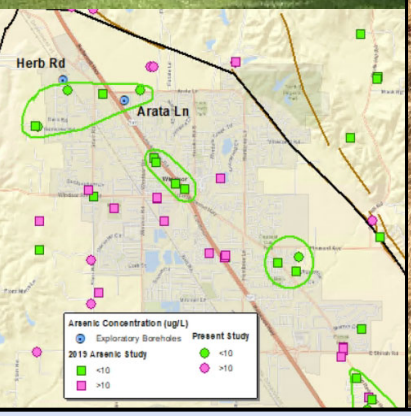
August 2024

Town of Windsor
CALIFORNIA

Groundwater Master Plan

Final







Trussell

TODD GROUNDWATER

GHD

GROUNDWATER MASTER PLAN—FINAL

TOWN OF WINDSOR, CALIFORNIA

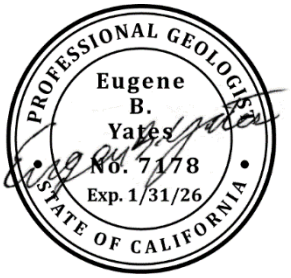
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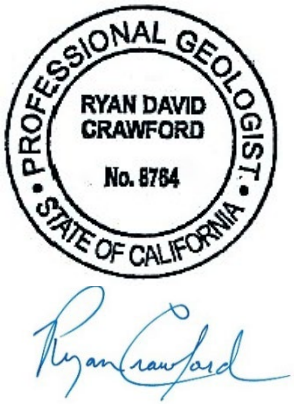
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1. INTRODUCTION

The Town of Windsor and the Windsor Water District (referred throughout this document as the "Town") obtains all of its potable water supply from the Russian River or its underflow (RR Well System and Sonoma County Aqueduct). In the late 1990's, the Town had several off-river wells that were used to supplement the RR Well system, especially in times of emergency, such as contamination of water on the river, or an earthquake that could temporarily interrupt the pipeline from the river to Town, or during droughts. But in 2000, the Environmental Protection Agency (EPA) adopted a new, much lower allowable limit for arsenic in drinking water and then none of the off-river wells could be used unless treated. Arsenic occurs naturally in the Santa Rosa Plain groundwater basin and is commonly detected in wells in Sonoma County, but treatment to remove arsenic can be expensive.

In response, the Town looked at multiple options, and in 2010, obtained grant funding for two new wells that were drilled to replace the two main off-river wells with arsenic levels exceeding the maximum contaminant level (MCL) for drinking water. The Esposti potable well and the Bluebird B well. These wells were drilled much deeper, in hope of pumping groundwater from a deeper aquifer. Water quality samples immediately following construction appeared to be low in arsenic. Unfortunately, arsenic concentrations in samples collected shortly thereafter were high enough to require treatment. Due to the cost of arsenic treatment, the Town has since completed several investigations to fully understand where the arsenic occurs, what water quality parameters affect the arsenic, and what treatment option would remove the arsenic most cost-effectively.

Also in the last two droughts, the Town's potable water supply was subject to State regulatory production reductions of 20 percent. The Town came to within days of having to cut 30 percent of RR well system production due to the extended drought. The public was able to conserve water to meet the 20% reduction requirement, but a 30% reduction would have been much more difficult to achieve as demand hardening has already occurred due to implementation of permanent water conservation measures, such as lawn removals.

It became clear a plan would be needed to determine the best path forward for an off-river well program, presented here as a Groundwater Master Plan.

The focus of this Groundwater Master Plan (Plan) is to document water quality beneath the Town, determine if new wells could be drilled that would not encounter arsenic, identify the best options for renewing the off-river potable water supply, consider the most cost-effective treatment for arsenic and present the costs to augment the Russian River well supply with an off-river well system to use during droughts, emergencies, and occasional summer peak demand periods.

This Plan estimates cost, likelihood of success, permitting requirements and funding options. The water supply objective is essentially an off-river water supply of approximately 800 gallons per minute (gpm) to back up a portion of the Russian River well system.

Technical studies were completed during this Plan development process to provide the information needed to identify and rank water supply alternatives. These included an evaluation of sediment texture distribution within the groundwater basin in the Town area, canvassing of water quality at additional wells to fill data gaps in historical water quality records, and drilling exploratory boreholes in two locations to obtain depth-specific water quality information.

Based on the results of the technical studies, the Plan identified and ranked a range of water supply alternatives, including rehabilitation of existing wells, new deep extraction wells, new shallow extraction wells, groundwater treatment, aquifer storage and recovery (ASR) wells, and indirect potable reuse (IPR). At a conceptual level, all of the alternatives could theoretically satisfy the water supply objective. Specific locations were identified for implementing some of the conceptual alternatives, which enabled more detailed evaluation of cost and feasibility. The Plan describes each alternative in terms of technical feasibility, permitting feasibility, approximate cost and certainty of success. Feasible alternatives were ranked on the basis of cost and certainty of success to identify a recommended alternative. Given that many of the conceptual alternatives involve pumping from the groundwater basin, discussion also is provided of groundwater basin budgets, basin yield, and climate change. Finally, next steps are described for implementing the recommended alternative.

2. PLANNING BACKGROUND

The motivation for preparing this Groundwater Master Plan began in 2001, when the U.S. Environmental Protection Agency reduced the maximum contaminant level (MCL) for arsenic in drinking water from 50 micrograms per liter (µg/L , also parts per billion or ppb) to 10 µg/L. Naturally-occurring arsenic is present in groundwater throughout the Windsor area, except in Russian River underflow. Arsenic concentrations are often between 10 and 50 µg/L, thus lowering the MCL rendered all of the Town's off-river wells unusable for potable supply. This triggered a long series of planning and technical studies aimed at finding the most economical way to obtain a low-arsenic water supply independent of the river. Some key reports include the following:

- **2001—Richard C. Slade study recommending off-river sites for new municipal wells.** The report includes descriptions of the three Town off-river wells active at the time (Bluebird No. 3, Keiser Park, and Esposti Park). Six sites for potential new wells were evaluated, and three were recommended for test drilling. All three were on Town-owned parcels near the confluence of Windsor Creek and Pool Creek, north of Sonoma County Airport. Groundwater quality was not considered in site selection.
- **2007— Winzler & Kelly well siting study for off-river wells.** The study reviewed 965 well completion reports and entered key data for approximately 75 percent of them (the ones with higher-quality data) into a GIS database. Patterns in well information were used to identify seven locations where relatively high yields might be found. Of these, the Pool Creek area, golf course area, and northwest Old Redwood Highway area were particularly recommended. Groundwater quality was not considered in site selection.
- **2010— RMC report on installation and testing of Bluebird B and Esposti municipal wells.** Initial water quality sampling during drilling at 5-7 depths in the open borehole indicated low arsenic for both wells (average of 4 µg/L for Bluebird and 10 µg/L for Esposti). But samples of the well discharges after development were much higher (average of 350 µg/L and 58 µg/L, respectively).
- **2011— RMC Water Master Plan and EIR**.
- **2015— GHD Urban Water Management Plan.** Recommended installing a water treatment plant for the Esposti municipal well and drilling a new "north Windsor" well.
- **2017— GHD Esposti Municipal Well Study.** The well was redeveloped and tested again for arsenic, but the concentration (57 µg/L) still exceeded the MCL.
- **2017—Rincon Consultants, Inc. Windsor 2040 General Plan Environmental Impact Report (2040 GP EIR)**. In the Utilities and Service Systems section of the 2040 GP EIR, two new-off-river wells are discussed, which indicate would supply the Town with additional potable water with the addition of a treatment system for the Esposti well and a second well will likely be drilled in the future to meet projected demands through 2040.
- **2019— Woodard & Curran Arsenic Study**. Completed a comprehensive compilation of well logs, yields and arsenic data for wells near Windsor. Some evidence of increasing arsenic concentrations with increasing depth and temperature in the groundwater basin was presented. The study recommended further exploration of groundwater in the northern part of Windsor as the area most likely to have low arsenic.
- **2019— Woodard & Curran Water Master Plan update.** Retained Esposti municipal well treatment and a new north Windsor supply well as top capital improvement projects. Much of

the analysis focused on distribution system capacity needs. Appendix A provided a history of the Town's off-river wells.

- **2020— Woodard & Curran 2020 Urban Water Management Plan**. Noted that the Town's capital improvement projects program included a new supply well in the northern part of Windsor and treatment of Esposti Well water, with the order of implementation to be determined by results of exploratory drilling in the north part of Town.
- **2021— GHD updated Esposti treatment cost estimate**. Retained the recommendations of the 2017 Esposti Well study but updated the cost estimate.

Compliance with the California Environmental Quality Act (CEQA) will be required when the Town budgets for a project and begins design work for the recommended water supply alternative. The project will need to be consistent with the Groundwater Sustainability Plan (GSP) for the Santa Rosa Plain groundwater subbasin and with other state and local ordinances and directives. Consistency and permitting issues are evaluated in the detailed discussion of the recommended water supply alternative.

3. EXISTING TOWN WATER SUPPLIES

The Town's water supply and distribution system are shown in **Figure 1** and include wells near the Russian River, off-river wells, a connection to a regional aqueduct, and pipeline networks to distribute potable and recycled water. These are described below.

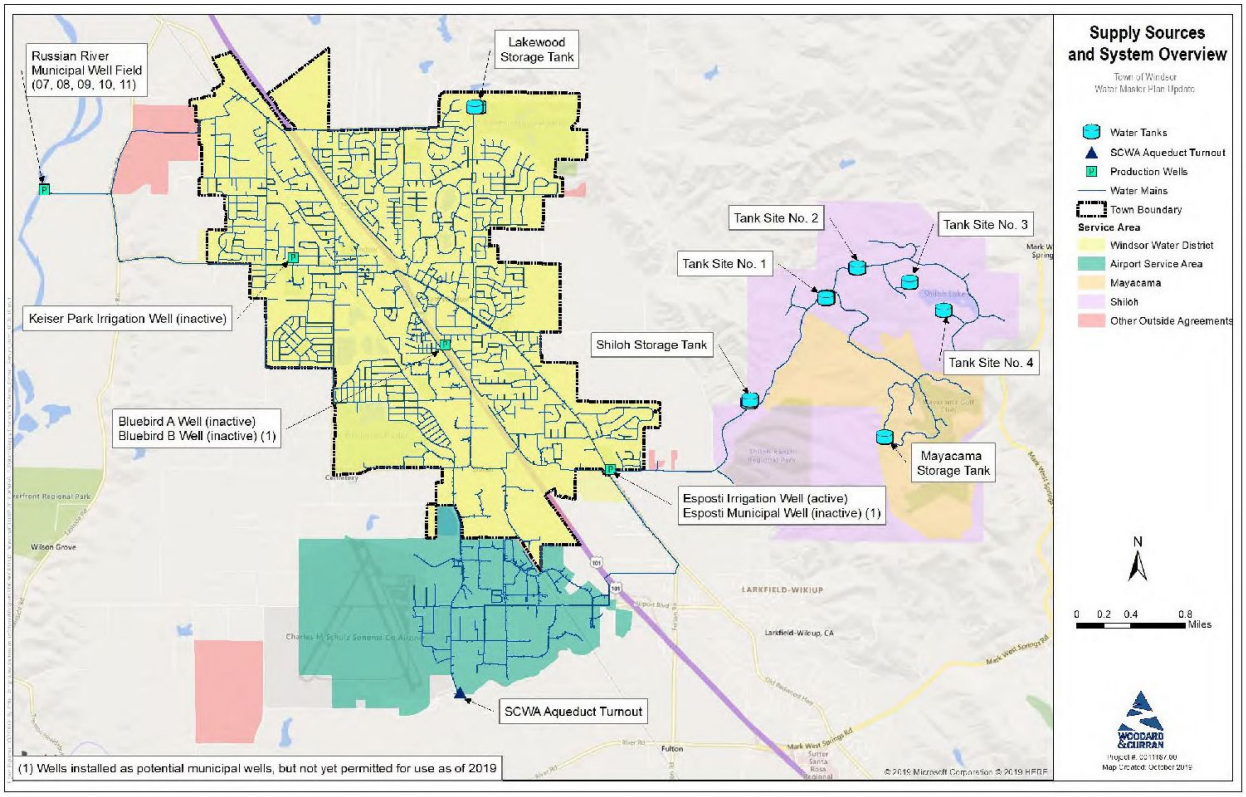


Figure 1 Map of Town Water Infrastructure

3.1. RUSSIAN RIVER WELL FIELD

The Town owns and operates five municipal supply wells located about 300 feet (ft) from the Russian River beyond the west end of Windsor River Road and screened in the shallow alluvial deposits of the river floodplain. The wells are 16-18 inches in diameter and range in depth from 88-102 ft (Woodard & Curran, 2021). They currently supply about 95 percent of the Town's potable water use. Because the alluvial groundwater is considered underflow of the Russian River, extractions are limited by contractual agreements with Sonoma Water (formerly Sonoma County Water Agency) and their extractions are limited by the State Water Quality Control Board for Russian River diversions of surface water right users. Those include the "Restructured Agreement with Sonoma County Water Agency" and an October 2006 "Memorandum of Understanding Regarding Water Transmission System Capacity Allocation during Temporary Impairment" (Woodard & Curran, 2019). This agreement has a Local Production Capacity goal so that during droughts, earthquakes, spills, or temporary impairments, it is highly desirable that Windsor achieve and maintain local water production capacity of approximately 40 percent (40%) of the average day maximum month demand.

Acting on an order from Governor Gavin Newsom (Drought Executive Order N-7-22), the State Water Resources Control Board voted to adopt emergency drought regulations that require water suppliers to activate their local drought plans to prepare for a shortage of up to 20%.

Several times over the last 15 years, the State Water Resources Control Board adopted emergency drought regulations that required a 20-25% reduction in Russian River diversions. Sonoma Water required the Town to reduce its annual pumping by 20 percent below its normal usage amount, even if the normal amount already reflects substantial conservation and low per-capita water use. The 20 to 25 percent reduction has been imposed five years since 2006.

3.2. SONOMA COUNTY AQUEDUCT

The Town also purchases surface water from Sonoma Water, which is derived from a Russian River diversion and conveyed to near the southwest corner of the Town via the Santa Rosa Aqueduct. The contract allows the Town to purchase up to 900 acre-feet per year (AFY) of water and to withdraw the water from the aqueduct at an instantaneous rate no greater than 3.7 cubic feet per second (cfs) or a monthly average rate no greater than 2.3 cfs. The agreement for this water was created for the Town, but also to provide water to the outside Airport Service Area, which uses approximately half of the water, or 450AFA.

3.3. OFF-RIVER WELLS

The Bluebird A well has a 12-inch diameter steel casing screened at 260-324, 332-336 and 380-400 ft below the ground surface (bgs). The well was tested at 500-525 gpm when it was first constructed in 1972. As of 1993, it had a pump capable of producing 450 gpm. As of 2001, it was the only off-river well operated for municipal supply. When the arsenic standard was lowered that year, the well was removed from service. Equipment at the well site included a chemical feed building, reaction tank, filtration tank, hydropneumatic tank, and electrical control panels (Brelje & Race, 1996). The water treatment was for manganese and chlorination, because the arsenic MCL had not yet been lowered at the time of the equipment inventory. Much of that equipment is still on-site.

The Bluebird B well was drilled in 2010. It is a 10-inch diameter well with a steel casing and stainless steel wire-wrapped screen at 695-745 ft bgs. After 5 days of well development, a test pump was installed. The well yield was too low to even conduct an aquifer test, and further well development was not possible at the time due to budget and schedule constraints. When water quality samples following development indicated high arsenic, efforts to place the well into service were discontinued. The well was simply capped and left in place without a pump (RMC, 2010). The well is currently used for water level measurements of the deeper aquifer, by the Santa Rosa Plain Groundwater Sustainability Agency.

The Esposti Park irrigation well is screened from 100-220 ft and 240-300 ft bgs. The yield reported by the driller was 230 gpm (Richard C. Slade, 2001). The well continues to provide irrigation water for the park, producing an estimated 50 AFY (Woodard & Curran, 2021).

The Esposti Park municipal well was drilled in 2010, about 59 ft from the irrigation well. It is a 10-inch diameter well with steel casing and stainless steel screens at 380-420, 430-450, 460-470, 480-510, 545-565 and 615-655 ft bgs. After development, the well was pumped for 16 hours at 400 gpm, reaching 95 ft of drawdown by the end of the test. A redevelopment and testing program in 2016 confirmed the recommended sustainable pumping rate of 400 gpm, with an instantaneous pumping rate of 800gpm

for a day, obtained new water quality samples showing an arsenic concentration of 57 µg/L and a manganese concentration of 860 µg/L (GHD, 2017).

The Keiser Park well was drilled in 1981. It has an 8-inch diameter poly vinyl chloride (PVC) casing screened at 57-67 ft, 82-102 ft, 246-256 ft and 418-428 ft bgs. The submersible pump reportedly produced 150-175 gpm. It was permitted as an emergency municipal well and park irrigation well for several years in the 1990's and 2000's. It provided water for park irrigation only, until recycled water was brought to the park and the well was removed from the Town well system by 2015 (Woodard & Curran, 2019).

3.4. RECYCLED WATER

The Town produces and distributes tertiary recycled water for injection at the Geysers geothermal field, for High School bathrooms, Fire Station No. 3, irrigation of nearby agricultural areas and for irrigation use in the Town. Of the 1,645 acre-feet (AF) of recycled water produced in 2020, 542 AF was sent to the Geysers, 384 AF was discharged to Mark West Creek, 244 AF was used to irrigate a local golf course, 228 AF was used for irrigation of agricultural fields near the Town, and 247 AF was used for urban irrigation and minor other nonpotable uses (Woodard & Curran, 2021). The Town expects that its contribution to the Geysers geothermal plant have and will increase substantially between 2020 and 2025 and then again between 2035 and 2040. Deliveries for urban irrigation are also expected to increase. Thus, except for wet weather periods in winter when recycled water is discharged to the creek, the recycled water supply is earmarked for use through 2040. In addition to being available only seasonally, the discharge to Mark West Creek amounts to only about half of the additional water supply the Town seeks to achieve through this Plan.

3.5. WATER USE

Total potable water use by Town customers decreased from 2010-2020, but the 2010, 2015 and 2020 Urban Water Management Plans (UWMPs) all projected future increases in population and water demand in the Town service area. **Figure 2** shows historical and projected population and water use for 2000-2040. Potable water use averaged 3,328 AFY during 2017-2021. The future projections are from the 2020 UWMP and are based on a water demand forecasting study prepared for the Town in 2020 (EKI Environment & Water, Inc., 2020). That study resulted in projected increases in future water demand and also calculated a deficit in potable water during single year and multiyear droughts by 2030. There has been a temporary drop in the population of Windsor since 2020, due to fires, the high cost of living and the pandemic, but the Town projects that the population will increase in 2024 and beyond, so the 2020 UWMP will remain as the best projections to be used for this Plan for a reliable potable water supply. In the 2020 UWMP, the Town estimates that if two off-river wells supplying a combined 700 AFY of water over the 6-month maximum demand season could be installed by 2030, the water system would be able to balance the sources of water during droughts or other water shortages.

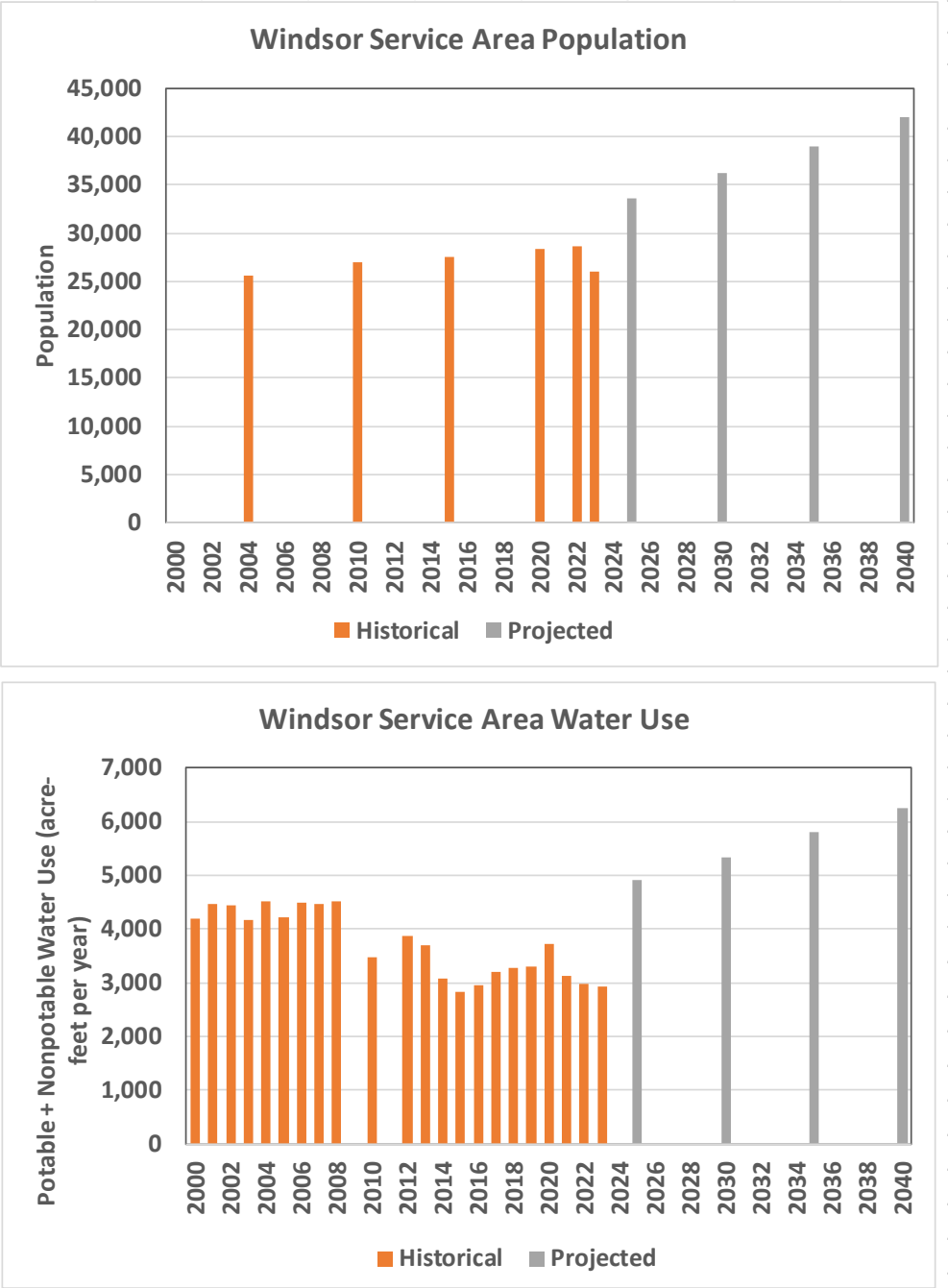


Figure 2. Historical and Projected Population and Water Use

4. GROUNDWATER CONDITIONS IN TOWN AREA

4.1. TEXTURE OF BASIN FILL DEPOSITS

The Town area is located at the northern end of the Santa Rosa Plain Groundwater Basin, in a region shown on geologic maps primarily as alluvium (**Figure 3**). These surficial deposits are underlain by the Glen Ellen Formation, which crops out to the east and west of the Town. Quaternary alluvium and the Glen Ellen Formation have similar patterns of texture and strata. Both formations consist of thin local strata of clay, silt, sand and gravel. The primary differences are that the Glen Ellen Formation is more consolidated and cemented, but those differences can be subtle.

