Insurance (3%)* | $1,012,380.84 | $1,103,459.64 | $786,414.00 | $1,168,594.44 | $1,010,935.26 |
| *Contractor Overhead and Profit (15%)* | $5,061,904 | $5,517,298 | $3,932,070 | $5,842,972 | $5,054,676 |
| *Engineering & Construction Contingency (45%)* | $15,185,713 | $16,551,895 | $11,796,210 | $17,528,917 | $15,164,029 |
| TOTAL (2025 – Rounded to nearest $1000) | $56,694,000 | $61,794,000 | $44,040,000 | $65,442,000 | $56,613,000 |

Table K.46: Option C GAC with NF/RO Polish – Detailed CAPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| Greensand Filters (Equipment, Media, Installation) | $3,888,000 | $3,888,000 | $2,592,000 | $3,888,000 | $3,888,000 |
| GAC Skids (Equipment, Media, Installation) | $4,881,600 | $5,695,200 | $4,068,000 | $5,695,200 | $4,881,600 |
| Greensand Filter/GAC Backwash Storage and Pumps | $919,872 | $919,872 | $819,872 | $919,872 | $919,872 |
| NF/RO System (Equipment, Installation) | $5,076,400 | $5,076,400 | $3,626,000 | $5,801,600 | $5,076,400 |
| Chemical Tanks & Chemical Feed Skids | $1,430,500 | $1,565,500 | $1,039,000 | $1,700,500 | $1,423,750 |
| Finished Water Pumping | $556,200 | $610,200 | $399,600 | $664,200 | $553,500 |
| Process Piping | $148,320 | $162,720 | $106,560 | $177,120 | $147,600 |
| Valves and Flow Control | $436,000 | $482,000 | $354,000 | $482,000 | $436,000 |
| Building (Architecture, Plumbing, Electrical, HVAC) | $22,625,856 | $24,598,816 | $17,353,248 | $25,841,376 | $22,587,840 |
| SUBTOTAL | $39,962,748 | $42,998,708 | $30,358,280 | $45,169,868 | $39,914,562 |
| *Mobilization & Site Setup (5%)* | $1,998,137 | $2,149,935 | $1,517,914 | $2,258,493 | $1,995,728 |
| *Bonding & Insurance (3%)* | $1,198,882.44 | $1,289,961.24 | $910,748.40 | $1,355,096.04 | $1,197,436.86 |
| *Contractor Overhead and Profit (15%)* | $5,994,412 | $6,449,806 | $4,553,742 | $6,775,480 | $5,987,184 |
| *Engineering & Construction Contingency (45%)* | $17,983,237 | $19,349,419 | $13,661,226 | $20,326,441 | $17,961,553 |
| TOTAL (2025 – Rounded to nearest $1000) | $67,138,000 | $72,238,000 | $51,002,000 | $75,886,000 | $67,057,000 |

Table K.47: Option D GAC Treatment with IX Polish – Detailed CAPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| Greensand Filters (Equipment, Media, Installation) | $3,888,000 | $3,888,000 | $2,592,000 | $3,888,000 | $3,888,000 |
| GAC Skids (Equipment, Media, Installation) | $4,881,600 | $5,695,200 | $4,068,000 | $5,695,200 | $4,881,600 |
| Greensand Filter/GAC Backwash Storage and Pumps | $919,872 | $919,872 | $819,872 | $919,872 | $919,872 |
| IX System (Equipment, Media, Installation) | $2,099,429 | $2,424,509 | $1,774,349 | $2,424,509 | $2,099,429 |
| Chemical Tanks & Chemical Feed Skids | $1,430,500 | $1,565,500 | $1,039,000 | $1,700,500 | $1,423,750 |
| Finished Water Pumping | $556,200 | $610,200 | $399,600 | $664,200 | $553,500 |
| Process Piping | $148,320 | $162,720 | $106,560 | $177,120 | $147,600 |
| Valves and Flow Control | $436,000 | $482,000 | $354,000 | $482,000 | $436,000 |
| Building (Architecture, Plumbing, Electrical, HVAC) | $21,805,696 | $24,204,576 | $17,071,648 | $24,964,896 | $21,767,680 |
| SUBTOTAL | $36,165,617 | $39,952,577 | $28,225,029 | $40,916,297 | $36,117,431 |
| *Mobilization & Site Setup (5%)* | $1,808,281 | $1,997,629 | $1,411,251 | $2,045,815 | $1,805,872 |
| *Bonding & Insurance (3%)* | $1,084,969 | $1,198,577 | $846,751 | $1,227,489 | $1,083,523 |
| *Contractor Overhead and Profit (15%)* | $5,424,843 | $5,992,887 | $4,233,754 | $6,137,445 | $5,417,615 |
| *Engineering & Construction Contingency (45%)* | $16,274,528 | $17,978,660 | $12,701,263 | $18,412,334 | $16,252,844 |
| TOTAL (2025 – Rounded to nearest $1000) | $60,759,000 | $67,121,000 | $47,419,000 | $68,740,000 | $60,678,000 |