Well yield and groundwater quality are the two major challenges for siting a new municipal well. Because of the heterogeneous and generally fine-grained texture of geologic deposits in the basin, the target yield of 400 gpm cannot be achieved with certainty at any given location. Concentrations of naturally occurring arsenic and manganese are both commonly above their respective maximum contaminant levels for drinking water, and the probability of obtaining water not needing treatment for those constituents at any given location is moderate to low.

For this study, two compilations of subsurface texture were analyzed to identify regions in and near the Town where coarse, permeable sediments are relatively abundant within the top 600 feet of basin materials. Those regions would be favorable for drilling a well that would meet the 400-gpm target yield for a new municipal well. The subsurface texture analysis is described in detail in **Appendix B** and is summarized here.

The first texture compilation was done for this Plan was based on well completion reports obtained directly from Well Completion Reports (WCRs) from the California Department of Water Resources (DWR) via its Online System of Well Completion Reports (OSWCR). WCRs are prepared by drillers and are notoriously uneven in terms of location accuracy and the quality and detail of lithologic descriptions. Only 246 of the 1,000 wells were more than 100 ft deep and could be located on a map based on street address. Of those, only 95 had lithologic descriptions sufficiently accurate to calculate percent coarse sediments in the 50-200 foot depth interval, which was expected to have higher yields and lower arsenic than deeper intervals.

The second compilation of subsurface texture was completed by the U.S. Geological Survey (Sweetkind and others, 2010). It was also based on WCRs. Using reports that could be located with reasonable accuracy, texture descriptions were assigned to 19 categories which were then lumped into “coarse” and “fine” major categories. Maps of the percent coarse material for 50-foot and 100-foot depth intervals were prepared by applying the data for one well over a region extending halfway to the nearest neighboring well.

For both compilations, wells with greater than 40 percent coarse material were rare and generally not clustered in certain regions. This reflected the predominantly fine-grained texture of basin deposits and the large degree of spatial variability in texture. One local area where multiple wells had above-average values of percent coarse material was at the northwest corner of the Town area, roughly bounded by Eastside Road, Highway 101, and Gumview Road. This region has also been suggested by previous investigators as potentially favorable for a new municipal well (GHD, 2015; Woodard and Curran, 2019a and 2019b).

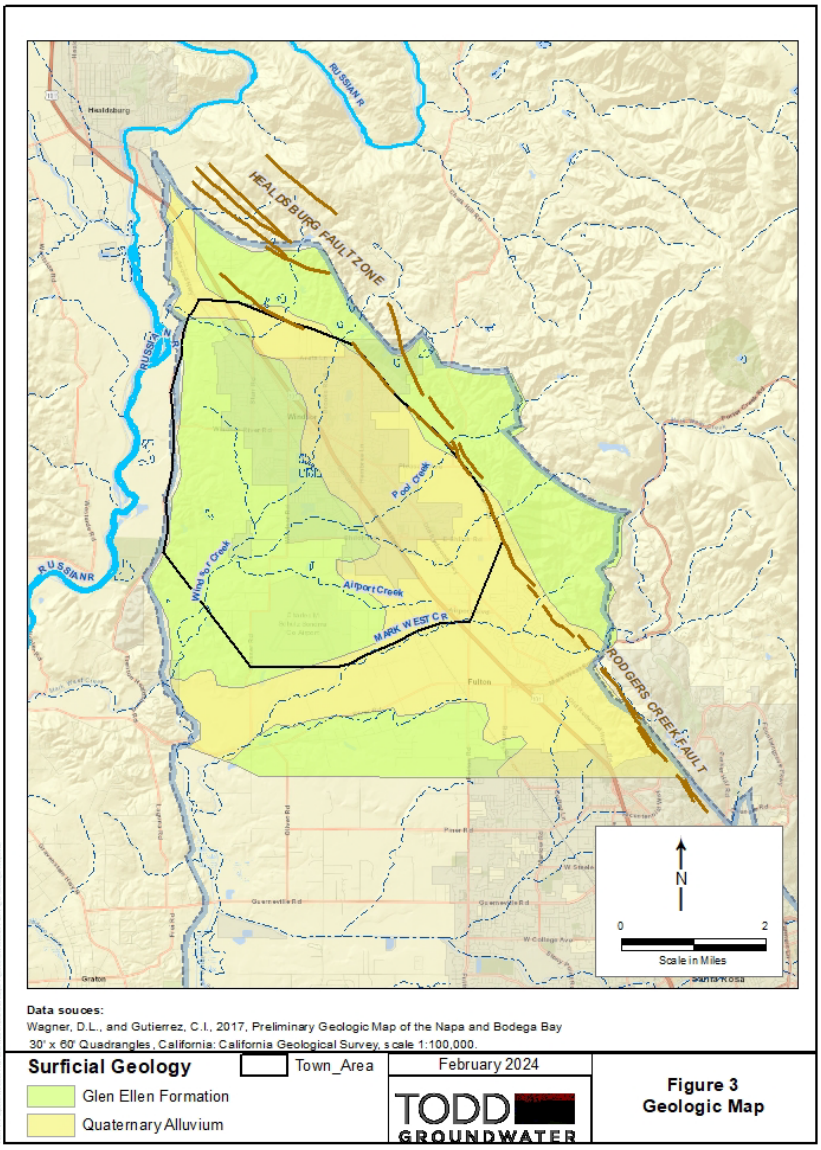


Figure 3. Geologic Map

4.2. GROUNDWATER QUALITY

Groundwater quality in the Town area generally meets the water quality requirements for drinking water except for high concentrations of arsenic and manganese. A comprehensive compilation of arsenic data from public water quality databases was completed in 2019 (Woodard and Curran, 2019a). Weak correlations between arsenic concentration and well depth were noted, but no obvious geographic patterns emerged from the data. Noting that the historical arsenic data were sparse, preparation of this Plan included additional sampling of wells in the Town area and drilling of two exploratory boreholes with water quality sampling at discrete depth intervals (zonal sampling). The well

sampling was done in two phases in 2022-2023 and was followed by the exploratory boreholes. Details of all three efforts are provided in **Appendix C**, and the results are summarized here.

Sampling of existing wells for this Plan included five wells near Arata Lane and ten wells scattered throughout other parts of the Town. Arsenic concentrations from those samples were combined with data from the 2019 arsenic study to produce the map shown in **Figure 4**. The data are still too sparse to clearly identify regions with low arsenic, particularly given that the wells also represent a range of depths. However, several areas with possibly low arsenic were tentatively identified and are indicated by the green polygons.

The Herb Road and Los Amigos Road sites were selected for drilling exploratory boreholes in which groundwater quality was sampled at discrete depth intervals ("zonal testing"). The drilling and testing program is described in **Appendix E**. The zonal sampling results provided the best data available to date of the depth distribution of arsenic and manganese concentrations. Arsenic and manganese concentrations for the four depth zones at Herb Road and five depth zones at Los Amigos Road are shown in **Figure 5**. The deepest zone at Herb Road was completed in Sonoma Volcanics. The arsenic and manganese concentrations were low, but the volcanic materials do not yield much water and would not be targeted for a municipal well. Among the remaining samples, arsenic at both sites was consistently lower in shallow zones (less than 215 ft bgs) than in deeper ones. It is likely this represents a difference between Quaternary alluvium and Glen Ellen Formation, but that could not be verified based on the geologic or geophysical logs.

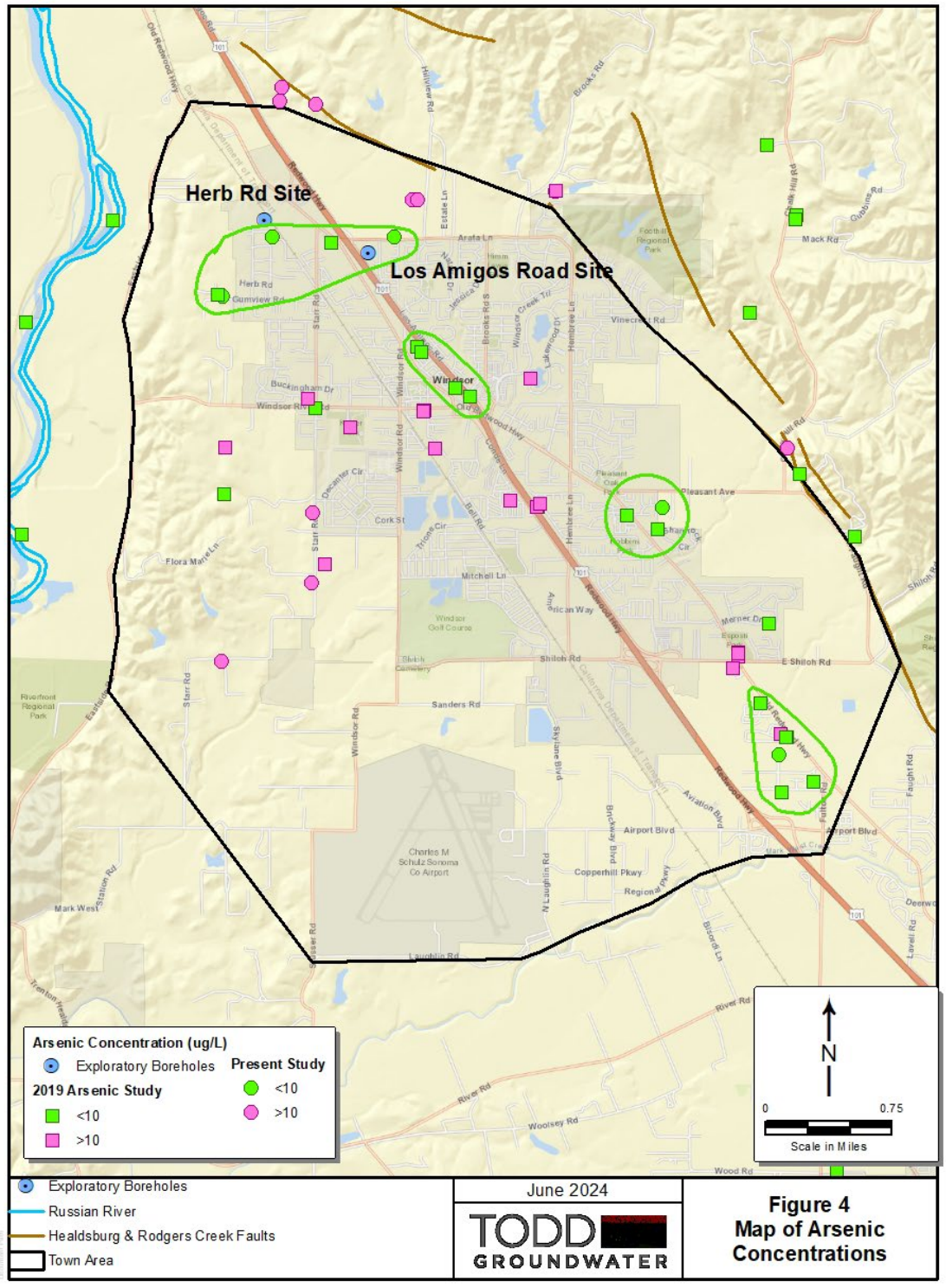


Figure 4. Map of Arsenic Concentrations in Groundwater



Figure 5. Arsenic and Manganese versus Depth in Exploratory Boreholes

5. WATER SUPPLY ALTERNATIVES

A central element of this Plan is to identify and rank alternative sources of municipal potable water supply. The Town presently derives almost all its water from surface and underflow of the Russian River, and it is seeking to diversify its water supply portfolio with a focus on the Town area east of the Russian River.

Two wells drilled in the Town area in 2010 have arsenic levels exceeding the maximum contaminant level. Arsenic occurs naturally in the region and is commonly detected in wells in Santa Rosa Plain Groundwater basin. Due to the high cost of arsenic treatment, the Town seeks to fully understand all viable alternatives in the Town area to ascertain whether one of them would be more cost-effective than treatment. This section describes and ranks a broad range of water supply alternatives, including deep extraction wells, shallow extraction wells, groundwater treatment, aquifer storage and recovery (ASR) wells, and indirect potable reuse (IPR). For some of the alternatives, specific locations have been identified for evaluation, while other alternatives are considered at a conceptual level.

The water supply objective is essentially an off-river water supply able to produce approximately 800 gpm to back up the existing wells along the Russian River. All the alternatives can satisfy this objective. First, the conceptual alternatives are described generally in terms of technical feasibility, permitting feasibility, and cost. Cost is a major discriminator and was evaluated at a reconnaissance level sufficient to rank the alternatives from least to most expensive. Additional technical and permitting considerations are discussed for each of the conceptual water supply alternatives.

The alternatives analysis presented here expands and refines a preliminary analysis completed in May 2023. The preliminary analysis presented a list of conceptual water supply alternatives and ranked them primarily on the basis of cost. That analysis is included in this Plan as **Appendix D**. Since then, more specific information has become available for some of the alternatives, including water quality results from exploratory boreholes in northwest Windsor and the results of test drilling by a private landowner near the eastern edge of the Russian River floodplain. In addition, it became clear that feasibility of implementation, or "certainty of success" needed to be considered in addition to cost. For example, the preliminary analysis clearly pointed to deep wells not requiring treatment as the lowest-cost option. That led to drilling exploratory boreholes at the Herb Rd and Los Amigos Road sites, where low-arsenic groundwater was thought to be present. That proved not to be the case and showed that "certainty of success" needs to be considered. Thus, a second version of the ranking process is presented here using a scoring matrix that includes certainty of success. For example, encountering low-arsenic groundwater at a candidate well location has a relatively low certainty of success, whereas treating well water to remove arsenic and manganese has a high certainty of success. The Town requires a high level of certainty that it can obtain the new supply in the near future.

5.1. YIELD OBJECTIVE FOR NEW WATER SUPPLY

The yield objective for the new water supply can be described in terms of rates or volumes. For brief periods of use, the instantaneous or daily flow rate is most important, and for longer periods of use, the total volume produced is a more relevant metric. The starting point for planning purposes is to develop two sources of water each with a flow rate of 400 gpm. All of the water supply options considered here involve wells. It is standard practice to operate wells cyclically such that they are pumping on average no more than 50 percent of the time. This allows water levels near the well to recover between pumping cycles, avoid accumulating excessive drawdown, and reduce the operational and maintenance costs for

pumping and discharge equipment and infrastructure. Two 400-gpm wells each operating 50 percent of the time would provide approximately 1.8 AF per day, 54 AF per month, 322 AF over a six-month dry season, or approximately 700 AF over a year. For context, total annual water use in the Town service area has been about 3,500 AFY in recent years. If operated all year, the capacity of the new supply would equal about 18 percent of existing water use.

The new water supply is intended to meet short-term needs of various durations, such as:

- Replacement supply for Russian River wells in the event that those wells are temporarily inoperable due to flooding, mechanical failure, contamination, or pipeline failure.
- Supplemental supply during peak demand periods in dry season.
- Supplemental supply during drought years when pumping reductions are imposed on the Russian River wells.

The new supply is considered a replacement for the original Bluebird and Esposti municipal wells, which had to be removed from service as municipal supply wells when the drinking water standard for arsenic was lowered from 50 µg/L to 10 µg/L in 2001. Replacements for those two wells were drilled in 2010 under a grant, but those also failed to produce water that met the new standard. Efforts to replace those wells or treat the groundwater they produce have continued since 2010, including an evaluation of arsenic and manganese treatment and cost for the Esposti Well (GHD, 2017) and a study of arsenic occurrence in groundwater in the northern Santa Rosa Plain Basin area (Woodard & Curran, 2019a).

The new supply is not intended to provide a new increment of everyday supply to support Town growth. In spite of decreasing water demand during 2010-2022, projections in the Urban Water Management Plan are for increased demand. A water demand forecasting study prepared for the Town in 2020 (EKI Environment & Water, Inc., 2020) projected increases in future water demand reaching a deficit in potable water during single-year and multiyear droughts by 2030. The Town estimates that if two off-river wells capable of producing a combined 700 AFY could be installed by then, the water system would be able to balance the sources of water and maintain total supplies during droughts.

5.2. DESCRIPTIONS OF WATER SUPPLY ALTERNATIVES

Ten water supply alternatives were identified and evaluated for feasibility, cost and certainty of success. In some cases—such as treatment of Esposti Municipal Well water—specific locations and designs are already known. Other alternatives—such as indirect potable reuse—are evaluated at a more conceptual level. For those alternatives, sufficient information was developed to support a ranking process. Each of the ten alternatives is described below.

5.2.1. Treatment of Esposti Municipal Well

The Esposti Municipal Well was drilled at Esposti Park in 2010 and was found to have a yield of 400 gpm but with manganese and arsenic concentrations both substantially above their respective MCLs (RMC, 2010). Results were similar when the well was redeveloped and resampled in 2016. Manganese was measured at 860 µg/L (the MCL for manganese is 50 µg/L), and arsenic was measured at 57 µg/L (the MCL is 10 µg/L) (GHD, 2017). Treatment options were presented in both of those previous studies. A more in-depth treatment design effort was completed for this Plan (Trussell 2022) and is included as **Appendix A**. That study compared treatment processes represented by the diagrams in **Figure 6**.

Manganese can be removed by a catalytic oxidation and filtration process. Arsenic can be removed by either an oxidation/filtration process or adsorptive filtration process.

To address both the manganese and arsenic present in the Esposti Supply Well, a combination of treatment processes is needed. To remove both arsenic and manganese, two treatment approaches were developed in a one-step and two-step configuration, as shown in Figure 6. A two-step treatment approach would utilize catalytic oxidation and filtration to remove manganese (Figure 6, part a), followed by removal of arsenic using adsorptive filtration (Figure 6, part b). This approach maintains separate pressure vessels, each with different media, for removal of arsenic and manganese. A one-step treatment option (Figure 6, part c) would utilize supplemental iron added as ferric chloride with Greensand™ media instead of a generic filter media. This approach leverages the filtration properties of the greensand media to capture arsenic-adsorbed hydrolyzed iron while also providing a catalyst for the oxidation of manganese. Pilot-scale testing is recommended to verify the removal efficiencies of arsenic and manganese with the selected treatment process and confirm that the design will meet the drinking water regulatory requirements.

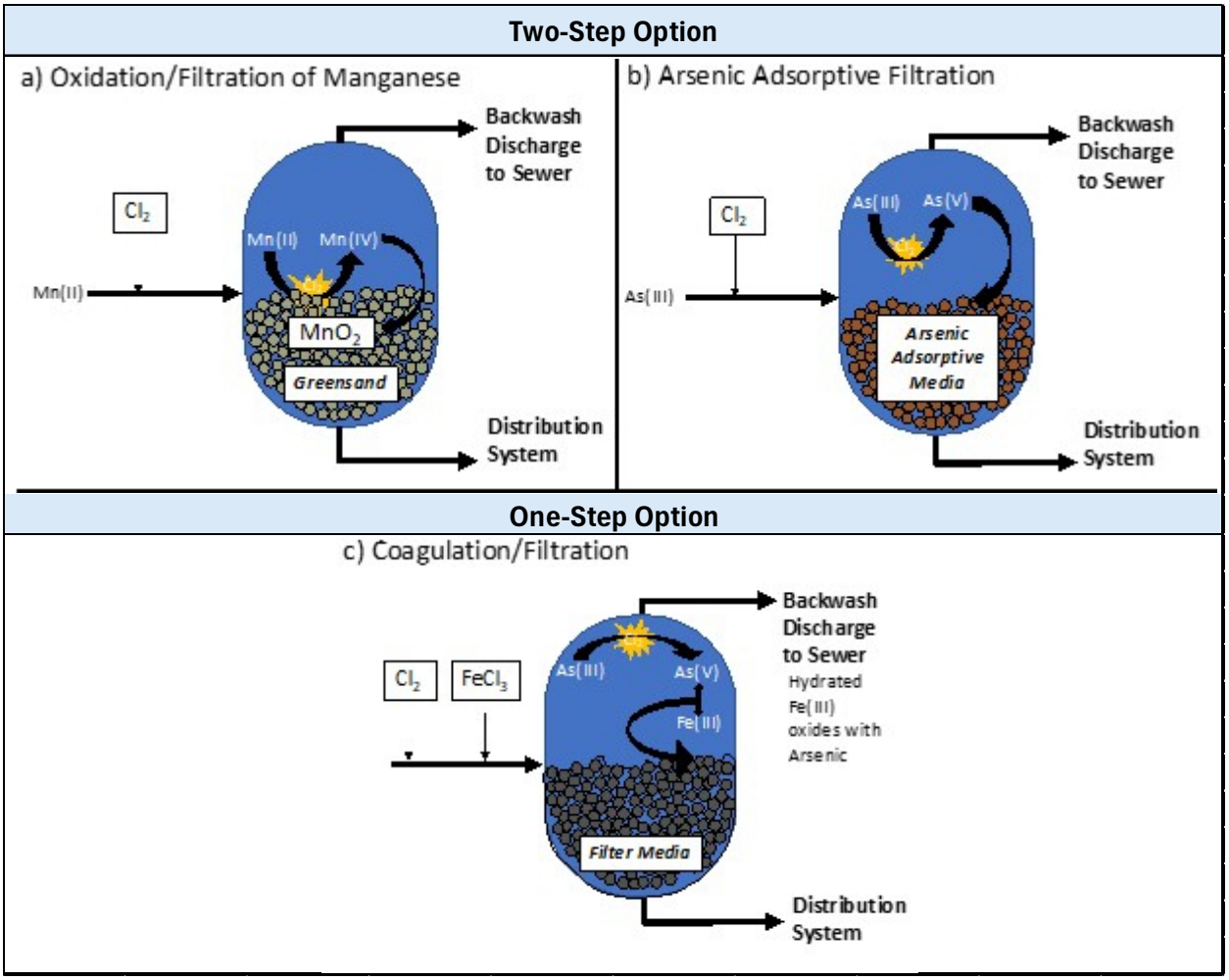


Figure 6. Process Mechanisms for Treating Arsenic and Manganese in Water

Pending confirmation by pilot testing, the one-step treatment option (Figure 6c) is preferable due to its lower cost. A study evaluated the costs of the one step and two step treatment approaches in detail. The lowest cost option, as a 30-year net present cost, is the one-step oxidation/filtration greensand process with supplemental iron added as ferric chloride. In this process, arsenic adsorbs to hydrolyzed iron while manganese undergoes catalytic oxidation. Ferric hydroxide with adsorbed arsenic, as well as manganese are removed in the same pressure vessel. The Esposti Supply Well has low levels of naturally occurring iron, thus supplemental addition of ferric chloride would be needed to coprecipitate arsenic. This approach generates significant waste backwash water that would contain arsenic and ferric hydroxide, and the study assumed that could be accepted into the Town's sanitary sewer system if a backwash storage tank were included in the design to produce a low, continuous inflow to the sanitary sewer. Alternatively, a reclamation system could be added to the Esposti treatment plant to reclaim backwash wastewater and generate a sludge for disposing offsite.

The study found that the one-step treatment process would be the most economical approach. The one-step oxidation/filtration train has an estimated capital cost of $4,120,000 and an O&M cost of $216,000 per year in 2023 dollars. The net present value of the capital cost and 30 years of O&M costs is $8,350,000. The plant would be located in the northwest corner of Esposti Park. Additional details regarding design are presented in **Appendix A** and the itemized cost estimate is presented in **Appendix F**.

The certainty of success for implementing this alternative is high. The planned treatment plant site is on Town-owned property, the proposed treatment process involves standard equipment, and building the facilities would be a routine construction process. The sewer would receive either periodic 400-600 gpm backwashes or a continuous 10-20 gpm flow of equalized backwash. The Town's wastewater treatment plant operators have indicated that the additional continuous 20 gpm flow of backflush water from the Esposti treatment plant would not create any flow or quality problems for the sewer system and WWTP.

5.2.2. David Smith Memorial Park Well Testing

The David Smith Memorial Park (formerly known as Pleasant Oak Park) is an 8-acre park located on the northeast side of Old Redwood Highway at Pleasant Ave. A "very old" 10-inch diameter well owned by Mattie Washburn Elementary School is present in the park, and water quality tests were completed in summer 2023 to determine its viability as a municipal well. A well completion report is not available for the well, and it presently has no pump. A video log of the well confirmed that its depth is at least 367 ft. The water was turbid, but the video log revealed 12 possible corrosion holes and one place with possible casing compression. Visibility was too low to record features below a depth of 264 ft.

A layer of oil was present at the water surface in the well and was probably residual pump lubrication oil from a prior turbine pump installation. Laboratory analysis confirmed that it was petroleum hydrocarbons.

Town staff decided not to proceed with well pumping and sampling for two reasons. First, the casing appeared too corroded to withstand wire-brush cleaning and pumping, which would have been necessary prior to collecting a water quality sample representative of aquifer water quality. Second, the presence of the oil layer would have added considerable expense to containerize and dispose of development water. In any case, it was clear that to proceed with a municipal well at the park would require drilling a new well and possibly constructing a treatment plant to remove manganese and arsenic.

If the well had been sound enough to withstand rehabilitation, the estimated cost for a new well pump is $95,000. A treatment plant would add another $4,057,000 as itemized in **Appendix F**.

The certainty of success for rehabilitating the old well is low, given its age and physical condition. A new well could be drilled at that site, but it is likely that the water produced from that well would need treatment. Therefore, this alternative would consist of a new deep well with a medium likelihood of producing 400 gpm plus a treatment plant with a high certainty of success.

5.2.3. Reactivation of Bluebird Well

The Bluebird A well is now 52 years old, which is roughly the life expectancy of a water supply well. It has not been operated since 2001. When the adjacent Bluebird B well was drilled in 2010, drilling fluid reportedly flowed through an aquifer layer and entered the Bluebird A well (Cargay 2023). The impact

on well yield was not ascertained in detail, but the well is considered damaged beyond repair. Even if the well could be restored to an operable condition for a few more years, treatment for arsenic and manganese would be needed.

In spite of the drilling fluid incident, construction of the Bluebird B well was completed. It was pumped for 2 days following initial development, but the yield was very low. Additional development was not possible at that time, and the well was abandoned. The prospects for reactivating the well are slim, given its history of low yield and with only a 50' screen interval near the bottom of the well. Well B continues to be used to monitor water levels in the deeper aquifer zone.

The Bluebird A and B wells are both physically impaired to the point that rehabilitation is not a reasonable option. A treatment plant to remove arsenic and manganese would also be needed. Consequently, this site offers no water quality or cost advantages for installing a new municipal well. This alternative was not carried forward as distinct from a new deep well located anywhere else in Town, which is the alternative described in section 5.2.4.

5.2.4. New Deep Well in Town Area

This alternative consists of drilling and constructing a deep well with a capacity of 400 gpm somewhere in the Town Area. No specific location is associated with this alternative; it represents a hypothetical location with low arsenic and manganese in groundwater. If the arsenic and manganese concentrations in the well are below their MCLs, the water could be used for municipal supply with only disinfection at the wellhead. If concentrations exceed the MCLs, a treatment plant similar to the one proposed for the Esposti Municipal Well would be needed.

The target yield for a deep well would be 400 gpm, and two such wells would be needed to meet the water supply objective. Wells in that capacity range are present in and near the Town, but they are not common. For example, the Esposti Municipal Well has a demonstrated capacity of more than 400 gpm (GHD, 2017), and the Bluebird A well reportedly had a similar capacity when it was first drilled (Town of Windsor, 1993). Previous groundwater studies compiled well depth and capacity information from well completion reports and found that, as expected, yield generally increased with well depth. For example, one study tabulated well depth and pumping capacity as reported on well completion reports for 39 off-river wells (Richard C. Slade & Associates, 2001). For the nine wells with capacities of 400-800 gpm, the average depth was 406 ft and the average capacity was 611 gpm, for a capacity-to-depth ratio of 1.5 gpm/ft. No wells less than 300 ft deep had capacities of 400 gpm or more, and of the 15 deeper wells only 9 had capacities of 400 gpm or more. A similar exercise in 2007 concluded that most off-river wells had ratios <1.0 gpm/ft but identified several areas where multiple wells had ratios of 1.25-2.0 gpm/ft (Winzler & Kelly, 2007). To obtain a well with a 400 gpm capacity, a well depth of at least 400 ft should be expected. For costing purposes, a well depth of 600 ft was assumed.

No specific location is associated with this alternative at this time. The Esposti Well and Bluebird Well replacement project and exploratory boreholes drilled for this Plan all strove to encounter low-arsenic groundwater, but they did not. The certainty of success for drilling a deep, low-arsenic well is relatively low due to the widespread occurrence of groundwater exceeding the MCL.

The capital cost of drilling, constructing, developing, testing and equipping a 600-foot-deep well and pump with a 400 gpm capacity is estimated to be approximately $2,100,000, with an annual O&M cost of $102,000. The net present value of the capital cost and 30 years of O&M costs is $4,100,000. This does not include land costs. Details of the cost estimate are listed in **Appendix F**.

The certainty of success for drilling a new deep well that produces 400 gpm or more is medium, given that only 60 percent of deep wells have historically had yields in that range. However, the likelihood that the well would have arsenic and manganese concentrations below their respective MCLs is low, given the results of the exploratory boreholes drilled during development of this Plan.

5.2.5. New Deep Well in Russian River Floodplain

A new deep extraction well located somewhere near the Russian River could theoretically extract groundwater not considered underflow of the Russian River. This would require that the well be screened beneath the relatively young alluvial deposits of the Russian River floodplain. Near Windsor, the floodplain extends east from the river to near Eastside Road. In the Town area, the geologic formation underlying younger alluvial materials is the Glen Ellen Formation. Moving westward across the Russian River floodplain, the formation underlying the surficial alluvial deposits transitions from Glen Ellen Formation to Petaluma Formation. The latter is typically too fine-grained to support high-capacity wells (Nishikawa, 2013).

The California Department of Water Resources' database of well completion reports was searched for deep wells in the floodplain area near Windsor, and none were found. Shallow wells in the river alluvium are so productive that deep wells have not been needed to meet local water demands.

The owner of a parcel on the west side of Eastside Road south of Windsor River Road drilled three deep test holes in 2022 with the objective of accessing groundwater beneath the alluvium and not subject to regulatory restrictions on pumping from shallow alluvial wells. A hydrogeological evaluation prior to drilling concluded that wells screened below a clay layer expected to be present at 80-100 ft bgs would be tapping the Glen Ellen Formation, not river alluvium (O'Connor Environmental, Inc., 2022). All three boreholes were drilled along the east edge of the property, next to Eastside Road. The first two boreholes were drilled to depths of 307 and 368 feet and were dry. The third borehole was completed as a well with 140 feet of screen in four segments between 150 and 350 ft bgs. The driller reported that the well produced about 100 gpm and had high arsenic (Burgess, 2023).

The poor results of the test drilling program on Eastside Road indicate that the certainty of success for drilling a well with high yield and low arsenic below the Russian River floodplain is low.

5.2.6. Imported Water from Non-Russian-River Source

The Town presently obtains part of its supply from the Santa Rosa Aqueduct, but that water derives from Russian River underflow and is subject to the same risks of regulatory reduction in availability, contamination, or interruption due to natural disaster or drought as the Town's existing Russian River wells. There are no existing regional water projects that could potentially supply water imported from outside the Russian River watershed. Within Sonoma County, there presently is no availability of excess supplies from Sonoma Water facilities other than the Santa Rosa Aqueduct. Therefore, this alternative was not considered feasible and was not carried forward to the ranking process.

5.2.7. Two Shallow Wells at the Los Amigos Road Site

Two exploratory boreholes drilled in the northwestern part of Windsor as part of the Plan preparation process confirmed that arsenic concentrations were lower in the two shallowest aquifers relative to deeper ones. The borehole locations are shown in **Figure 4**, and details of the drilling and depth-specific water quality sampling are presented in **Appendix E**. The two sites were informally designated the Herb

Road site and the Los Amigos Road site (referred to as the Arata Lane site in Appendix E). At the Herb Road site, the upper aquifers were within the 100-170 foot depth interval and totaled about 30 feet of coarse (sand and gravel) material. At the Los Amigos Road site, the upper aquifers were within the 130-220 foot depth interval and totaled about 35 feet of coarse material. The exploratory boreholes were designed for water quality sampling, not yield testing. Given the small total thickness of coarse-grained layers, a shallow well screened opposite those layers could plausibly produce 200 gpm, but not 400 gpm. Therefore, two shallow wells would be needed to achieve 400 gpm at one of these sites. This alternative would need to be combined with another alternative also supplying 400 gpm to achieve the total water supply objective of 800 gpm.

Town staff prefer the Los Amigos Road site over the Herb Road site primarily because the Town owns the Los Amigos Road site. Also, if wells north of Arata Lane become available for municipal use at some point in the future, they could be connected more easily to the Los Amigos Road site than the Herb Road site. This potential for system expansion is desirable.

Town staff have tentatively identified the northwest, southwest and southeast corners of the Los Amigos Road site as prospective well locations. Pairing the northwest and southeast corners would provide the greatest distance between the two wells (approximately 430 ft). This would minimize well interference, which is the effect of pumping at one well on water levels in the other well and thereby minimize energy costs when extracting groundwater. If the wells are also used for injection (see ASR alternative, below), maximizing the distance between them would also improve the efficiency of injection because there would be less mounding interference in the water levels at the wells. The efficiency of recovering high-quality water would also be higher because injected water would travel a smaller radial distance from each well if the wells are far apart and have less overlap between their respective aquifer storage areas. The arsenic concentration measured in one of the upper aquifers was 6.3 µg/L, which is lower than the drinking water MCL of 10 µg/L. However, the concentration in the other aquifer was 33 µg/L. Manganese was several times higher than the secondary MCL in both aquifers. Therefore, if the wells are used only for extraction (not ASR), it is assumed that treatment would be needed for water produced by the wells.

The cost of installing two shallow wells at the Los Amigos Road site was estimated by adjusting assumptions from the cost estimate for a single deep well. The resulting capital cost and annual O&M costs estimated for the two wells and pumps are $2,665,000 and $114,000, respectively. The 30-year net present value of capital and O&M costs is $4,899,000. The cost estimates are detailed in **Appendix F**. If treatment to remove arsenic and manganese is needed, the cost would approximately equal the capital cost of a treatment plant like the Esposti Well treatment plant ($4,120,000) plus the capital cost of the two shallow wells ($2,665,000) plus the net present value of the O&M cost of the treatment plant ($4,230,000), for a total present value cost of $11,015,000. Note that the O&M costs of operating the treatment plant include the well pumping costs.

The certainty of success of obtaining 400 gpm from two shallow wells is considered medium. The exploratory boreholes drilled for this Plan were designed to test water quality, not yield. Thus, the ability of the two shallowest aquifer units to yield 200 gpm per well was inferred from the lithologic and geophysical logs.

5.2.8. Wells North of Arata Lane

The Town indicated the possibility of locating a municipal well or two on land north of Arata Lane. For example, a proposed development on parcels north and west of Arata Lane and Los Amigos Road that has expressed a willingness to allow a municipal well within the development. If a well of reasonable capacity were successfully installed, it could be connected directly to an existing water main at Arata Lane if the arsenic and manganese concentrations were low. If the concentrations were above the MCLs, the well could be connected to a treatment plant at the Los Amigos Road.

Another parcel north of Arata Lane has an existing high-capacity well with relatively high concentrations of both arsenic and manganese. It demonstrates that single high-yield wells are possible in the area, but it also suggests that treatment would likely be needed and that the well would need to be connected to the proposed Los Amigos Road treatment plant. The cost to construct a water main from a property north of Arata Lane to a treatment plan at the Los Amigos Road site would be expensive, comparatively.

The possibility of municipal wells north of Arata Lane is speculative and more of a long-term consideration than a realistic near-term option. This conceptual alternative has insufficient detail to develop a cost estimate and was not carried forward to the ranking analysis for near-term water supply augmentation.

5.2.9. Aquifer Storage and Recovery

ASR is a technology involving injection of water into the aquifer and extraction through the same well. Other options exist for managed aquifer recharge, including surface percolation facilities (e.g., spreading in basins) or injection wells with recovery through other wells. In Windsor, ASR is a preferred option that was identified in previous investigations (e.g., GEI, 2013).

The surface percolation option is limited because local soils and shallow basin materials have low permeability rates and large areas of land would be required for surface spreading. Also, the depth to the water table is small in most areas—about 20 feet throughout most of the Town area, for example. The regional water-level gradient must be low to recover high-quality groundwater injected into an ASR well. Otherwise, the injected water would flow away from the well during the interval between injection and recovery. The regional gradient for groundwater levels in the Town area is low, so injected water would not drift a long distance downgradient between the ASR injection and extraction phases. Details of soil permeability, depth to water and regional gradients as they relate to ASR feasibility are documented in **Appendix D**. They pose some challenges for implementing ASR but do not preclude it.

The source of water for ASR injection is assumed to be potable water from the Town distribution system derived from the Town's existing Russian River wells. The Town also obtains water from the Santa Rosa Aqueduct, but that water is relatively expensive and also subject to the same reductions during droughts as the Town's Russian River wells. Water from the river wells and aqueduct is available under Sonoma Water's appropriative water right, of which 5,625 AFY is allocated to the Town. On an average annual basis, surplus water is available from the Town's Russian River well field. Annual use of water from the wells and aqueduct during 2005-2019 ranged from 2,881 AFY (in 2015) to 4,331 AFY (in 2008) and was 3,300 AFY in 2019 (Woodard & Curran, 2021). Thus, at present there is roughly 2,300 AFY of water available under the Town's existing allocation of Russian River underflow to use for ASR injection. There are no other developed sources of local surface water or imported water nearby.

For a successful ASR project, it is recommended that an extra increment of water be injected at project start-up to create a buffer zone of mixed water quality between native groundwater and subsequent injections of high-quality water (Pyne, 2005). This helps ensure that future recovery cycles retrieve high quality water not appreciably degraded by comingling with native groundwater. Water for creating the buffer zone can be injected at a time when the source supply is abundant (in winter, for example). The cost of the buffer zone water can be considered a capital cost of building the ASR project.

Successful operation of an ASR project requires close monitoring of system performance, which is usually accomplished with sensors connected to a SCADA system. Injection wells require frequent backflushing to maintain the specific injection capacity. Continuous monitoring of water levels and injection rates is used to determine an appropriate backflush frequency (e.g., weekly) and detect any sudden changes due to unanticipated changes in injection source water quality. The costs of a percolation basin, instrumentation and staff time to monitor the SCADA information and implement backflush cycles need to be included when calculating the total cost for this alternative.

The most promising near-term ASR option is to add it to the alternative for two shallow wells at the Los Amigos Road site. Those wells have not yet been drilled, so their designs could be slightly modified as described above to accommodate ASR operation. Also, shallow groundwater at that location is relatively low in arsenic (6.3-34 µg/L), which facilitates the recovery of water below the MCL. The shallow depth of the wells precludes installing deep well screens, so the vertical water-level range available for draw-up during injection and drawdown during extraction would be limited. The top of the shallowest well screen would likely be about 130 ft bgs. Given the presence of confining layers above the shallowest aquifer, injection could probably be done under moderate pressure (e.g. 40 psi) without causing the overlying water table to rise to the land surface, waterlogging soils and damaging buildings and infrastructure.

The estimated capital cost designing, permitting and constructing two shallow ASR wells at the Los Amigos Road site is $3,160,000, with an estimated annual O&M cost of $176,000. The capital cost plus net present value of 30 years of O&M costs is estimated to be $6,610,000. The additional capital costs relative to two shallow extraction-only wells include substituting stainless steel casing for mild steel casing, installing a small-diameter drop pipe in the casing to regulate flow during injection, additional piping to bring potable water to the site for injection, and additional SCADA monitoring and control system components. It also covers the cost of additional permitting from the Regional Water Quality Control Board and California Division of Drinking Water, which is expected to involve an ASR pilot study for which a monitoring well will need to be installed. ASR design and permitting requirements are discussed in **Appendix D,** and details of the cost estimate are presented in **Appendix F**.

The certainty of success of implementing ASR using two shallow wells at the Los Amigos Road site is considered medium, primarily due to uncertainty regarding the feasible injection and extraction rates and the efficiency of completely recovering injected water during extraction.

5.2.10. Indirect Potable Reuse

IPR via groundwater recharge consists of surface spreading or injecting highly treated recycled water into an aquifer and pumping the water out at a downgradient extraction well. IPR allows use of recycled water, a local and highly reliable source. This alternative would face major hurdles due to the limited availability of surplus recycled water and the high cost of constructing the necessary facilities and

implementing permitting requirements. Details of implementing an IPR project are presented in **Appendix D** and summarized below.

Almost all of the recycled water produced at the Town's wastewater treatment plant is already delivered to non-potable users. For example, in 2020 only 384 AF of the 1,643 AF of recycled water was discharged to Mark West Creek because it could not be put to use for other purposes. Demand for recycled water deliveries for urban irrigation and to the Geysers geothermal facility is expected to increase in the future (Woodard & Curran, 2021). Thus, to implement the IPR alternative, the Town would need to give that use priority over some of the competing uses.