Table K.48: Option E Sacrificial GAC with IX Lead/Lag – Detailed CAPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| Greensand Filters (Equipment, Media, Installation) | $3,888,000 | $3,888,000 | $2,592,000 | $3,888,000 | $3,888,000 |
| GAC Skids (Equipment, Media, Installation) | $3,417,120 | $3,986,640 | $2,847,600 | $3,986,640 | $3,417,120 |
| Greensand Filter/GAC Backwash Storage and Pumps | $919,872 | $919,872 | $819,872 | $919,872 | $919,872 |
| IX System (Equipment, Media, Installation) | $2,935,349 | $3,399,749 | $2,470,949 | $3,399,749 | $2,935,349 |
| Chemical Tanks & Chemical Feed Skids | $1,430,500 | $1,565,500 | $1,039,000 | $1,700,500 | $1,423,750 |
| Finished Water Pumping | $556,200 | $610,200 | $399,600 | $664,200 | $553,500 |
| Process Piping | $148,320 | $162,720 | $106,560 | $177,120 | $147,600 |
| Valves and Flow Control | $436,000 | $482,000 | $354,000 | $482,000 | $436,000 |
| Building (Architecture, Plumbing, Electrical, HVAC) | $21,805,696 | $24,204,576 | $17,071,648 | $24,964,896 | $21,767,680 |
| SUBTOTAL | $35,537,057 | $39,219,257 | $27,701,229 | $40,182,977 | $35,488,871 |
| *Mobilization & Site Setup (5%)* | $1,776,853 | $1,960,963 | $1,385,061 | $2,009,149 | $1,774,444 |
| *Bonding & Insurance (3%)* | $1,066,112 | $1,176,578 | $831,037 | $1,205,489 | $1,064,666 |
| *Contractor Overhead and Profit (15%)* | $5,330,559 | $5,882,889 | $4,155,184 | $6,027,447 | $5,323,331 |
| *Engineering & Construction Contingency (45%)* | $15,991,676 | $17,648,666 | $12,465,553 | $18,082,340 | $15,969,992 |
| TOTAL (2025 – Rounded to nearest $1000) | $59,703,000 | $65,889,000 | $46,539,000 | $67,508,000 | $59,622,000 |

Table K.49: Option A GAC Treatment for PFAS – Detailed OPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| GAC Changeout per Year | $12,706,737 | $13,940,401 | $9,129,112 | $15,174,065 | $12,645,054 |
| Landfill Disposal of GAC Media | $2,258,976 | $2,478,294 | $1,622,953 | $2,697,612 | $2,248,010 |
| Chemical Costs | $22,959 | $48,323 | $18,750 | $31,493 | $26,244 |
| Process/NPDES Testing (Non-PFAS) | $52,000 | $52,000 | $52,000 | $52,000 | $52,000 |
| PFAS Testing | $291,200 | $327,600 | $254,800 | $327,600 | $291,200 |
| Electrical costs ($0.10/kWh) | $170,181 | $170,181 | $104,832 | $170,181 | $170,181 |
| Labor Costs | $426,400 | $426,400 | $426,400 | $426,400 | $426,400 |
| Sewer Costs ($2.31/1000 gal) | $139,685 | $139,685 | $95,976 | $139,685 | $139,685 |
| Replacement Parts & Operations Equipment | $199,313 | $216,665 | $153,989 | $217,745 | $199,259 |
| TOTAL (2025 – Rounded to nearest $1000) | $16,268,000 | $17,800,000 | $11,859,000 | $19,237,000 | $16,199,000 |

Table K.50: Option B GAC and NF/RO Parallel Trains – Detailed OPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| GAC Changeout per Year | $6,353,369 | $6,970,201 | $4,564,556 | $7,587,032 | $6,322,527 |
| Landfill Disposal of GAC Media | $1,129,488 | $1,239,147 | $811,477 | $1,348,806 | $1,124,005 |
| Chemical Costs | $22,959 | $48,323 | $18,750 | $31,493 | $26,244 |
| Process/NPDES Testing (Non-PFAS) | $52,000 | $52,000 | $52,000 | $52,000 | $52,000 |
| PFAS Testing | $182,000 | $218,400 | $182,000 | $218,400 | $182,000 |
| Electrical costs ($0.10/kWh) | $810,607 | $810,607 | $562,278 | $902,096 | $810,607 |
| Labor Costs | $426,400 | $426,400 | $426,400 | $426,400 | $426,400 |
| Sewer Costs ($2.31/1000 gal) | $139,685 | $139,685 | $95,976 | $139,685 | $139,685 |
| Replacement Parts & Operations Equipment | $252,025 | $269,377 | $193,965 | $284,961 | $251,971 |
| NF/RO Membrane Replacement | $94,500 | $94,500 | $67,500 | $108,000 | $94,500 |
| TOTAL (2025 – Rounded to nearest $1000) | $9,464,000 | $10,269,000 | $6,975,000 | $11,099,000 | $9,430,000 |