An 800 gpm IPR project would require an advanced wastewater treatment plant, two deep injection wells, two downgradient extraction wells, at least two monitoring wells, a tracer study to verify subsurface travel times of injected water, an extensive SCADA system to monitor process performance at the treatment plant and flows and water levels in the wells, substantial ongoing monitoring and reporting, skilled treatment plant operators, and an engineering report documenting all of the above in detail. The wells would all likely need to be new wells, some of which might require property acquisition. The advanced treatment process involves reverse osmosis, an advanced oxidation process, additional disinfection and chemical stabilization. The reverse osmosis process produces a waste brine that must be discharged under a permit from the RWQCB or hauled by truck to a permitted disposal facility. Brine disposal can be the most difficult aspect of IPR to implement.

There would be some uncertainty in location the injection and extraction wells such that subsurface residence time requirements are met. The residence time of water between the injection well and nearest downgradient drinking water well must be at least two months and must exceed the response retention time, which is the time required to detect the accidental injection of off-specification water and implement an alternative water supply for the downgradient wells. The concentrations of pathogens in the wastewater must be reduced by 10 to 12 orders of magnitude by multiple steps that are quantified and monitored.

The cost of an IPR alternative is clearly higher than that for any of the other water supply alternatives considered in this Plan. It was not necessary to develop detailed cost estimates for each component of the alternative to conclude that the total cost would at least several times more expensive than the second most expensive alternative. An order-of-magnitude estimate of capital and O&M costs was obtained from a survey of "medium-sized" IPR projects in inland locations in the United States (Herman, 2017). The study produced regression equations of capital and O&M costs versus plant capacity. A 1.2 MGD plant would be smaller than almost all of the plants included in the survey, but the regression equations indicated an all-in capital cost of roughly $30 million (in 2023 dollars) and annual O&M costs of approximately $2.9 million. Converting 30 years of O&M costs to net present value leads to an overall net present value of approximately $87 million. Although this cost estimate is approximate, it demonstrates that the cost would greatly exceed that of the other water supply alternatives.

The certainty of success is probably high as long as the Town is willing to pay the high price for the numerous project elements.

5.3. RANKING OF WATER SUPPLY ALTERNATIVES

The alternatives were ranked on the basis of cost and certainty of success. Low cost is obviously desirable, but so is a high certainty of success. The cost and certainty information from the foregoing

descriptions of the alternatives is compiled in **Table 1**. The overall certainty of success for each alternative is the lowest certainty of success of any of its components. For example, the certainty of success of rehabilitating and enhancing the treatment plant at the Bluebird Well is high, but the certainty of success of rehabilitating the existing well is low. Thus, the overall uncertainty is low. A new well could theoretically be drilled at the Bluebird site, but then the alternative would be equivalent to a new deep well and treatment plant at any location already owned by the Town.

The least expensive alternative—a deep well not requiring treatment—has a low certainty of success because groundwater not requiring treatment has proven to be very difficult to find. Among the alternatives with a high certainty of success, the Esposti Well treatment plant has the lowest cost. The second least expensive alternative with a high certainty of success is two shallow wells at the Los Amigos Road site with a treatment plant. A much less expensive alternative with a medium certainty of success is ASR using two shallow wells at the Los Amigos Road site. If successful, ASR would eliminate the need for treatment of the recovered groundwater, thereby greatly reducing the cost. A reasonable option would be to design the two shallow wells for ASR operation—which entails relatively little additional expense—and test ASR performance. If it meets the yield and water quality objectives, then a treatment plant need not be built. If it doesn't, a treatment plant would need to be built and the wells would simply be operated as extraction wells.

Table 1 Water Supply Alternatives Selection Matrix

Component of Alternative	Component Capital Cost	Water Supply Alternatives Itemized Costs and Certainty of Success					
					Los Amigos Site		
		Esposti Well Treatment Plant	Deep Well without Treatment	Deep Well with Treatment	Two Shallow Wells with Treatment	Two Shallow Wells with ASR	Indirect Potable Reuse
Component capital cost							
New deep well	$2,100,000		$2,100,000	$2,100,000			
Two shallow wells	$2,665,000				$2,665,000		
Two shallow ASR wells	$3,160,000					$3,160,000	
Arsenic-manganese treatment plant	$4,120,000	$4,120,000		$4,120,000	$4,120,000		
IPR wells and treatment plant	$30,000,000						$30,000,000
Estimated total capital cost		**$4,120,000**	**$2,100,000**	**$6,220,000**	**$6,785,000**	**$3,160,000**	**$30,000,000**
Annual O&M cost		**$216,000**	**$102,000**	**$216,000**	**$216,000**	**$176,000**	**$2,920,000**
Present value of O&M cost		**$4,230,000**	**$2,000,000**	**$4,230,000**	**$4,230,000**	**$3,450,000**	**$57,230,000**
Present value of capital and O&M costs		**$8,350,000**	**$4,100,000**	**$10,450,000**	**$11,015,000**	**$6,610,000**	**$87,230,000**
Overall certainty of success		**H**	**L**	**M**	**H**	**M**	**H**
Factor limiting certainty of success		None	Obtaining target yield and low arsenic and manganese	Obtaining target yield.	Yield of shallow wells	Yield of shallow wells and quality of recovered ASR water	Permitting, property access, RO concentrate disposal and cost.

Notes:

The recommended alternatives are highlighted in yellow. L = low, M = medium, H = high. RO = reverse osmosis.

Present value of capital cost calculated using an annuity factor of 19.60. This assumes a discount rate of 3% and a term of 30 years.

6. RECOMMENDED WATER SUPPLY ALTERNATIVE

6.1. SITES, WELLS AND TREATMENT

The recommended water supply consists of two of the alternatives described and ranked in the preceding sections. None of the specific sites identified with the alternatives would produce the target yield of 800 gpm. They were all evaluated at a capacity of 400 gpm, which is a yield that is estimated to be available from a single deep well. Thus, the need to implement two alternatives was built into the definitions of the alternatives.

The first component of the recommended alternative is a treatment plant for the existing Esposti municipal well, which had the lowest cost among the alternatives with a high certainty of success. The first step for building that component is to complete initial studies, engineering-level design and permitting. Design work for infrastructure projects of this type is typically phased based on the level of detail, with deliverables for the 30-, 60-, 90- and 100-percent levels of detail.

The second component consists of two shallow wells at the Los Amigos Road site operated as ASR wells. The wells would be designed for ASR use, with stainless steel casing and screens, flow-restricted drop pipes for injection under gravity, and additional wellhead plumbing and SCADA equipment to accommodate and monitor injection and extraction. The greatest uncertainties related to ASR at Los Amigos Road are whether the two shallow wells could produce a combined total of 400 gpm and whether injected water would drift away from the wells under the influence of the prevailing regional gradient before recovery. With drift, water extracted during recovery would be a blend of injected and native groundwater, and arsenic-manganese treatment may be needed. Options for addressing the yield issue include 1) installing deeper wells that also draw from high-arsenic aquifers below the shallow aquifers, and 2) installing a third shallow well on the Los Amigos Road site. The latter would more likely produce favorable ASR results in terms of water quality.

A pilot ASR study is recommended to investigate potential drift of injected water and the associated recovery efficiency. Construction and operation of ASR projects using potable water are regulated under State Water Resources Control Board Order 2012-0010, which allows for a pilot study lasting up to 2 years. The pilot study is exempt from CEQA, and the water produced during the recovery phase of the study may be used for municipal supply provided it meets drinking water standards. The pilot study must be pursuant to a work plan approved by the Regional Water Quality Control Board. To address the question of drift and recovery efficiency, each of the ASR wells could serve as a monitoring well for the other, with the two wells alternating between active and idle status. Nearby offsite wells might turn out to be available for use as monitoring wells. However, it is likely that at least one additional on-site monitoring well would be needed, and the cost estimate for ASR includes the cost of one monitoring well. Pilot studies typically implement injection/extraction cycles of increasing duration, with frequent monitoring of water quality at the ASR wells and monitoring wells to assess drift and recovery efficiency.

A treatment plant to remove arsenic and manganese at the Los Amigos Road site is a potential third component of the recommended water supply alternative, contingent on the results of the ASR pilot study. For example, the recovery percentage of high-quality injected water might turn out to be low if injected water drifts away from the well between the injection and extraction cycles. In that case, a treatment plant similar to the Esposti Well treatment plant would be needed and could be constructed on the Los Amigos Road site.

6.2. CEQA COMPLIANCE

CEQA compliance documents will be needed when the Town Council decides to proceed with designing and constructing any of the components of the recommended alternative. Separate CEQA documents for each component would be reasonable because the components would likely be built at different times and are in two different locations.

Mitigated negative declarations are probably sufficient to comply with CEQA. Construction impacts associated with the shallow wells and the one or two treatment plants are typically mitigated by using best management practices for erosion, stormwater, noise, dust and traffic. Visual impacts associated with the presence of water supply infrastructure in a park can be mitigated by visual screening using fencing or vegetation.

Additional CEQA analysis and documentation may be required for ASR at Los Amigos Road after the pilot study period, assuming the pilot study is successful. It is anticipated that information relating to potential impacts to groundwater, including to other beneficial uses and users, will be assessed as part of the pilot study and that the remaining CEQA requirements will be minimal, as noted above.

The recommended water supply alternative arguably has no growth-inducing impacts because its purpose is to maintain the Town's supply of water during drought periods when existing sources of water must be curtailed.

Water treatment and pumping accounted for seven percent of the energy used by municipal operations in Windsor in 2017-2018. Adding the recommended water supply alternative will increase the energy requirements for that sector. The Town has a goal of zero net carbon by 2030 and was still significantly short of meeting that goal as of 2018 (Gilleran Energy Management, Inc. 2020). The Town originally adopted a GHG emission reduction action plan in 2008 and has continued to implement reduction measures and update the plan since then. GHG emissions and climate impacts associated with the recommended water supply alternative will be addressed and mitigated in the context of the Town's overall GHG footprint through measures identified in updates of the GHG emission reduction action plan.

Documents prepared for complying with CEQA should be expanded to address additional elements required for complying with NEPA. This "CEQA-plus" approach will enable the Town to qualify for federal grant funds to support project implementation, in the event that funds are available.

6.3. OTHER PERMITTING

Any new well requires a permit from Permit Sonoma, and permits are issued according to the rules stated in Permit Sonoma's well ordinance. The ordinance was last amended on April 18, 2023, ending a moratorium on drilling new wells that had been in force since the previous October. None of the amendments appear to constrain implementation of the recommended water supply alternative. Neither the Esposti Well nor the Los Amigos Road wells would be within the public trust review area, which are areas along streams and rivers that support coho salmon. The amendments require applicants for well permits to implement water conservation measures. These include leak detection, low-flow toilets and showerheads, prohibitions on new lawns that are not compliant with the water efficient landscaping regulations and other items. The Town has an active water conservation program that includes rebates for lawn conversion, sprinkler controllers and graywater kits. It provides free home water use audits and has a leak reporting form. A detailed comparison of the Town's program with the items in the Permit Sonoma ordinance was not completed. However, on the surface it appears that the program would meet the requirements.

A new municipal supply well also requires a permit from the State Water Resources Control Board Division of Drinking Water (DDW), which involves completing a Drinking Water Source Assessment and Protection (DWSAP) study. The study would focus on evaluation of nearby land uses and testing to ensure that the quality of the water produced meets all drinking water standards.

The ASR component of the recommended alternative will require a permit from the North Coast Regional Water Quality Control Board (RWQCB). ASR projects in California are regulated under State Water Resources Control Board General Order 2012-0010. The 33-page order is detailed with respect to criteria for applicability, project design, required technical studies, implementation and monitoring. The next step for the Town would be to prepare the documentation needed to submit a Notice of Intent (NOI) to conduct a pilot study. Pilot studies may last up to two years. The injected water must meet drinking water standards. A hydrogeological report and proposed monitoring and reporting program must accompany the NOI. RWQCB staff recommend that applicants contact them informally prior to submitting the NOI package to ensure that it contains all of the information staff will need to review it (Watt, 2024). The paramount concern of the RWQCB is that ASR injection not degrade groundwater quality. This could occur by three mechanisms: contaminants such as disinfection byproducts in the injected water, geochemical reactions caused by the injected water such as arsenic mobilization, and changes in groundwater levels and flow that affect the size or movement of existing groundwater contamination. In spite of arsenic and manganese concentrations that already exceed MCLs, groundwater in the Town area is considered a "potential source of drinking water" by the RWQCB. The General Order does not specify locations for monitoring. It is up to the applicant to propose monitoring well locations.

6.4. FUNDING OPPORTUNITIES

As presented in the sections above, there are two drivers for the Town's water supply improvement projects. The first is to ensure potable water meets water quality standards in regard to arsenic and manganese concentrations. The second is to ensure a sustainable reliable water in consideration of future climate changes, drought, and potential man-made disasters. This section of the Plan presents a summary of potential funding options applicable to new treatment systems, new groundwater wells, and ASR. Potential sources of funder that focus on potable water quality and system reliability were considered.

The recommended water supply alternative consists of adding treatment to an existing well owned by the Town (the Esposti Well) and constructing two new shallow wells at the Los Amigos Road site and operating them as ASR wells. The Town is currently proposing to use potable water from existing wells or the Santa Rosa aqueduct for ASR operations. As the Town is forward thinking in planning for future supplemental potable water needs, programs relating to drought emergencies that provide bottled water and other emergency support are not currently applicable to the Town's projects. For the highest success rate in obtaining funding, it is recommended that the Town reach out to funding agencies prior to and during the application period to obtain insights into making the most competitive application.

An initial evaluation of potential factors that may influence grant funding was completed. These factors include disadvantaged community status based on the American Community Survey, USEPA environmental justice screening, CalEnviro screening data, unemployment, age distribution, and social vulnerability. The evaluation showed pockets of disadvantaged communities in and near the Town, with potential environmental justice benefits depending on the final project location and population that benefits from the project. With a population of over 25,000, the Town does not qualify as a small municipality under state and federal drinking water programs. The Town of Windsor 5-year (2018- 2022) median household income was $128,115, which does not qualify as disadvantaged under state or federal programs. **Figure 7** and **Figure 8** below show the screening results for disadvantaged census block groups and CalEnviro screening data.

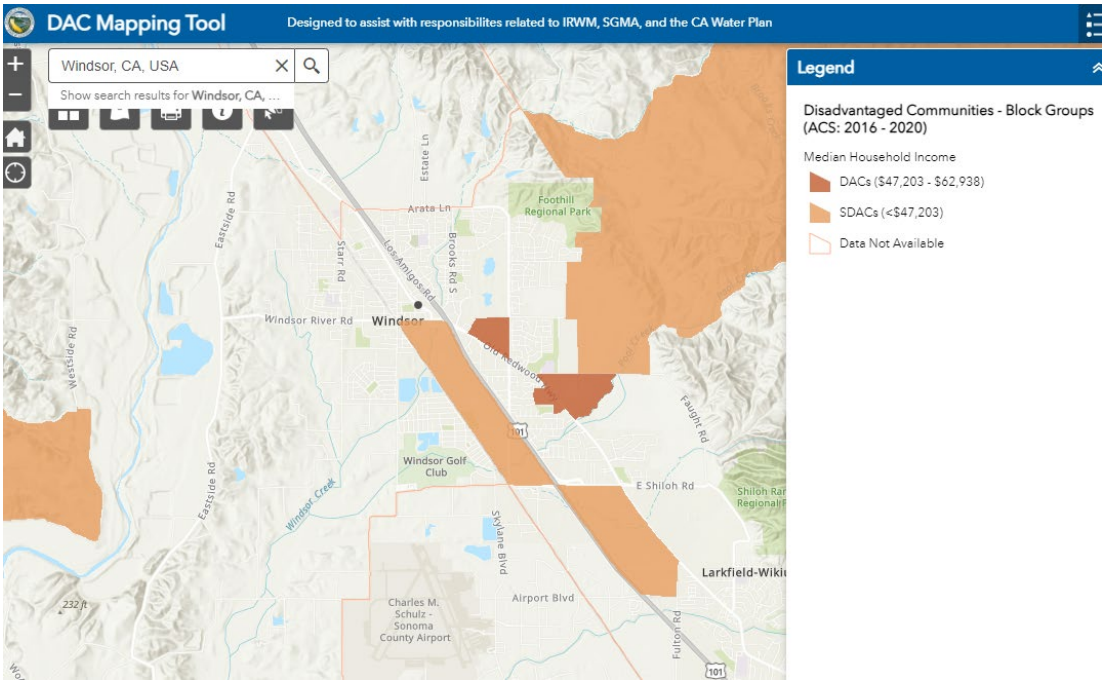


Figure 7 American Community Survey Map of 5-Year Average Disadvantaged Communities

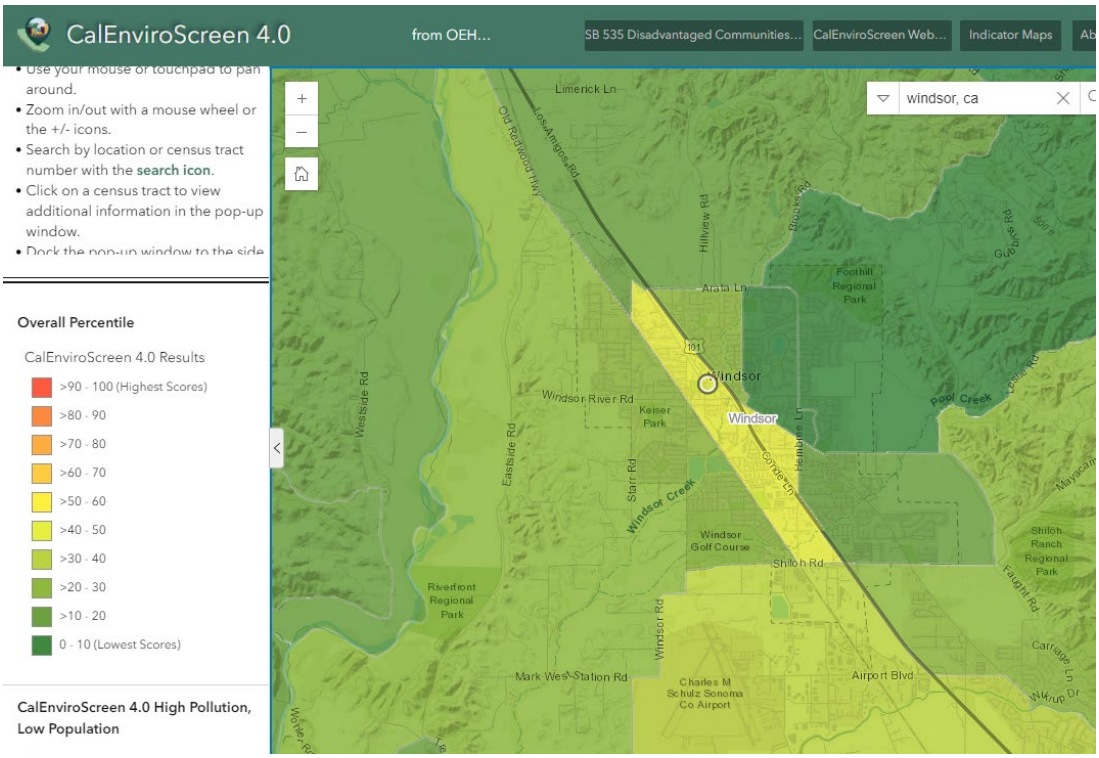


Figure 8 CalEnviro Screen 4.0 Disadvantaged Communities Map

One of the motives underlying this Plan is avoidance of supply reductions during drought conditions. Accordingly, funding related to mitigation of future drought conditions may be an option. Sonoma County has experienced multiple declared droughts over the last decade. The Federal Emergency Management Agency's mitigation funding is described below. The Town participated in the 2021 Sonoma County Multi-Jurisdictional Hazard Mitigation Plan, and major elements of the recommended water supply alternative in this Plan were included in the recommended actions for Windsor.

The Town has expended considerable effort to advance drought resiliency projects for the community. The completed work provides a good basis for preparing funding applications. Additional progress on preliminary design, planning, and/or permitting would continue to improve the project competitiveness. It is also noted that many of the programs below modify their selection criteria on an annual basis and the competition for these funds also varies. Re-submission of previously unfunded applications can result in different outcomes under different funding cycles. **Table 2** and **Table 3** below present a summary of the federal and state funding programs that may be applicable to the recommended water supply alternative.

Table 2 Summary of Applicable Federal Grant Programs

Grant Program	Summary	Discussion
US Bureau of Reclamation Water SMART: Drought Response Program	The Bureau of Reclamation's Drought Response Program supports a proactive approach to drought by providing assistance to water managers to develop and update comprehensive drought plans and implement projects that will build long-term resiliency to drought. Reclamation will provide funding for projects that will help communities prepare for and respond to drought. Typically, these types of projects are referred to as "mitigation actions" in a drought contingency plan.	Project Design Grants: The Town may consider applying for a Project Design Grant, which would fund up to the 60% design stage of the Project. Design grants require a 50% cost share and the funding amount ranges from $100,000 to 400,000. Drought Resiliency Projects: The Town previously submitted a USBR Water SMART Drought Resiliency Project application, and it was positively received. The Town should continue to stay in contact with USBR to obtain review comments from the previous application and solicit input on areas to make it stronger. Implementation grants also require a 50% cost match and the maximum funding is $500,000 for projects completed within two years and up to $5 million for projects completed within three years.
Federal Emergency Management Agency	FEMA's Hazard Mitigation Assistance (HMA) grant programs provide funding for eligible hazard mitigation activities that reduce or eliminate potential disaster losses to state, local, tribal and	Section 404 HMGP: Triggered based on federally declared disasters, applicant must have a FEMA approved Hazard Mitigation Plan (HMP), and the program typically pays 75% and requires a 25%

Grant Program	Summary	Discussion
Hazard Mitigation Grant Programs (Sections 404 and 406) Building Resilience Infrastructure and Communities Grant (BRIC) Program	territorial governments. Fostering resilience against the effects of natural hazards, including slow onset hazards such as drought, is a top priority for the agency. FEMA administers HMA grant programs that provide funding for hazard mitigation projects, capability- and capacity building, technical assistance, and planning-related activities. FEMA specifically calls out ASR as an eligible drought mitigation project in their Drought Mitigation Policy Aid. The Town will need to have good backup documentation on the recurrence of drought events and the populations affected.	non-federal cost share. There is currently no maximum federal share. Section 406 HMGP: Can be used to add mitigation enhancements to already approved FEMA Public Assistance Projects to rebuild damaged infrastructure better. BRIC Program: This program aims to categorically shift the federal focus away from reactive disaster spending and toward research-supported, proactive investment in community resilience. Funding is allocated on an annual basis and was given an infusion of funds through the Bipartisan Infrastructure Law.