Table K.51: Option C GAC with NF/RO Polish – Detailed OPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| GAC Changeout per Year | $12,706,737 | $13,940,401 | $9,129,112 | $15,174,065 | $12,706,737 |
| Landfill Disposal of GAC Media | $2,258,976 | $2,478,294 | $1,622,953 | $2,697,612 | $2,248,010 |
| Chemical Costs | $22,959 | $48,323 | $18,750 | $31,493 | $22,959 |
| Process/NPDES Testing (Non-PFAS) | $52,000 | $52,000 | $52,000 | $52,000 | $52,000 |
| PFAS Testing | $291,200 | $327,600 | $254,800 | $327,600 | $291,200 |
| Electrical costs ($0.10/kWh) | $810,607 | $810,607 | $562,279 | $902,097 | $810,607 |
| Labor Costs | $426,400 | $426,400 | $426,400 | $426,400 | $426,400 |
| Sewer Costs ($2.31/1000 gal) | $139,685 | $139,685 | $95,977 | $139,685 | $139,685 |
| Replacement Parts & Operations Equipment | $300,841 | $318,193 | $226,509 | $333,777 | $300,787 |
| NF/RO Membrane Replacement | $94,500 | $94,500 | $67,500 | $108,000 | $94,500 |
| TOTAL (2025 – Rounded to nearest $1000) | $17,122,000 | $18,654,000 | $12,469,000 | $20,213,000 | $17,053,000 |

Table K.52: Option D GAC Treatment with IX Polish – Detailed OPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| GAC Changeout per Year | $9,076,241 | $9,957,429 | $6,520,794 | $10,838,618 | $9,032,181 |
| IX Changeout per Year | $1,555,593 | $1,706,621 | $1,117,610 | $1,857,649 | $1,548,041 |
| Landfill Disposal of GAC & IX Media | $1,701,999 | $1,867,242 | $1,222,796 | $2,032,485 | $1,693,737 |
| Chemical Costs | $26,098 | $41,604 | $18,750 | $31,493 | $26,244 |
| Process/NPDES Testing (Non-PFAS) | $52,000 | $52,000 | $52,000 | $52,000 | $52,000 |
| PFAS Testing | $291,200 | $327,600 | $254,800 | $327,600 | $291,200 |
| Electrical costs ($0.10/kWh) | $170,181 | $170,181 | $104,832 | $170,181 | $170,181 |
| Labor Costs | $426,400 | $426,400 | $426,400 | $426,400 | $426,400 |
| Sewer Costs ($2.31/1000 gal) | $139,685 | $139,685 | $95,977 | $139,685 | $139,685 |
| Replacement Parts & Operations Equipment | $238,323 | $262,177 | $186,497 | $263,257 | $238,269 |
| TOTAL (2025 – Rounded to nearest $1000) | $13,678,000 | $14,951,000 | $10,001,000 | $16,140,000 | $13,618,000 |

Table K.53: Option E Sacrificial GAC with IX Lead/Lag – Detailed OPEX Estimate for Each Scenario.

| Equipment | Scenario 1 | | Scenario 2 | | Scenario 3 |
|---|---|---|---|---|---|
| | Oakdale | Lake Elmo | Oakdale | Lake Elmo | Lake Elmo |
| GAC Changeout per Year | $939,940 | $1,031,197 | $675,297 | $1,122,453 | $935,377 |
| IX Changeout per Year | $1,555,593 | $1,706,621 | $1,117,610 | $1,857,649 | $1,548,041 |
| Landfill Disposal of GAC & IX Media | $184,446 | $209,032 | $143,543 | $217,619 | $184,016 |
| Chemical Costs | $26,098 | $41,604 | $18,750 | $31,493 | $26,244 |
| Process/NPDES Testing (Non-PFAS) | $52,000 | $52,000 | $52,000 | $52,000 | $52,000 |
| PFAS Testing | $291,200 | $327,600 | $254,800 | $327,600 | $291,200 |
| Electrical costs ($0.10/kWh) | $170,181 | $170,181 | $104,832 | $170,181 | $170,181 |
| Labor Costs | $426,400 | $426,400 | $426,400 | $426,400 | $426,400 |
| Sewer Costs ($2.31/1000 gal) | $139,685 | $139,685 | $95,977 | $139,685 | $139,685 |
| Replacement Parts & Operations Equipment | $225,752 | $247,510 | $176,021 | $248,590 | $225,698 |
| TOTAL (2025 – Rounded to nearest $1000) | $4,012,000 | $4,352,000 | $3,066,000 | $4,594,000 | $3,999,000 |