Table 3 Summary of Applicable State Grant Programs

Grant/Loan Program	Summary	Discussion
Drinking Water State Revolving Fund (DWSRF) Planning/ Construction	The Drinking Water State Revolving Fund (DWRSF) program assists public water systems in financing the cost of drinking water infrastructure projects needed to achieve or maintain compliance with Safe Drinking Water Act (SDWA) requirements and support to human right to water.	Windsor would qualify under the loan program, with a term of up to 30 years and interest rates of approximately 2.1%. There are currently no grant programs under this funding that Windsor is eligible for. Loan applications are accepted on a continuous basis.
I-Bank Infrastructure State Revolving Fund (ISRF) Program	I-Bank's ISRF Loan Fund program provides low-cost, direct loans to local governments and nonprofits sponsored by public agencies for a wide variety of public infrastructure and economic expansion projects (excluding housing) that improve and sustain communities, helping individuals and families thrive. The focus is on small and mid-/moderate-sized local governments and special districts — including those in underserved regions and communities.	The I-Bank program that Windsor would qualify under is the loan program, with a term of up to 30 years and interest rates currently around 2.1%. There are currently no grant programs under this funding that Windsor is eligible for. Loan applications are accepted on a continuous basis.
DWR Integrated Regional Water Management Grant Program	The IRWM Grant Program is designed to encourage integrated regional strategies for water resource management in California by providing funding for projects and programs throughout the state including climate change adaptation, providing incentives for collaboration and setting priorities in water	The Town falls within the boundary of the North Coast Integrated Regional Water Management Plan (IRWMP) for Funding Allocations. Future funding for IRWMPs is unknown but this may be a future source in the next several years. The

Grant/Loan Program	Summary	Discussion
	resource and infrastructure management, and improving regional water self-reliance.	IRWMP funds have typically been driven by State proposition funding.
Future Department of Water Resources Programs	DWR initiated several programs in the last few years in response to drought pressures and to better address groundwater resources. With a strong state budget, programs such as the Small Community Drought Relief Program and the Urban Multi-Benefit Drought Program were initiated. However recent state budget shortfalls have temporarily halted these programs.	Winsdor can continue to make steady progress on planning studies and design concepts to be prepared to take advantage of future DWR drought or groundwater funding opportunities.
Strategic Growth Council	The Affordable Housing and Sustainable Communities Program (AHSC) reduces emissions from personal vehicle use by funding projects that make it easier for residents to get out of their cars and walk, bike, or take public transit. Funded by auction proceeds from California's cap-and-trade emissions-reduction program, AHSC is administered by the Strategic Growth Council and implemented by the California Department of Housing and Community Development.	As the Town potentially implements affordable housing programs, this funding source could be used to supplement the project budget for new treatment or wells that will contribute to water supply for new affordable housing. Minimum award is $10 million, and maximum is $50 million. Approximately 50% of funding application costs must go towards housing-related expenses.

7. GSP CONSISTENCY: SUSTAINABLE YIELD AND CLIMATE CHANGE

The Santa Rosa Plain Groundwater Sustainability Agency (SRP-GSA) prepared a groundwater sustainability plan (GSP) for the Santa Rosa Plain Groundwater Basin, which includes the Windsor area (Sonoma Water, 2021). The GSP evaluated groundwater sustainability based on six indicators, including long-term trends in groundwater levels and storage. It also evaluated the effects of climate change on sustainability. The recommended water supply alternative for this Plan involves pumping native groundwater, which would affect groundwater levels and storage. The ASR component internally balances injection and extraction, but the source of the injected water is Russian River underflow produced by the Town's existing wells near the Russian River. This section evaluates the recommended water supply alternative with respect to sustainable management criteria and GSP implementation.

7.1. GROUNDWATER BUDGETS

An important issue is how the hydrologic system will respond to the increase in groundwater pumping due to implementing the recommended water supply alternative and whether the increase will be within the sustainable yield of the basin. Average annual groundwater budgets for areas within the Santa Rosa Plain Groundwater Basin were estimated by the United States Geological Survey (USGS) as part of a groundwater and surface water modeling study (Woolfenden and Nishikawa, 2014). The study evaluated numerous hydrologic processes using linked rainfall-runoff, stream flow and groundwater flow models. Average annual groundwater budgets for water years 1976-2010 were simulated for four subareas within the Basin. The Windsor Subarea covers 47.8 square miles (mi^2) at the northern end of the Basin and includes the Town of Windsor. The Town area used for this study is 17.0 mi^2 in size, or 35 percent of the Windsor Subarea used by the USGS.

Table 4 shows the estimated average annual groundwater budget for the Town area under climate and land use conditions present during 1976-2010. The entries are simply 35 percent of the Windsor Subarea values in the USGS modeling report. This reflects an assumption that groundwater recharge per square mile in the Town area is similar to that for the USGS Windsor Subarea, which is reasonable given similar geology, soils, land use and stream network density. Average annual inflows to the Windsor Subarea during 1976-2010 were equivalent to a recharge rate of 0.59 feet per year (ft/yr) from all sources, on a per-area basis. Applying that recharge rate to the Town area produces an estimated average annual recharge of 6,437 AFY.

The 4 percent excess of total outflows over total inflows is not meaningful; it is the result of model calibration error. Three of the five wells near Windsor with water-level hydrographs extending from the 1970s to 2000s showed net rising trends, and two had level trends. The USGS modeling report showed simulated water levels for four of the wells, and the model produced declining trends at two wells where measured water levels were rising and level trends at two wells with level or rising trends. The modeling report noted this discrepancy

and stated that "the trend toward decreasing levels for the simulated hydraulic heads could be the result of overestimation of rural pumpage or underestimation of recharge in this area" (Woolfenden and Nishikawa, 2014). Underestimation of recharge could be due to the fact that the USGS model did not include recharge from irrigation return flow, pipe leaks or septic systems.

The response of the groundwater system to an increase in extraction can be inferred by identifying which inflows and outflows are essentially fixed in magnitude and which are head-dependent, meaning that the flow varies depending on water levels. In **Table 4**, 46 percent of inflows and 57 percent of outflows were head-dependent, which means they would change in response to a change in pumping and water levels. These include seepage to and from streams and inflows and outflows across internal and external basin boundaries.

Table 4 Estimated Average Annual Groundwater Budget for the Windsor Town Area

Inflows and Outflows	Flow (acre-feet per year)
Inflows	
Deep percolation of rainfall	3,450
Percolation from streams	1,814
Inflow from outstide Basin	711
Inflow from other Basin subareas	462
Total inflows	**6,437**
Outflows	
Wells	2,916
Evapotranspiration	925
Discharge to streams	1,280
Surface leakage	391
Outflow to Healdsburg Basin	1,031
Outflow to other Basin subareas	178
Total outflows	**6,722**

Source: Average values during 1976-2010 values for Windsor Subarea (Woolfenden and Nishikawa (2014) multiplied by 0.356 area ratio to estimate values for Town area.

The increase in groundwater extraction for the recommended water supply alternative would be balanced by shifts in the head-dependent boundary fluxes. The response of each type of boundary flux to a change in pumping was investigated by the USGS by comparing simulations of the basin with and without all of the historical pumping. Comparing the water budgets showed that 53 percent of historical groundwater pumping was derived from a reduction in stream flow (increased percolation from streams and decreased groundwater discharge to streams), about 25 percent from a reduction in evapotranspiration, 13 percent from a decrease in storage and about 8 percent from changes in net boundary flows

(Woolfenden and Nishikawa, 2014). Although these percentages are averaged over a broader region, the proportional responses of head-dependent flows in the Windsor area would likely be similar.

Applying the USGS results to the Town area, 53 percent of a 700 AFY increase in groundwater pumping equals 371 AFY. Most of the simulated pumping effect on stream flow manifested as a decrease in groundwater discharge to streams. For example, if 100 AFY of pumping manifested as an increase in percolation from streams, it would correspond to a 6 percent increase in stream percolation. At the same time, if the remaining 271 AFY of pumping increase became a decrease in groundwater discharge to streams, it would correspond to a decrease of 21 percent. The USGS results also indicated that about 25 percent of a change in pumping is absorbed by a change in groundwater consumption by phreatophytes as evapotranspiration (ET). In this case, 25 percent of 700 AFY of pumping would produce a 175 AFY decrease in phreatophyte ET, which corresponds to 17 percent of existing ET.

The groundwater basin in the Town area could physically sustain a 10 percent increase in total groundwater outflows without overdraft because of the compensating shifts in head-dependent flows. Whether such a shift in the water balance is sustainable from the perspective of the Sustainable Groundwater Management Act (SGMA) depends on how it would affect each of six sustainability indicators defined in the Santa Rosa Plain GSP (Sonoma Water, 2021). In this situation, the most relevant are the criteria related to water quality, water levels and depletion of interconnected surface water. The minimum threshold for water quality states that no more than two municipal wells should experience increases in arsenic, nitrate or TDS above the drinking water MCLs. Because the Town wells would be new, with water treatment as needed to meet all drinking water standards, the wells would not cause an exceedance of the minimum threshold. Injection of water from the Town's municipal supply for ASR at the Los Amigos Road site would also not cause any constituents in groundwater to increase above the MCLs because the injected water would meet the MCLs.

The water level minimum threshold states that water levels should remain above the historical low (adjusted downward for an additional 4 years of drought) and above the depths of 98 percent of the wells in the Basin. This criterion is presented in the GSP as a basin-wide metric; it is not intended to be applied at a local scale for individual production wells (Trotta, 2023). Instead, drawdown impacts of new municipal wells on nearby existing wells would be evaluated as a potential impact during CEQA review.

The minimum threshold (MT) for interconnected surface water (ISW) consists of groundwater elevations at seven representative monitoring point (RMP) wells in the Santa Rosa Plain Basin. The MTs represent July-September water levels during 2014-2016, which were the lowest of all years during the 2004-2020 analysis period. The nearest RMP well to Windsor is SRP0707 next to Mark West Creek 7,300 ft south of the Esposti well.

The USGS groundwater model was used to identify stream reaches hydraulically interconnected with groundwater for the GSP. The nearest ISW reaches to the Los Amigos

Road site are an unnamed creek 2,290 ft to the north and Windsor Creek 3,760 feet to the east. For the Esposti site, the nearest ISW reaches are the south fork of Pool Creek 1,700 feet to the east and south, and the north fork of Pool Creek 3,770 ft to the north. All of these channels host dense tree and shrub canopy visible in Google Earth aerial imagery, although not all of them are mapped as wetland or riparian vegetation in the Nature Conservancy's Natural Communities Commonly Associated with Groundwater (NCCAG) geodatabase. The NCCAG vegetation category in these and nearby streams is almost all "mixed riparian hardwood".

The potential for increased depletion of surface water due to pumping at the Esposti and Los Amigos wells should be addressed in the project-level CEQA analysis. Available data suggest that the timing and magnitude of drawdown at the creeks would not be large enough to cause significant biological impacts, but there are data gaps that should be filled to improve the evaluation. Assuming the Los Amigos wells are operated as ASR wells, drawdown during extraction periods would be offset by injection during preceding normal and wet periods, resulting in no net impact. The Esposti Well will be used for extraction only, but extraction will primarily occur during dry periods when the nearest stream channels might already be dry due to a naturally intermittent flow regime. The horizontal distances between the Esposti Well and the ISWs—and the large vertical separation of the pumped aquifer and the riparian root zone—would tend to reduce and delay drawdown impacts. Also, vegetation along those stream reaches might consist largely of facultative phreatophytes, such as coast live oak. Those species are naturally adapted to intermittent access to the water table. These stream flow and habitat data gaps should be filled so that potential impacts can be better evaluated and appropriate monitoring and management measures can be implemented. A basic habitat survey and more detailed analysis is recommended to more accurately quantify potential ISW impacts and evaluate consistency with this element of the GSP.

It is unlikely that pumping from the Esposti Well would cause measurable flow depletion at the ISW monitoring sites, given their large distance from the well. Thus, the GSP would consider pumping at the Esposti Well to be sustainable. Significant depletion and biological impacts are also unlikely at the creek reaches closest to the well, for the reasons stated above. In any event, there are various mitigation strategies that could be implemented if impacts were detected, such as reallocation of pumping among Town wells, reduced pumping at other wells near the impacted reaches, ASR operation of the Esposti Well, or temporary irrigation of riparian vegetation with recycled water. Thus, a CEQA analysis would also likely conclude that the effects of Esposti Well pumping are less than significant.

7.2. CLIMATE CHANGE EFFECTS

The GSP included an extensive evaluation of the effects of climate change. The GSP Technical Advisory Committee reviewed ten global circulation models (GCMs) and selected the HadGEM2-ES model because it reproduced historical conditions in the Russian River watershed well and produced less extreme results than the other models. The model was paired with RCP 8.5, which is a "worst-case" representative concentration pathway (RCP) for

future greenhouse gas emissions. This pathway was warmer than historical conditions throughout the 2021-2070 analysis period. It was wetter than historical from 2021-2050 and mostly dry from 2051-2070. The evaluation of climate change also incorporated projected changes in land use.

Predictably, the modeling showed higher stream flows during the first part of the scenario and lower stream flows during the second part. There was a consistent shift to greater net stream percolation, however, due to the assumed increase in groundwater pumping and the relatively wet conditions during the first half of the scenario. The simulated cumulative change in groundwater storage shows the net effect of all the changes in all the groundwater budget items. The basinwide cumulative storage change was essentially flat during the historical 1976-2020 period. It remained essentially flat during 2021-2040, when greater pumping was accompanied by relatively wet climatic conditions. During 2050-2070, however, a combination of greater pumping and chronically dry conditions produced a steady decrease in basinwide storage of 3,100 AFY.

A previous climate change analysis using the same groundwater model was done in 2014 (Woolfenden and Nishikawa, 2014). That study used an "ensemble" approach, comparing results for two GCMs paired with two RCPs. Three of the four resulting scenarios produced decreases in long-term average precipitation, and all of them produced greater precipitation variability. Basinwide groundwater pumping increased by about 26 percent compared to the 1981-2010 average due to urban growth and warmer summer temperatures that increased irrigation demand. All elements of the groundwater budget changed, but stream flow gains and losses absorbed most of the net changes in rainfall recharge and pumping.

Stream flows are sensitive to assumptions about future precipitation, and net stream percolation is sensitive to groundwater pumping. Thus, stream flows are likely to exhibit the largest hydrologic response to increased pumping—including new Town wells—combined with climate change.

8. MONITORING PROGRAM

The Santa Rosa Plain GSP includes monitoring programs for groundwater levels, groundwater quality and stream flow. The relationship of the recommended water supply alternative to those programs and additional required or recommended monitoring are described below.

8.1. GROUNDWATER LEVELS

The water-level monitoring program in the GSP differentiates between shallow (less than 200 ft deep) and deep monitoring. In the Windsor area, the Bluebird well and a private irrigation well in the northeast part of Town are monitored semiannually for the deep monitoring program. There are no local wells in the shallow monitoring program. The nearest one is at Sonoma County Airport. There is also a shallow well for monitoring interconnected surface water at Mark West Creek near Old Redwood Highway. There is no need for the Town to expand upon the GSP water level monitoring program other than the project-specific monitoring for the Esposti and Los Amigos Road sites described below.

Under the recommended water supply alternative, the Esposti Municipal Well and the two new shallow wells at the Los Amigos Road site would be capable of extracting 700 AF of water over a 6-month period during a dry year. The magnitude and duration of pumping could affect water levels at nearby existing wells. The following water-level monitoring near the Esposti well is recommended:

- Monitor the Mobile Home Estates well 1,700 ft south of the Esposti Well, which was monitored during the 2016 Esposti pumping test (GHD, 2017). No construction or geologic information is available for the well, but it was assumed to be shallower than the Esposti well. Baseline monitoring should be done monthly during the dry season in a year when the Esposti Municipal Well is not used. The baseline data would serve as a reference for evaluating potential impacts by comparing them with water levels monitored in a year when the Esposti Municipal well is used. Although the test in 2016 showed no effect of Esposti pumping at the Mobile Home Estates well, the much longer duration of pumping during actual operation (6 months versus 28 hours) could allow effects to materialize.
- Canvass properties near the Esposti Well to identify any other existing nearby wells and invite the well owners to participate in the water level monitoring program.

For the Los Amigos Road site, a monitoring plan for water levels and quality will be developed as part of the ASR pilot study work plan. In the initial phase of ASR testing, one of the two shallow wells at the site could be used to monitor injection at the other. However, one or two additional wells might be needed to investigate geochemical reactions and lateral drift of the injected water.

It is recommended that the Town canvass properties near the Los Amigos Road site to identify existing wells that might potentially be affected by injection and/or extraction at the

Los Amigos Road site and invite the well owner to participate in the monitoring program. Few domestic well owners in the Los Amigos Road area responded to the Town's invitation to participate in the one-time arsenic sampling that was done for this Plan. However, there is a small water system well serving a mobile home park, approximately 1,200 feet northwest (downgradient) of the Los Amigos Road site that would be good to include in the program.

In addition, monitoring of water table elevations next to stream reaches near the Los Amigos Road and Esposti sites is recommended in Section 8.3.

8.2. GROUNDWATER QUALITY

The Santa Rosa Plain GSP relies on existing programs to monitor long-term trends in groundwater quality. Prominent among these are the requirements for monitoring of public drinking water supply wells issued by the State Water Resources Control Board Division of Drinking Water. The recommended water supply alternative will add three new municipal supply wells to the Town's water system, and they will be monitored pursuant to those regulations. Constituents of particular interest include total dissolved solids, arsenic, manganese and nitrate. The regulations require that samples from the wells be periodically monitored for a broad suite of contaminants and constituents of emerging concern. This monitoring will meet the Town's need for evaluating long-term water quality trends.

Water quality monitoring is an integral part of an ASR project. The pilot study for ASR operation at the Los Amigos Road site would include monitoring injected water for disinfection byproducts and extracted water for arsenic and manganese on a frequent basis to evaluate performance of the ASR system. One or two monitoring wells will likely be installed for the pilot project to evaluate geochemical reactions within the aquifer and movement of injected water under the influence of the regional gradient. Details of the monitoring well locations and sampling frequency would be developed as part of the pilot study work plan.

8.3. INTERCONNECTED SURFACE WATER

The water budget analysis (Section 7.1) indicated that net extraction of groundwater by the recommended water supply alternative could potentially deplete interconnected surface water. As explained in the GSP, depletion of stream flow can be difficult to detect by measuring stream flow. Instead, the GSP includes a program for monitoring water levels in shallow wells near interconnected stream reaches as a proxy for measuring stream flow. That approach is recommended for this plan.

The first step in evaluating potential impacts on stream flow or riparian vegetation is to conduct a reconnaissance site visit during the dry season to identify flow conditions and vegetation species. Given the relatively small size of their contributing drainage areas, the stream reaches near the Esposti and Los Amigos sites might be seasonally intermittent. That means pumping impacts would not occur during the dry season of dry years, which is when most of the well extraction would occur. The inventory of riparian vegetation species would

indicate whether some or most of the species are facultative phreatophytes that are relatively insensitive to small changes in water table depth.

If the reconnaissance survey and drawdown analysis demonstrate a potentially significant impact on stream flow or riparian vegetation, a monitoring program would be designed and implemented. This might include installing shallow monitoring wells near the interconnected stream reaches closest to the Esposti and Los Amigos Road sites or finding nearby existing shallow wells to monitor. Water-level monitoring at those wells would facilitate detection of drawdown and stream flow depletion from groundwater pumping at those sites. For the Esposti site, the preferred monitoring location would be next to the south fork of Pool Creek 1,700 ft to the east. For the Los Amigos Road site, the preferred location would be next to the unnamed channel 2,290 ft to the north. To monitor potential stream depletion and vegetation impacts, the wells should be screened no more than about 10 feet below the seasonal low water table elevation. For a monitoring well located at the top of the stream bank, a well depth of 30 feet would likely suffice. Monthly water level measurements during the dry season of a year when the Esposti and Los Amigos Road wells are not operating (baseline period) can be compared with monthly measurements during a year with operation to determine whether the wells are affecting water levels enough to stress vegetation or significantly deplete stream flow.

9. IMPLEMENTATION OF RECOMMENDED WATER SUPPLY ALTERNATIVE

Implementation of the recommended water supply alternative would occur in phases over several years. The Town has indicated it would proceed with the Esposti Well treatment plant first, followed by the two ASR wells at the Los Amigos Road site. For each of those projects a design and permitting phase would be followed by actual construction. To support the Town's planning process for capital improvements, this section presents relatively detailed and accurate cost estimates for design and permitting of both projects, suitable for near-term budgeting purposes. For longer-term budgeting, approximate estimates of construction costs are provided. Finally, a plausible timeline for implementing those phases is presented.

Table 5 lists task-level design, permitting and construction costs for the Esposti municipal well treatment plant. The pre-construction phase of the project would include the design, engineering, permitting and bench testing items highlighted in green, which total $1,080,000. The remaining costs to complete construction are estimated to be $2,950,000 for a total project cost of $4,030,000. The estimate assumes that a one-step treatment plant would be built in the northwest corner of Esposti Park, with pipelines connecting to water and sewer mains in the adjacent streets. Permitting activities would include canvassing nearby parcels to identify existing wells potentially impacted by drawdown from the municipal well, a drawdown impact evaluation, a reconnaissance level inventory of habitat and flow conditions at the nearest creek channels, completion of a CEQA compliance document (anticipated to be a mitigated negative declaration) and completion of a Drinking Water Source Assessment and Protection (DWSAP) study to accompany the application to the State Water Resources Control Board Division of Drinking Water for adding the well to the municipal water supply.

Table 5 Cost Estimate for the Esposti Municipal Well Treatment Plant

Cost Estimate for Esposti Supply Well Treatment Plant			
DESCRIPTION	**ONE STEP: OXIDATION/FILTRATION**		
	ESTIMATE		
	GHD Fee	**Trussell Fee**	**TOTAL**
Site Survey[1]	$110,000		**$110,000**
System Design and Bid Package			**$770,000**
Basis of Design Report[2]	$30,000	$75,000	$105,000
30% Design Drawings and Specifications	$150,000	$80,000	$230,000
60% Design Drawings and Specifications	$250,000		$250,000
90% Design Drawings and Specifications	$100,000	$30,000	$130,000
Bid Documents	$40,000	$15,000	$55,000
Permitting[3]	$45,000	$70,000	**$110,000**
Well Pump Development[4]	$40,000		**$40,000**
Piloting and Bench Scale Testing[5]		$60,000	**$60,000**
Engineering Support	$60,000	$40,000	**$100,000**
Prefabricated Treatment Plant			**$840,000**
Contractor Site Work			**$600,000**
General Conditions (8%)			**$120,000**
Bond / Insurance (2%)			**$30,000**
O&P (18%)			**$260,000**
Construction Management	$150,000		**$150,000**
Subtotal			**$3,100,000**
Predesign-Level Estimating Contingency (30%)			**$930,000**
Predesign-Level Project Budget Estimate			**$4,120,000**
Net present value of O&M costs			**$4,230,000**
Total project net present value			**$8,350,000**

1. Costs are in 2023 dollars, rounded to nearest $5,000.
2. Site surveying includes location selection, surveying, geotechnical evaluation, visual and noise impact assessments, sewer capacity evaluation, field verification, and power connection evaluation.
3. Report to compile predesign results and finalize treatment process
4. Includes CEQA Plus analysis, DDW application, and sewer discharge permit application.
5. Installation of permanent pump for 400 gpm system
6. Includes pilot testing of Cat. Oxidation (Mn & As) - field trailer and well pumping
7. Net present value assumes 30-year period and 3% discount rate.
8. See Table F-6 for O&M cost details.

Table 6 lists the estimated costs for initial studies, design, permitting and construction of the Los Amigos Road ASR wells project. Permitting activities would include the same ones listed above for the Esposti treatment plant project. In addition, the ASR pilot study listed separately would likely be requested by the RWQCB to address water quality issues associated with ASR operation. The RWQCB would need to approve the pilot study work plan. The subtotal for pre-construction initial studies, design and permitting is $550,000. An additional $2,596,000 would be needed to complete construction and complete the ASR pilot study. Note that the pilot study—which can continue for up to two years following the start of ASR operation—would require that some of the infrastructure be built.

Table 6 Estimated Design and Permitting Costs for the Los Amigos Road ASR Wells

Cost Estimate for Two Shallow Wells with ASR	
Cost Item	**Estimated Cost[1]**
Pre-Construction Costs	
BODR, 30-60-90-100% design, bid documents	$395,000
Initial studies, CEQA, DWSAP and Local Permitting	$135,000
Design and permit ASR pilot study	$10,000
Engineering support during bidding	$10,000
Subtotal pre-construction phase	**$550,000**
Construction Phase Costs	
Production well drilling and construction[2]	$780,000
Well development and testing	$160,000
SCADA equipment	$170,000
Two 25 HP pumps & motors, installed[3]	$65,000
Contractor site work[4]	$390,000
Subtotal construction phase	**$1,565,000**
General Conditions (8% of contractor site work)	$30,000
Bond / Insurance (2% of contractor site work)	$10,000
O&P (18% of contractor site work)	$70,000
Construction Management and Inspection	$80,000
Subtotal capital costs	**$2,305,000**
Predesign-Level Estimating Contingency (30%)	$690,000
ASR pilot study for RWQCB[5]	$165,000
Predesign-Level Capital Cost Estimate	**$3,160,000**
Net Present Value of O&M Costs	$3,450,000
Predesign-Level Total Cost Estimate	**$6,610,000**

Assumptions: two 230-foot deep wells; 200 gpm each; 40 ft static depth to water

[1] Costs are in 2023 dollars, rounded to nearest $5,000.

[2] Equals the estimate for two shallow extraction wells adjusted to add stainless steel casing and the injection drop pipe.

[3] 2024 price for two Franklin electric 6-inch, 25HP, 200 gpm submersible pumps and motors at R.C. Worst, Inc. ($35,000) plus installation ($30,000)

[4] Same items as for single deep well but increased by 50% to include the second well. For ASR, includes costs for additional valves, flow meters and pressure gages for injection/extraction switching at each well, and excavation of small percolation basins for injection backflush water. Includes only on-site infrastructure; additional pipelines will be needed to connect to off-site Town water and sewer mains.

[5] Includes $108,000 for installing one monitoring well.

[6] See Table F-7 for O&M cost details.

A tentative schedule for designing, permitting and constructing the Esposti Well treatment plant and Los Amigos ASR wells is shown in **Table 7**. The table is a preliminary estimate that indicates the approximate sequence and duration of tasks to support budget planning activities.

Table 7 Tentative Implementation Schedule

Task	2024			2025				2026				2027				2028			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Initial Surveys																			
Canvass nearby wells and creeks																			
Evaluate drawdown impacts on wells and creeks																			
Esposti site survey																			
Esposti Treatment Plant Design and Construction																			
Basis of design report																			
"CEQA+" mitigated negative declaration, DWSAP and local permitting																			
30%-60%-90% design and bid documents																			
Piloting and bench-scale testing																			
Engineering support during bidding and selection																			
Construction																			
Well pump selection and installation																			
Engineering support during construction and commissioning																			
Los Amigos ASR Wells Design and Construction																			
Basis of design report																			
"CEQA+" , DWSAP and local permitting																			
30%-60%-90% design and bid documents																			
Engineering support during bidding and selection																			
ASR pilot study work plan																			
Construction																			
ASR pilot study implementation																			

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APPENDIX A

Esposti Municipal Well Treatment Evaluation

TECHNICAL MEMORANDUM
ESPOSTI SUPPLY WELL EVALUATION

Town of Windsor

Draft Date: October 3, 2022

Revised Final Date: December 12, 2022

Prepared For: Town of Windsor

Authors: John Kenny P.E., BCEE, Brie Post P.E., Brandon Cruz

Subject: Arsenic and Manganese Treatment Evaluation Update

Executive Summary

The Town of Windsor owns the Esposti Supply Well, located in Esposti Park, where high levels of arsenic and manganese were detected shortly after construction in 2010. California requires arsenic and manganese to be removed to concentrations below a maximum contaminant level (MCL) before the water can be introduced into a community water system. Trussell evaluated Esposti Supply Well water quality, available arsenic and manganese treatment technologies, and GHD's 2017 *Esposti Supply Well Treatment Feasibility Study* (Esposti Supply Well Study) to determine the best treatment approach at this location.

Manganese can be removed by a catalytic oxidation and filtration process. Arsenic can be removed by either an oxidation/filtration process or adsorptive filtration process. The lowest cost option, as a 30-year net present cost, is a one-step oxidation/filtration process. In this process, arsenic adsorbs to iron hydroxide while manganese undergoes catalytic oxidation. Iron hydroxide with adsorbed arsenic as well as manganese are removed in the same pressure vessel. Low natural iron presence at the Esposti Supply Well is supplemented with ferric chloride to coprecipitate arsenic. This approach generates significant waste backwash water that would contain arsenic and ferric hydroxide. A reclamation system can be added to the system to reclaim backwash wastewater and generate a sludge for disposing offsite.

An alternative arsenic treatment approach is a two-step process consisting of manganese oxidation and arsenic adsorptive filtration. The catalytic oxidation of manganese requires a pressure vessel with manganese dioxide coated media and an oxidant. Arsenic is removed by adsorption to a media that is selective for arsenic. A benefit to this system compared to the one-step oxidation/filtration process is that it generates less backwash wastewater, and the wastewater would not contain arsenic and ferric hydroxide. However, the downside to this approach is the adsorption media is expected to be replaced frequently due to low capacity from phosphate and silica interferants, resulting in high operational costs.

The one-step process is estimated to be the most economical approach. The one-step oxidation/filtration train has an estimated capital cost of $3,000,000[1], O&M cost of $230,000/year, and 30-year net present cost of $7,600,000 in 2022 dollars. The two-step catalytic oxidation of manganese and arsenic adsorptive filtration train has an estimated capital cost of $3,900,000, O&M cost of $340,000/year, and 30-year net present cost of $10,600,000 in 2022 dollars.

The Esposti Supply Well Study recommended the two-step process. One of the reasons for this recommendation was the inability of the sewer system to accept large backwash flows from the one-step process. Trussell recommends decreased vessel diameters to provide reduced backwash flow requirements and acceptable flowrates to the sanitary sewer. Trussell also recommends the use of a storage tank to equalize backwash waste flows and reduce the flowrate discharged to the sewer. Six-foot or eight-foot diameter vessels provide acceptable backwash flow rates of 400 to 600 gpm. These smaller diameter options are in contrast to the 2017 design approach of 120" and 96" vessels with backwash flow rates of 1,245 gpm and 850 gpm, respectively.

Trussell recommends conducting additional sampling to further characterize the Esposti Supply Well raw water quality to refine the design assumptions for treatment, particularly with respect to the need for pH adjustment. Bench-scale and pilot-scale testing will also be an important tool for refining the design and accurately quantifying capital and O&M costs. This testing will likely also be a requirement for permitting with the Division of Drinking Water (DDW). The Esposti well has unusually high silica and phosphate concentrations. Bench-scale testing could confirm the estimated frequent replacement of arsenic adsorptive media in the two-step approach. Pilot-scale testing is recommended to verify removal efficiencies of the one-step approach, given the high ferric hydroxide dose requirements due to the low iron levels in the well. Lastly, backwash reclamation systems could be further evaluated as a method to reduce wasted backwash water and loading to the sewer. Water reclamation plant operational concerns should also be explored before discharging large concentrations of iron, manganese, and arsenic. With additional data, the two feasible treatment approaches described in this TM can be further evaluated to refine the design of the preferred approach.

[1] Quotes for the one-step treatment system differed by a factor of two. The most expensive quote was used for comparison with the two-step treatment system in this memo. However, the lower cost quotes may provide acceptable systems. Further evaluation of the equipment provider's systems is recommended to refine the Esposti Supply Well treatment cost estimate.

1 Introduction

The Town of Windsor (Town) installed the Esposti Supply Well in 2010 to replace the existing Esposti well. The replacement well was deeper, and it was hoped that arsenic levels in the raw groundwater would be below the Maximum Contaminant level (MCL) to improve the Town's off-river water supply portfolio. The Esposti Supply Well is located in Esposti Park and is owned and operated by the Town. The installation was in response to requirements from the Sonoma County Water Agency to broaden water supply options that are not reliant on the Russian River. After construction, the Esposti Supply Well's groundwater showed higher than expected concentrations of arsenic and manganese. Treatment would be required to reduce the arsenic and manganese concentrations to levels below their MCLs. Due to the large cost of arsenic treatment, the Town looked to alternative locations that would not have to treat for arsenic, and so treatment implementation was delayed. The Esposti Supply Well has sat idle since 2010 and is of current interest to the Town for utilization as a potable source.

GHD Inc., in conjunction with Hazen and Sawyer, conducted a supply well redevelopment and treatment feasibility study in 2017, referred to as the Esposti Supply Well Study in this TM [1]. The study included redevelopment of the well and completion of zone sampling and a pumping test to obtain a more accurate understanding of the arsenic. This then led to evaluating options for regulatory compliance and indicated the Esposti Supply Well would be costly to bring into production as a potable source. To provide an updated evaluation of treatment options for the Esposti Supply Well, Trussell reviewed the Esposti Supply Well Study and assessed the findings in comparison to the latest treatment literature and vendor experience. This memorandum documents the high-level feasibility study and the information used to inform Trussell's recommendation for treatment at the Esposti Supply Well.

2 Feasibility Evaluation Approach

Arsenic and manganese are regulated at the state and federal level. The Final Arsenic Rule, enacted in 2001, established an Environmental Protection Agency (EPA) standard for arsenic in drinking water to an MCL of 10 µg/L [2]. California Title 22 regulations for arsenic match the EPA MCL [3]. Manganese is regulated at the federal and state level with a secondary MCL (sMCL) of 0.05 mg/L [4] [5]. The current notification level (NL) and response level (RL) for manganese is 0.5 mg/L and 5 mg/L, respectively. The NL and RL are based on the possibility of adverse health effects at very high concentrations. On May 3, 2022, a new health protective concentration of 0.02 mg/L was recommended by the California Division of Drinking Water (DDW) staff to serve as the basis for new NL and RL regulations. Arsenic and manganese regulations could be revised by DDW in the upcoming years.

The Esposti Supply Well Study determined the design arsenic and manganese concentrations for the raw water to be 57 µg/L and 860 µg/L, respectively (based on 28-hour pump tests). These concentrations exceed the drinking water standards introduced above of 10 µg/L and 0.05 mg/L for arsenic and manganese, respectively. Additional water quality monitoring data for arsenic and manganese are not available, and so these same design concentrations were assumed in Trussell's treatment alternatives evaluation.

For successful implementation of a treatment system at the Esposti Supply Well, the following requirements were identified:

- Operable and maintainable by Town personnel
- Operable without the presence of fulltime staff
- Automated with a supervisory control and data acquisition (SCADA) interface
- Operated with National Sanitation Foundation (NSF) certified chemicals
- Capable of providing 400 gpm of treated water into the Town water distribution system (the steady-state flow of the well)
- Of acceptable footprint for minimization of impact on the recreational area at the Esposti Park
- Effective at removing manganese and arsenic to levels below California MCL and sMCL
- Capable of meeting disinfection and distribution requirements
- Providable by vendors in the region

The feasible treatment options identified in the following section meet these requirements. In addition, the design parameters that were defined in Table 17 of the Esposti Supply Well Study were assumed for this evaluation. Appendix A provides a summary of the assumed well water quality.

Another requirement of the Town is that the treatment system produces water that meets their overall corrosion control strategy. This may require chemical addition (e.g., pH adjustment or a corrosion inhibitor) as the last treatment step prior to distribution. Corrosion control was not included in this initial assessment because it is not anticipated to be a cost differentiator since the same approach would be applied to any treatment system supplying water for the Town. However, corrosion control would be included in the final design of a treatment system for the Esposti Supply Well.

3 Evaluated Treatment Technologies

This section describes the various treatment technologies available today for arsenic and manganese removal and identifies the most feasible options for the Esposti Supply Well.

3.1 Overview of Best Available Arsenic Treatment Technologies

The EPA published guidelines for compliance with the arsenic MCL and indicated best available technologies (BAT) in the 2001 Final Arsenic Rule. Treatment approaches are listed as a BAT when the following criteria are met: high removal efficiency, history of full-scale operation, general geographic applicability, reasonable cost, reasonable service life, compatibility with other treatment processes, and the ability to bring all of the water in a system to compliance. The arsenic BAT list has not been updated since its initial conception and, based on investigation from Trussell, does not reflect changes in industry approach to arsenic treatment in the last decades. Best available technologies were described by the EPA in 2001 as:

- Ion Exchange
- Arsenic Adsorptive Filtration
- Oxidation/Filtration
- Enhanced Coagulation/Filtration
- Enhanced Lime Softening
- Reverse Osmosis
- Electrodialysis Reversal

Ion exchange, the highest priority treatment approach in the 2003 EPA guidelines for arsenic treatment in small scale systems, is not feasible at this location due to water quality constraints [6]. Concentrations of phosphate and silica are high at 1.4 mg/L as (PO_4) and 50 mg/L as SiO_2, respectively. Phosphate and silica are strong competitors with arsenic for exchange sites [7]. Ion exchange has other drawbacks including increased chemical requirements, poor lifespan from phosphate and silica presence, and brine waste management. Ion exchange has seen very little implementation in the past 20 years for arsenic removal and was only implemented in two out of fifty instances of arsenic treatment in the EPA-sponsored Arsenic Treatment Technology Demonstration Program from 2003 to 2011 [8]. Ion exchange is excluded from analysis at the Esposti Supply Well due to poor applicability and lack of industry familiarity.

Arsenic Adsorptive Filtration using activated alumina consists of granular media contained in a pressure vessel that adsorbs arsenic ions in a flow-through configuration. This process has developed over time from activated alumina to modified activated alumina and iron-based sorbents [6]. Currently, most adsorbent implementations utilize iron-based sorbents with granular ferric hydroxide like GFH® and Lenntech GEH® or granular ferric oxide like Bayoxide® E33. These sorbents have higher capacity for adsorption and increased treatment efficiency compared to activated alumina. Phosphate and silica can interfere with arsenic and manganese sorption and reduce the efficiency of this approach, similar to ion exchange. However, adsorptive filtration is a common arsenic removal technology. The prospect of arsenic adsorptive filtration using iron-based sorbents is further considered in this evaluation.

Oxidation/Filtration is a process that was originally designed to remove iron and manganese but has been observed to remove arsenic in waters with high levels of iron. Iron and manganese are removed by oxidizing the soluble forms of the metals into their insoluble forms and the precipitates are removed by filtration media. This technology utilizes adsorption and coprecipitation to remove arsenic in the presence of iron. The arsenic primarily adsorbs onto iron hydroxide precipitates and is filtered out. Arsenic can also adsorb onto the manganese dioxide surface of the filtration media, if provided. This process is known to be economical for waters with high levels of manganese and iron. The raw water quality at this Esposti Supply Well is low in iron and cannot feasibly utilize the oxidation/filtration process without supplemental iron. A deficit in iron concentrations can be supplemented by ferric chloride addition and this treatment option is further evaluated in this report.

Enhanced coagulation/filtration utilizes the addition of iron or aluminum-based coagulants to remove arsenic. The mechanism involves the adsorption of arsenic to an aluminum or

ferric hydroxide precipitate. Iron-based coagulants, such as ferric chloride, would be more effective at removing As(V) than aluminum-based counterparts due to increased iron hydroxide stability at the Esposti Supply Well estimated pH of 7.6. Although the iron introduced from ferric chloride is not being oxidized, enhanced coagulation/filtration utilizes the same adsorption principles from oxidation/filtration. The arsenic is removed by adsorption to the ferric hydroxide and is coprecipitated. Installation and operation of a conventional coagulation/filtration process is not considered, but this general treatment concept is explored as oxidation/filtration in a pressure vessel.

Remaining BATs are not recommended for implementation. **Enhanced lime softening** is not recommended for sites without existing treatment infrastructure that can be modified. **Reverse osmosis** has high capital and operating costs and produces an undesirable waste stream. **Electrodialysis** has not been utilized in the EPA Arsenic Treatment Technology Demonstration Program and is not typical for municipal applications in the Western United States.

3.2 Overview of Manganese Treatment Options

Manganese is also present in high amounts at the Esposti Supply Well and will need to be removed. Manganese can be removed by chemical oxidation prior to filtration or on a catalyst such as manganese dioxide coated media. Manganese chemical oxidation can be facilitated by ozone, chlorine dioxide, or potassium permanganate without the use of a catalyst. Free chlorine requires a catalyst due to slow reaction kinetics that take up two to three hours of contact time at a pH of 8 [9]. A manganese dioxide coated media filter can aid in catalyzing the oxidation of Mn(II) by free chlorine [10]. Free chlorine concentrations can be increased to improve kinetics [11]. Once oxidized, the manganese will precipitate as MnO_2 and is filtered by the media, or forms MnO_2 on the media when using free chlorine. If arsenic adsorptive filtration is selected, the manganese dioxide filter media must be placed upstream of the arsenic adsorptive media to prevent unnecessary loading on the expensive arsenic adsorptive media. Reasoning for use of free chlorine as a chemical oxidant is discussed in the pre-treatment section. All further references involving manganese removal refer to catalytic oxidation of manganese by free chlorine and a catalyst manganese dioxide media filter.

3.3 Esposti Supply Well Study Treatment Recommendation

The 2017 Esposti Supply Well Study (GHD) recommended a two-step process that utilized arsenic adsorptive filtration. The first step removes manganese through catalytic oxidation (greensand filtration) and the second step removes arsenic through media adsorption. An alternative, one-step treatment approach was also identified in the study, which involved oxidation/filtration using iron coprecipitation. The reasoning provided in the study for selecting the two-step process using arsenic adsorptive filtration was due to one-step oxidation/filtration having unacceptable backwash storage requirements and frequent high iron loading to the water reclamation plant.

3.4 Selected Treatment Alternatives for Further Evaluation

From reviewing the latest BAT solutions, discussing various options with local system vendors, and considering the previous recommendations in the 2017 Esposti Supply Well Study, Trussell identified two feasible treatment options:

- **One-step Process:** oxidation/filtration with iron coprecipitation
- **Two-step Process:** oxidation/filtration and arsenic adsorptive filtration

The one-step train is a process containing oxidant pre-treatment (e.g., sodium hypochlorite addition), iron addition (e.g., ferric chloride), and granular media filtration in a pressure vessel. The filtration step removes precipitated iron with adsorbed arsenic and removes manganese through catalytic oxidation (e.g., by using Greensand media). The two-step train is a process containing oxidant pre-treatment (e.g., sodium hypochlorite), catalytic manganese oxidation and media filtration (e.g., by using Greensand media), and arsenic adsorptive filtration. Figure 1 shows the treatment train for the one-step process and Figure 2 shows the treatment train for the two-step process.

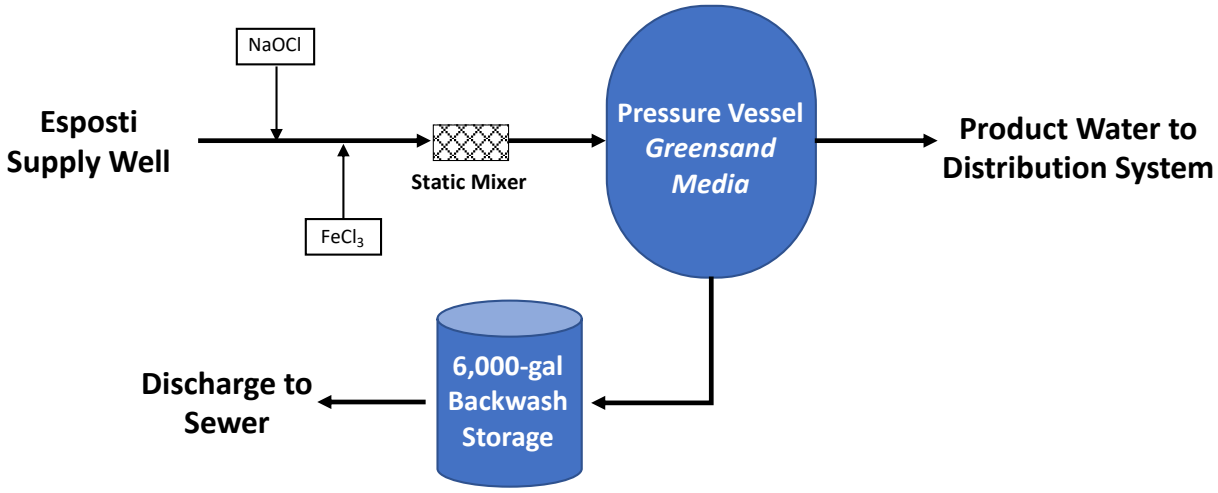


Figure 1 – Process Flow Diagram for Oxidation/Filtration Treatment Train (One-Step Process)

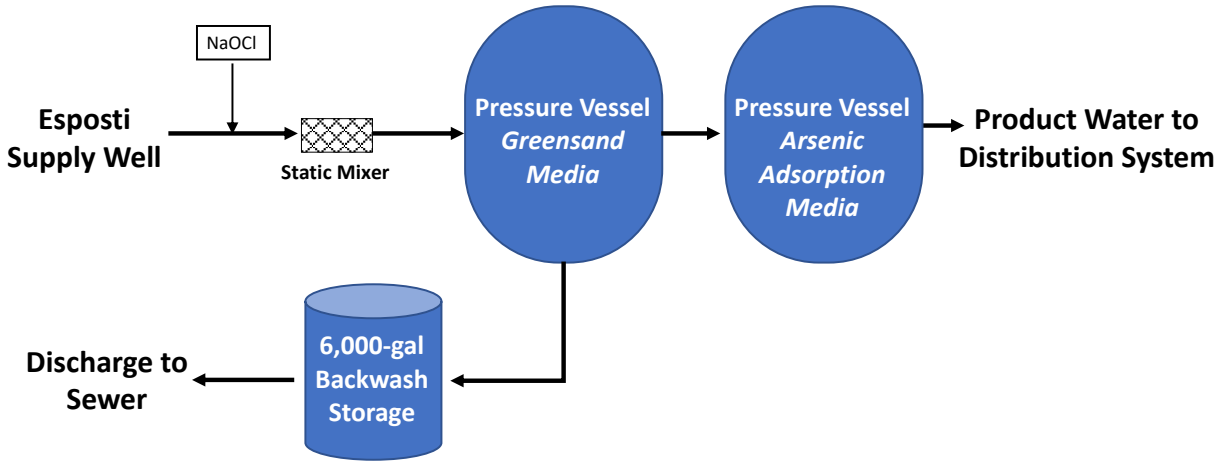


Figure 2 - Process Flow Diagram for Arsenic adsorptive filtration Treatment Train (Two-Step Process)

The "one-step" and "two-step" designation stems from the number of processes requiring pressure vessels to achieve the treatment goals. Oxidation/filtration—the one-step process—is achieved via one media filtration step (using specialized media for catalytic oxidation such as Greensand media) that removes both manganese and arsenic. Arsenic adsorptive filtration—the two-step process—requires media filtration to remove the manganese prior to media adsorption to remove the arsenic.

4 Design Considerations for Feasible Alternatives

The two feasible treatment options are evaluated in the following subsections by comparing high-level designs for the treatment trains. There are several assumptions for building the framework of high-level designs including: (1) well operation is assumed to be non-variable, full flow at 400 gpm with an annual utilization of 50%, (2) during utilization, the well will operate on a 24/7 schedule, and (3) space required by the footprint of the treatment is available for use at the Esposti Park. In addition, the assumptions defined in Table 17 of the Esposti Supply Well study are maintained in this analysis.

4.1 Pre-Treatment Design

Both arsenic and manganese must be chemically oxidized to facilitate removal, and so chemical oxidant pretreatment is included in the designs of both treatment options. Trussell recommends the system utilize free chlorine over alternative oxidants. This section discusses requirements for oxidation pre-treatment and justification for using free chlorine as an oxidant.

Arsenic has oxidation states that can affect treatment efficiency and the ability for technologies to achieve target removal levels. Arsenic has four oxidation states: -3, 0, +3, and +5. However, it is mainly found in +3 (As(III)) and +5 (As(V)) in the natural environment [12]. Under anaerobic conditions, like most groundwaters, arsenic is typically present as As(III). The ratio of As(III) and As(V) depends on the redox conditions of the water. Arsenic BATs are only applicable to arsenic in the +5 oxidation state due to poor removal in the +3

oxidation state. As(III), at the pH range of 6 to 9, exists in water as an uncharged particle, H_3AsO_3. Uncharged particles are more difficult to remove via means of adsorption, ion exchange, oxidation/filtration, and enhanced coagulation/filtration processes. As(V), at the pH range of 6 to 9, exists in water as a charged particle, $H_2AsO_4^-$ or $HAsO_4^{2-}$. Since As(V) exists as a negative particle at natural pH levels, it is more efficiently and effectively removed compared to As(III). As(III) should be oxidized to As(V) before treatment to improve removal efficiency.

The recommended manganese treatment is precipitation from chemical oxidation on catalytic media such as MnO_2 coated "Greensand". Manganese is most commonly found in its +2 oxidation state in water, Mn(II). Oxidation to its +4 state, Mn(IV) results in the formation of insoluble manganese oxide, MnO_2. Once oxidized, the manganese precipitates as manganese dioxide and will be filtered. Oxidation of Mn(II) can be rapidly achieved by ozone, chlorine dioxide, or potassium permanganate. Free chlorine's slow (2 to 3 hours) oxidation can be sped up by a catalytic, manganese dioxide coated media filter and by increasing the concentration of free chlorine in the water. For this evaluation, it was assumed that free chlorine would be dosed into the water in the form of sodium hypochlorite purchased as a 12.5% solution. However, on-site generation of sodium hypochlorite or the use of potassium permanganate without a specialized manganese dioxide media could also be considered during future phases of design.

Clarification before the filters is likely not necessary since the combined iron and manganese concentrations are less than 10 mg/L [13]. Therefore, the only pre-treatment step prior to the pressure vessel for manganese removal is the dosing of an oxidant. The manganese dioxide coated media requires a constant dosage of an oxidant to maintain its oxidation-reduction capacity for catalytic oxidation of manganese and filtration. Sodium hypochlorite addition will maintain the removal capacity of the media and ensures the oxidation-reduction reactions quickly proceed to completion.

To activate the manganese dioxide coated media after installation and prior to operation, the media requires initial conditioning. This is typically performed by soaking the media in high concentrations of sodium hypochlorite (e.g., 1,000 mg/L) overnight to fully oxidize the manganese dioxide and maximize the media's capacity for manganese removal. After soaking, the filters are rinsed and the high chlorine wastewater is either quenched (e.g., by dosing sodium bisulfite) and discharged to the sewer or is collected by a third party (e.g., the system vendor performing startup) and trucked offsite for disposal. This conditioning process, also referred to as regeneration, may also be required if the system is offline for long periods of time (e.g., months). Once the media is activated, the continuous dose of sodium hypochlorite will maintain capacity for manganese removal. Means for regeneration, and quenching of the regenerate, if needed, should be further evaluated in the next stage of design

Oxidation of the raw water is an important pretreatment step for both treatment trains due to manganese and arsenic properties in different oxidation states. During the Esposti Supply Well Study, one sample was collected on 9/22/2016 and was analyzed to determine the speciation of arsenic. The results were 20 µg/L As (III) and 17 µg/L As (V). However, given this was done only once and several years ago, additional speciation analysis would be

needed to have confidence in whether this result is representative of current well conditions. For this high-level evaluation, the arsenic detected at the Esposti Supply Well is assumed to be As(III) because this represents the most conservative approach. Additional speciation analysis can be done to help more accurately determine the feed rate for oxidant pre-treatment.

Chlorine in the form of sodium hypochlorite must be dosed constantly to oxidize the compounds in the water and it should be added at the beginning of the treatment train to maximize contact time with arsenic and manganese. The chlorine should be dosed stoichiometrically to concentrations of As(III), Mn(II), Fe(II), and H_2S to ensure all constituents with oxidant demand are oxidized, as shown in Table 1. The total theoretical oxidant demand of the compounds in Table 1 is 1.6 mg Cl_2/L. The system has a target residual concentration of 1.00 mg Cl_2/L, for a total dosage of 2.6 mg Cl_2/L. This target dosage was rounded to 3.0 mg Cl_2/L to account for uncertainty in the actual operating scenario. Additional contact time can be added with the use of an appropriately sized contact vessel.

The chlorine feed rate to achieve the target dose of 3.0 mg Cl_2/L is calculated to be 15 gal/day of 12.5% sodium hypochlorite[2]. The feed rate will be similar between both treatment trains and can be used to estimate operation and maintenance costs for both. At this feed rate, about 200 gallons of sodium hypochlorite solution would be required for a two-week supply.

[2] The sodium hypochlorite feed rate is calculated assuming 10% by weight to account for decay that occurs in transit and storage.

Table 1 – Esposti Supply Well Chlorine Feed Rate for Stoichiometric Oxidant Demand

Term	Stoichiometric Demand [a]		Esposti Supply Well Water Quality		Notes
	Value	Units	Value [b]	Units	
As(III)	0.95	mg Cl_2/mg As(III)	0.057	mg/L	Assumed as As(III)
Fe(II)	0.71	mg Cl_2/mg Fe(II)	0.100	mg/L	MDL 100 ug/L
Mn(II)	1.44	mg Cl_2/mg Mn(II)	0.860	mg/L	Assumed as Mn(II)
H_2S	2.48	mg Cl_2/mg H_2S	0.1	mg/L	MDL 0.1 mg/L
	Chlorine Dose				
	Value		Units		Notes
Background Cl_2 Demand	1.61		mg Cl_2/L		From As(III), Fe(II), Mn(II) and H_2S
Target Residual Cl_2	1.00		mg Cl_2/L		1 mg/L target residual
Total Cl_2	3.0		mg Cl_2/L		Background + Residual
Total Flow	400		gpm		
Cl_2 Concentration	12.5 [c]		%		Bulk concentration
Sodium Hypochlorite Feed Rate	15		gal/day		

Notes:
a. US EPA, Arsenic Treatment Technology Evaluation Handbook, US EPA, 2003
b. The assumed water quality in this table is from the Esposti Supply Well Study Table A results for the "Entire Well Pumping at 800 gpm for 28 hours"
c. The sodium hypochlorite feed rate is calculated assuming 10% by weight to account for decay that occurs in transit and storage.

Another form of pretreatment that may be required for either process train is pH adjustment. The pH can impact the effectiveness of iron coagulation for the one-step process and can also impact the efficiency of arsenic adsorption filtration in the two-step process train. For successful coagulation with ferric chloride (discussed further in Section 5), the pH range is about 5 to 8.5. For arsenic adsorption filtration, pH around 7 has been shown to maximize bed volume. The Esposti Supply Well Study defines the pH of the raw water to be 7.6. However, this pH was measured in Alpha Analytical's lab, which does not meet the EPA specified 15-minute hold time for the method used to analyze the sample. To accurately determine the pH of the raw water, the pH should be measured in the field, taking care to not expose the sample to the atmosphere. A decision of whether pH adjustment is needed for either process train should be made in the future when field data for pH are available to

inform the design. For this high-level evaluation, it was assumed that pH adjustment would not be needed.

4.2 One-Step Train: Oxidation/Filtration

The one-step train removes arsenic and manganese by oxidation/filtration. Manganese is removed on a catalytic manganese dioxide media while arsenic is coprecipitated with iron and filtered. This process requires the use of chemical pretreatment, iron addition, media filtration, and backwashing. Oxidation/filtration can successfully achieve As(V) removals greater than 90 percent and achieve arsenic levels below 5 µg/L [14].

As shown in Figure 1, this treatment train consists of the following components:

- Sodium hypochlorite and ferric chloride addition
- Static mixer to promote blending of the added chemicals
- Optional pressurized contact vessel to provide additional time for oxidation and coagulation
- Pressurized vessel with oxidation/filtration media (GreensandPlus with anthracite cap)
- Optional backwash storage tank to equalize backwash flow prior to discharge

The first step of this treatment train after oxidant dosing is the addition of an iron-based coagulant such as ferric chloride or ferric sulfate. As(V) is removed by adsorbing onto iron hydroxide or aluminum hydroxide precipitates. However, iron hydroxides are more stable than their aluminum counterparts at the Esposti Supply Well estimated pH of 7.6. A 20:1 Fe(III) to As(V) ratio is recommended by the EPA for unchallenging waters. The Esposti Supply Well has <100 µg/L Fe and will require ferric chloride to be added for achieving adequate iron levels.

Industry feedback and academic studies on ferric chloride dosage for arsenic removal suggest the Fe(III):As(V) ratio may be much higher than 20:1 due to silica and phosphate interference [15]. Phosphate has nearly identical structure and chemical properties to As(V) and can take available adsorption and binding sites. Silica indirectly reduces treatment efficiencies by preventing adsorption to sites and inhibiting the formation of ferric hydroxide solids. The pH of the water can also impact the effectiveness of coagulation; however, because there is not an accurate pH measurement from the well, it was assumed that the pH was close to neutral and would not significantly impact ferric chloride dosing. For the Esposti Supply Well, a 100:1 Fe(III) to As(V) ratio, 5.7 mg/L Fe or about 17 mg/L as $FeCl_3$, is used for the oxidation/filtration application. This dose corresponds to a feed rate of about 18 gal/day of 37% ferric chloride solution. At this feed rate, 260 gallons of storage is required for a two-week supply. Figure 3 shows an example process design for ferric chloride dosing.

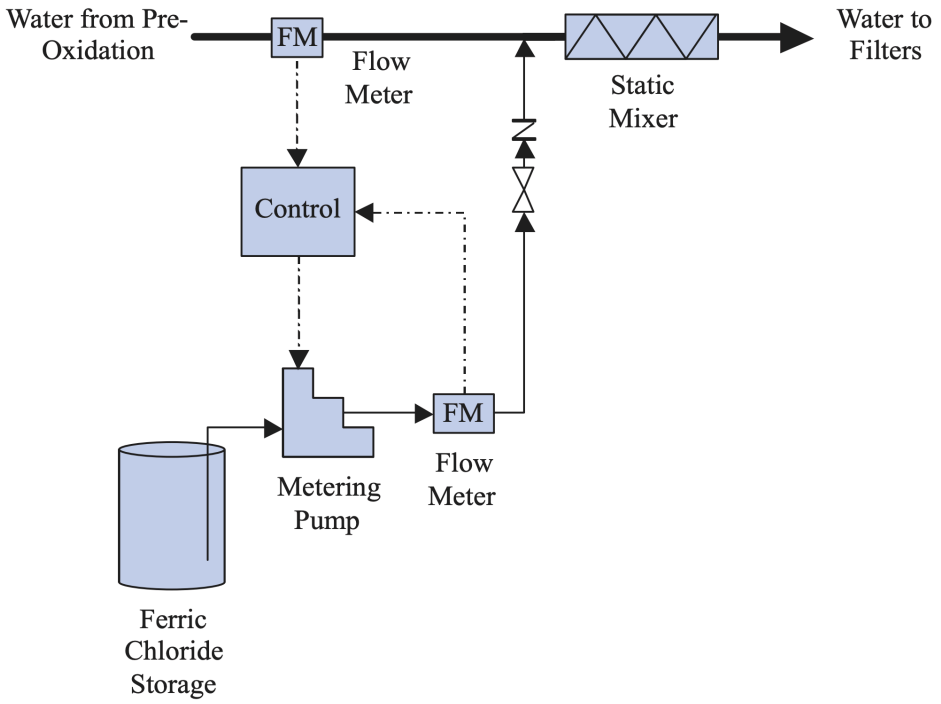


Figure 3 – Example Ferric Chloride Addition Flow Diagram [6]

Ferric chloride addition will create precipitants that load onto the filter media and must be removed by backwashing. High phosphate and silica in the raw water require higher than average concentrations of iron for oxidation/filtration. Sludge generation from high iron addition may create challenging filter media conditions and require frequent backwashing. An anthracite cap can be added on top of the manganese dioxide media to prevent excessive head loss buildup and reduce backwash frequency. The cap will also ensure the manganese dioxide media does not experience unnecessary loading.

Greensand™ is a proprietary silica sand coated in manganese dioxide that has been used for the removal of manganese and iron since the 1950s [16]. Greensand™ has an oxidizing capacity from its manganese dioxide coating that is continuously regenerated in the presence of an oxidant. The continuously regenerated manganese dioxide coating acts as a buffer that is capable of temporarily oxidizing Mn(II) and Fe(II) with loss of pre-treatment chemical. The coating also acts as a catalyst for the chlorine to ensure the redox reaction rapidly goes to completion. Greensand™ media has since seen the development of alternatives that have higher percentages of manganese dioxide that maintain their oxidation-reduction capacities at higher hydraulic loading rates of waters with high levels of iron and manganese. Operating conditions, media availability, and pricing influence the selection of manganese dioxide media. GreensandPlus™, the most recent iteration of Greensand™, is currently assumed for operation of this train in this high-level evaluation due to vendor familiarity and affordability ($75/cubic foot at the time of writing).

Backwash waste that is generated from this process can be disposed of through a connection to the sanitary sewer or can be further treated onsite. Backwash wastewater quality was estimated using a mass balance approach based on influent water quality and

chemical addition. Table 2 provides a summary of the estimated volume and quality of the backwash waste. This analysis assumes discharge of sludge and backwash water to the sanitary sewer to minimize capital and O&M costs. Without the reclamation system, overall system recovery is estimated to be approximately 96% (assuming flows shown in Table 2), and the system is designed to provide 400 gpm of product water accounting for losses due to backwashing. This design assumes use of potable water from the distribution system for backwashing the media vessels.

Table 2 – Estimated Residual Backwash Water Quality and Volume

Parameter	Value	Unit
Number Backwashes per Day	4 – 6	Times per day (varies based on number of vessels online and assumes 12-hour filter run)
Estimated Duration of Backwash	10	min
Backwash Waste Flow Produced	24,000 4,000 – 6,000 400 - 600	gpd gal per backwash gpm during backwash
Iron	202	mg/L
Phosphate	51	mg/L as PO_4
Arsenic	1.9	mg/L
Manganese	30	mg/L
Total Suspended Solids	130	mg/L

Vessels for holding granular media must be designed to accommodate operational requirements for backwashing and hydraulic loading. Adequate flow for fluidization of the media bed is required during backwashing. Backwashing at insufficient flow rates can inhibit removal of precipitated metals and generated ferric sludge. Poor backwashing can overload the media and increase pressure loss.

In lieu of discharging backwash waste to the sewer, additional treatment can be included to treat the backwash waste onsite. This option requires a larger footprint and higher capital and O&M costs but allows for up to 85% of the backwash water to be recycled, which increases the efficiency of the treatment system. Based on flows shown in Table 2, the backwash waste would be reduced to about 3,500 gpd and the system recovery would be approximately 99%. Backwash treatment may consist of a cone-bottom tank to provide settling and separation of solids and wash water, where the water can be decanted and recycled back to the head of the treatment system. The separated sludge can be pumped to

an on-site holding tank that would be periodically emptied (several times per year) and hauled to the landfill. Sludge intended for landfill disposal is required to be analyzed for compliance with Toxic Characteristic Leaching Procedure (TCLP) and California Waste Extraction Test (WET). Based on an initial investigation, the sludge generated from this treatment process can be disposed of in a landfill. Further evaluation of the sludge quality and disposal cost is recommended during future design phases.

For this evaluation and the planning-level cost estimate described in Section 5, it was assumed that the backwash waste would be discharged to a 6,000 gal holding tank and then discharged to the sewer at a rate of about 20 gpm. The Esposti Supply Well Study included a 28-hour pumping test to confirm the Esposti Supply Well capacity. During the testing, the water was discharged to sewer at a rate of 800 gpm without causing issues for the sewer collection system. However, this was conducted in 2016 prior to several large development projects that may have changed the sewer capacity in the area. It is recommended that further evaluation of the sewer capacity and the need for backwash equalization storage be conducted during future phases of design.

4.3 Two-Step Train: Manganese Oxidation and Arsenic Adsorptive Filtration

The manganese oxidation and arsenic adsorptive filtration train is a two-step process that removes manganese and arsenic separately. As shown in Figure 2, this treatment train consists of the following components:

- Sodium hypochlorite addition
- Static mixer to promote blending of the sodium hypochlorite
- Pressurized vessel with oxidation/filtration media (GreensandPlus)
- Pressurized vessel with arsenic adsorptive media (media type to be determined in further design stage)
- Optional backwash storage tank to equalize backwash flow prior to discharge

The catalytic oxidation of manganese requires a pressure vessel with manganese dioxide coated media and an oxidant. GreensandPlus™ is assumed for use for manganese removal in this train. The manganese is precipitated onto the manganese dioxide media and the arsenic is adsorbed onto the adsorptive media. This approach has the benefit of not requiring supplemental iron addition and not generating coagulant sludge. However, periodic backwashing of the Greensand vessel will still be required. The arsenic adsorptive media requires disposal of spent adsorptive media. Separating the manganese and arsenic treatment processes allows for easy troubleshooting and individual modification to the processes down the line.

Arsenic adsorptive media has a limited capacity for contaminants before breakthrough occurs. Breakthrough is where the effluent of the media vessel has a level of arsenic that exceeds the MCL or is detectable. Proper design of the vessels is important to prevent overloading of the media and premature breakthrough of contaminants. Empty bed contact time (EBCT), the length of time in which the feed water is in contact with sorption media, is important for arsenic removal. Adsorption has been shown to increase slightly with increased EBCT. The EPA Arsenic Treatment Technology Demonstration Program had EBCT

for iron-based sorbents Bayoxide® E33 and GFH® in the parallel configuration from 3.3 to 5.7 minutes. This range is used to inform vessel design in the parallel configuration.

Arsenic adsorptive media is sensitive to water quality parameters which can affect removal performance and efficiency. The optimum pH for iron-based sorbents is typically between 6.5 and 8 and may require adjustment for waters outside this range. The adsorption capacity of the media increases as the water approaches the lower end of the acceptable pH range [17]. Adsorption site competitors (e.g., phosphate, chromium, vanadium, and antimony) limit media life. High levels of silica also inhibit adsorption of arsenic at media sites. The Esposti Supply Well has very high levels of phosphate and silica, 1.4 mg/L as PO_4 and 50 mg/L as SiO_2. Arsenic adsorptive filtration implementations in the EPA Arsenic Treatment Technology Demonstration Program had a maximum phosphate of 0.55 mg/L as PO_4 and maximum silica of 72.6 mg/L as SiO_2. EPA sites with the highest level of phosphate and silica concentrations had the lowest media bed volume (BV) treatment capacities.

$$\boldsymbol{BV} = \frac{\boldsymbol{V_L}}{\boldsymbol{V_{AM}}} \qquad \text{(Equation 1)}$$

Where:
V_L = Volume of liquid treated
V_R = Volume of adsorptive media

4.4 Recommended Treatment Alternative

The Esposti Supply Well Study recommended a two-step treatment process that utilized arsenic adsorptive filtration. The stated reasoning for this recommendation was that the one-step oxidation/filtration had unacceptable backwash storage requirements and frequent high iron loading to the water reclamation plant. Trussell, with design adjustment, literature review, and vendor correspondence, recommends the one-step oxidation/filtration system instead of the two-step approach.

To reduce the backwash storage and flow requirements, Trussell's proposed high-level design includes decreased vessel diameters for the oxidation/filtration media. This change allows for less water to be used during the backwash step, reducing the amount of water discharged to the sewer. The Esposti Supply Well Study analyzed 120" and 96" vessels for one-step treatment, which resulted in backwash flow rates of 1,245 gpm and 850 gpm, respectively. The study stated that the maximum flow rate tested in the sanitary sewer was 900 gpm. A smaller diameter vessel requires lower backwash flow rates. The Esposti Supply Well, at 400 gpm, could utilize smaller diameter vessels. Trussell recommends 60" to 72" diameter vessels in parallel to provide backwash flow rates of 275 to 396 gpm. Additionally, backwash reclaim systems may reduce wasted backwash water and loading to the sewer.

Another important reason Trussell is recommending the one-step approach is the anticipated inefficiency of the arsenic adsorptive media. As noted in Section 4.3, the high levels of phosphate and silica detected in the Esposti Supply Well are anticipated to compete with adsorptive sites that provide arsenic removal. This can cause faster breakthrough of arsenic and leads to frequent media exchanges, which increases O&M expenses for this alternative.

To provide another aspect of comparison, the capital and O&M costs for the one-step and two-step treatment approaches are provided in Section 5.

4.5 Bench and Pilot Testing

Bench testing via rapid small-scale column tests (RSSCT) as well as pilot testing are important tools for further developing the designs for adsorptive media treatment systems. RSSCT is commonly used during the initial design stages of adsorptive media treatment systems to inform decisions for media selection and estimate media capacity. Based on the testing results, either the best performing media is selected, or it is determined that a different technology is required. For example, RSSCT can be used to confirm the poor capacity of arsenic sorption media on the Esposti well water.

RSSCT would not be needed to confirm design requirements of one-step process because it does not rely on exhaustible sorptive media for removal. For this process, it is recommended that pilot-scale testing be conducted at the future treatment site using the complete treatment system (i.e., including pretreatment and backwashing capabilities if applicable). Pilot testing of the selected treatment approach will likely be required by DDW as part of the permitting process. This testing will help determine the product water quality from the treatment system and confirm that the design meets all drinking water regulatory requirements. The testing will also provide important insight regarding design refinement to optimize the process as well as more information to accurately estimate the full-scall capital and O&M costs. For example, the Esposti well has a unique combination of challenging water quality including high silica, high phosphate, high arsenic, high manganese, but low iron. The low iron requires relatively high doses of ferric chloride. Pilot testing could confirm that manganese removal can be achieved with the high ferric chloride doses. This testing would also confirm other design parameters such as backwash frequency.

Because both RSSCT and pilot testing are common, the logistics associated with the testing are well understood and are summarized below.

Logistics for RSSCT Testing:

- Testing is performed with water collected from the well and shipped to either Trussell's Laboratory in Pasadena or to a vendor's lab. The typical volume of water that would be collected and shipped is 350 – 500 gallons. Sampled water can be collected in 55-gal drums or totes.
- Testing is conducted over the course of a couple of weeks, but is translatable, using scaling factors, to full-scale operation of months or years.

Logistics for Pilot Testing:

- Testing is performed on site using a vendor-provided treatment skid mounted on a trailer.
- Testing is conducted over the course of several weeks to several months and the pilot system is operated by an experienced engineer

Additional details regarding RSSCT and pilot testing are provided in Table 3.

Table 3 – Planning Information for Bench- and Pilot-Scale Testing

Parameter	Bench Scale RSSCT	Pilot Testing
Schedule Requirements	• 1 month to develop test plan • 1 month for testing • 1 month to develop test report	• 1 month to develop test plan • 1 to 3 months for testing • 1 month to develop test report
Space Requirements	• Truck access to load 55-gal drums or 350-gal totes for water collection	• Level ground • Enclosed pilot trailer • Raw water supply and effluent waste drain location by gravity flow • Electrical connection • Pilot staff access to toilet facilities
Planning-Level Estimated Cost	$75,000 • Includes test plan development, test execution, and final report development • Includes calls/coordination with Trussell	$75,000 - $100,000 • Includes test plan development, test execution, and final report development • Includes calls/coordination with Trussell

5 Planning-Level Treatment Costs

This section presents a cost analysis that estimates planning-level capital and O&M costs for the two treatment trains identified. Capital costs are based on the maximum flowrate for which the facility is designed. Capital costs include process costs (manufactured equipment, concrete, steel, electrical and instrumentation, pipes, and valves), construction costs (site-work and excavation, subsurface considerations, standby power, contingencies, and interest during construction), soft costs (general contractor overhead and profit, engineering fees, and legal, fiscal, and administrative fees), and costs associated with retrofitting, permitting, pilot testing, housing, and system redundancy.

Equipment costs are estimated from vendor-provided quotes. The following section describes the equipment and O&M costs and provides a net present cost analysis.

5.1 Summary of 2021 Esposti Supply Well Study Cost Estimate

GHD's 2021 update for treatment at the Esposti Supply Well reiterated the 2017 recommendation in the Esposti Supply Well study for two-step treatment. The 2021 update showed an equipment cost estimate for two-step treatment at $718,270. This equipment cost was provided by Tonka Water (a Kurita brand) in 2017 and assumed one 10-foot diameter vessel for manganese removal and one 9-foot diameter vessel for arsenic removal. With the addition of costs associated with design, construction, permitting, and contingencies, the overall capital cost was estimated to be $2,765,960 in 2021 dollars.

5.2 Equipment Costs

Equipment costs were evaluated for both the one-step and two-step design options. Budgetary quotes for equipment costs from vendors are provided as an estimate for planning purposes. Actual equipment cost may vary from provided quotes depending on design changes, timeline, and market conditions. Information provided to vendors included site location, water quality, flow rate, treatment objectives, and backwashing requirements.

Two-Step Treatment System

As described in Section 5.1, the equipment cost in GHD's 2021 update of the Esposti Supply Well Study for the two-step treatment was $718,270. A 2022 quote for the same design from Tonka Water places the equipment cost at $1,170,000. This cost increase is reflective of current market conditions such as supply chain challenges, labor shortages, and inflation. This more current cost is used to compare the two-step and one-step treatment options.

One-Step Treatment System

Considering the one-step treatment approach, several vendors were contacted to provide equipment costs. Table 4 provides a summary of the costs provided by each vendor.

Table 4 – Vendor Quotes for One-step Treatment

Vendor	Equipment Cost	Notes
Tonka Water	$590,000	• Three 6-foot diameter vessels with no redundancy • Backwash volume and flow assumptions provided in Table 2 are based on this design
Hungerford & Terry	$745,000	• Three 8-foot diameter vessels with redundancy • Backwash volume and flow rate would be about 24,000 gpd and 600 gpm, respectively (assuming two vessels online backwashing every 12 hours). Table 2 provides a conservative estimate of water quality • System recovery is estimated to be 94%
MISCO Water	$725,000	• Three 8-foot diameter vessels with redundancy • Backwash volume and flow rate would be about 24,000 gpd and 600 gpm, respectively (assuming two vessels online backwashing every 12 hours). Table 2 provides a conservative estimate of water quality • System recovery is estimated to be 94%
MISCO Water 6,000-gal Backwash Waste Equalization Tank	$25,000	• Slanted bottom tank with base, seismic constraints, and fittings • Bottom drain fitting allows for complete drainage of settled solids to facilitate cleaning and flushing when necessary

The design goals presented to each vendor were the same regarding raw water quality, flow rate, final product water quality, and a limit of 900 gpm flow to the sewer. Each vendor quoted their preferred design to meet the stated goals. Table 4 includes notes that highlight the key design differences for each vendor. The various options for treatment design should be further evaluated as a next step in the design process to identify the preferred approach and equipment vendor for the Esposti Supply Well. Pilot testing and additional water quality monitoring will also facilitate making informed design decisions.

For this high-level evaluation, the highest quoted equipment cost of $745,000 was used as the basis for capital costs (Section 5.3) and net present cost (Section 5.5) for a conservative estimate.

5.3 Capital Costs

The capital cost estimate provided in Table 5 follows the approach developed for the Esposti Supply Well Study and GHD's 2021 update. The Study had money in 2016 dollars and capital costs for all line items in Table 5 have been scaled to 2022 dollars with CCI data. The exception to this statement is the "prefabricated treatment plant with shipping and the backwash waste equalization tank" line items, which were provided by system vendors in 2022 per Section 5.2. The ENR CCI for the 20-city average in August 2022 and 2016 was $13,171.07 and $10,338, respectively.

Table 5 - Esposti Supply Well Treatment Options Capital Costs

DESCRIPTION	QUANTITY		ONE-STEP: OXIDATION/FILTRATION		TWO-STEP: MANGANESE REMOVAL & ARSENIC ADSORPTIVE FILTRATION	
			ESTIMATE		ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL
Preliminary Design						
Location selection, survey, geotech, visual and noise impact assessments	1	LS	$76,500	$76,500	$76,500	$76,500
Preliminary CEQA analysis, assume MND with traffic, GHG models, tribal consultation	1	LS	$63,800	$63,800	$63,800	$63,800
Preliminary DoDW application and meetings	1	LS	$15,300	$15,300	$15,300	$15,300
Evaluation of specific vendor designs and requirements	1	LS	$5,100	$5,100	$5,100	$5,100
Evaluation of power connection for site	1	LS	$5,100	$5,100	$5,100	$5,100
Install permanent pump for 400 gpm system and power[1]	1	LS	$31,900	$31,900	$31,900	$31,900
Sewer capacity evaluation, field verification, permit application[2]	1	LS	$19,200	$19,200	$19,200	$19,200
Pilot testing of Cat. Oxidation (Mn & As) - field trailer and well pumping @ 400 gpm	1	LS	$38,300	$38,300	$38,300	$38,300
Rapid small scale column tests (RSSCT) of 3 media (As)[3]	3	EA	~	~	$9,000	$27,000
Preliminary Design subtotal				**$255,200**		**$282,200**
Basis of Design Report						
Report to compile predesign results and finalize treatment process	1	LS	$23,000	$23,000	$23,000	$23,000
Basis of Design Report subtotal				**$23,000**		**$23,000**
Detailed System Design and Bid Package						
Prefabricated treatment plant design coordination with manufacturer[4]	1	EA	$4,500	$4,500	$4,500	$4,500

DESCRIPTION	QUANTITY		ONE-STEP: OXIDATION/FILTRATION		TWO-STEP: MANGANESE REMOVAL & ARSENIC ADSORPTIVE FILTRATION	
			ESTIMATE		ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL
Site Design (site, power, and piping connections) 15% of contractor site work subtotal[5]				$93,000		$83,900
Bid package and engineering bid support	1	LS	$10,200	$10,200	$10,200	$10,200
Design subtotal				**$107,700**		**$98,600**
Permitting Final Documents					$0	
CDPH Negotiations and Meetings due to SRF Loan	1	EA	$6,400	$6,400	$6,400	$6,400
CEQA Mitigated. Neg. Dec. with visual impact map and construction mitigation plan	1	EA	$28,100	$28,100	$28,100	$28,100
Sewer discharge permit application	1	EA	$5,100	$5,100	$5,100	$5,100
Permitting Document subtotal				**$39,600**		**$39,600**
Prefabricated Treatment Plant						
- Filter tanks				incl.		incl.
- Tank internal distributors				incl.		incl.
- Initial filter media				incl.		incl.
- Headers and interconnection piping				incl.		incl.
- Filter flow sensors				incl.		incl.
- Filter control panel				incl.		incl.
- Backwash controls and booster pump				incl.		incl.
Prefabricated treatment plant with shipping	1	LS	$745,000	$745,000	$1,170,000	$1,170,000
Backwash waste equalization tank	1	LS	$25,000	$25,000	$25,000	$25,000
Sales tax at 8.25% of total				$63,525		$98,588
Treatment Plant subtotal				**$833,525**		**$1,293,588**
Site work and installation of prefabricated treatment plant						
Markup on purchase of prefabricated treatment plant (10%)				$83,353		$129,359
Grade and soil support for treatment plant	1	LS	$38,300	$38,300	$38,300	$38,300
Cement pad for treatment plant and gravel access	1	LS	$15,300	$15,300	$15,300	$15,300
Unit Install	1	LS	$15,300	$15,300	$15,300	$15,300
Chemical metering and Delivery System	2	EA	$20,400	$40,800	$20,400	$40,800
Chemical System Install inside small prefabricated enclosure	1	LS	$14,100	$14,100	$14,100	$14,100
Process Piping inside treatment plant compound	1	LS	$70,100	$70,100	$70,100	$70,100
Pump booster for backwash water to sewer	1	LS	$12,800	$12,800	$12,800	$12,800
Backflow prevention	1	LS	$7,700	$7,700	$7,700	$7,700

DESCRIPTION	QUANTITY		ONE-STEP: OXIDATION/FILTRATION		TWO-STEP: MANGANESE REMOVAL & ARSENIC ADSORPTIVE FILTRATION	
			ESTIMATE		ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL
Site Electrical Design Modifications	1	LS	$30,600	$30,600	$30,600	$30,600
Process Controls and Integration	1	LS	$15,300	$15,300	$15,300	$15,300
Fence and visual screening of treatment tank (redwood panel)	1	LS	$15,300	$15,300	$15,300	$15,300
Power connection (overhead, new lines)	300	FT	$130	$39,000	$130	$39,000
Raw water well to treatment plant buried in road (4-inch)	400	FT	$200	$80,000	$200	$80,000
Treated water to distribution with backflow prevention buried in road (4-Inch)	100	FT	$200	$20,000	$200	$20,000
Sewer line connection backwash tank to S130 buried in road (4- inch force)	600	FT	$160	$96,000	$160	$96,000
Contractor Site Work subtotal				**$593,953**		**$639,959**
Contractor Site Work and Prefabricated Treatment Plant subtotal				**$1,427,478**		**$1,933,546**
General Conditions (8%)				$114,198		$154,684
Bond / Insurance (2%)				$28,550		$38,671
O&P (18%)				$256,946		$348,038
Contractor site work with prefabricated treatment plant subtotal				**$1,827,171**		**$2,474,939**
Construction Management (15% contractor site work subtotal)				**$89,093**		**$95,994**
Subtotal				$2,337,864		$3,026,433
Predesign-Level Estimating Contingency (30%)				$701,359		$907,930
Predesign-Level Project Budget Estimate (2022 Dollars)				**$3,040,000**		**$3,935,000**

The one-step, oxidation/filtration train has a capital cost of $3,040,000 in 2022 dollars. The two-step, manganese removal and arsenic adsorptive filtration train has a capital cost of $3,935,000 in 2022 dollars.

5.4 Operation and Maintenance Cost

In the one-step, oxidation/filtration train, natural iron is assumed to be supplemented with ferric chloride. Ferric chloride, 37% solution, is assumed for iron addition at a rate of 18 gallons per day. This cost estimate assumes a price of $11.12/gal of ferric chloride. Iron addition with ferric chloride will cost about $6,000 per month. The volume-normalized cost is $0.35 per 1000 gallons treated.

Sodium hypochlorite is assumed to be used for both treatment train options as a primary and secondary disinfectant and to maintain the catalytic oxidation capability of the manganese dioxide filtration media. The 12.5% sodium hypochlorite solution is assumed to be used at a rate of 15 gallons per day at $6.99/gal. Chemical costs for chlorination/oxidation are calculated to be about $3,100 per month. The volume-normalized cost is $0.18 per 1000 gallons. The costs for oxidant are the same between the oxidation/filtration and the manganese removal and adsorptive media trains.

For manganese removal in either treatment option, the GreensandPlus™ media is estimated to cost $15,010 per refill. GreensandPlus™ is quoted for budgetary purposes at $75 per cubic foot (provided by Hungerford & Terry). The media is assumed to last for five years. The same replacement frequency is assumed for both the one-step and two-step treatment options.

For arsenic adsorption in the two-step treatment option, the media has a finite number of sorptive sites that will be exhausted over time. The estimated bed volume prior to breakthrough of arsenic is 23,000. Based on the design flow rate of 400 gpm and the water quality assumptions, the estimated treatment time before breakthrough is 60 days. The cost of Bayoxide E33 media (used to estimate O&M cost—the final media selection would be done via pilot testing) is $235/cubic foot (provided by AdEdge), and so the monthly media cost is estimated to be about $24,000 or $1.37 per 1000 gallons treated.

Table 6 provides a summary of the estimated O&M costs for both treatment options. The total O&M cost for one-step oxidation/filtration is $234,100 per year and has a volume-normalized cost of $2.23 per 1000 gallons. The total O&M cost for the two-step manganese removal and arsenic adsorptive filtration is $339,700 per year and has a volume-normalized cost of $3.24 per 1000 gallons.

Table 6 - Operation & Maintenance Costs for Manganese and Arsenic Removal Trains

DESCRIPTION	QUANTITY		ONE-STEP: OXIDATION/FILTRATION		TWO-STEP: MANGANESE REMOVAL & ARSENIC ADSORPTIVE FILTRATION	
			ESTIMATE		ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL ANNUAL	UNIT COST	TOTAL ANNUAL
Monthly Costs						
Monthly power due to well pump and treatment system (150hp total @ $0.17/KWhr)	6	Month	$14,980	$89,880	$14,980	$89,880

DESCRIPTION	QUANTITY		ONE-STEP: OXIDATION/FILTRATION		TWO-STEP: MANGANESE REMOVAL & ARSENIC ADSORPTIVE FILTRATION	
			ESTIMATE		ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL ANNUAL	UNIT COST	TOTAL ANNUAL
Disinfection / Oxidation	6	Month	$3,100	$18,600	$3,100	$18,600
Compliance reporting	6	Month	$2,990	$17,940	$2,990	$17,940
Labor	6	Month	$2,990	$17,940	$2,990	$17,940
Sampling and analysis	6	Month	$2,990	$17,940	$2,990	$17,940
Additional training and/or operator license	6	Month	$2,990	$17,940	$2,990	$17,940
Ferric Chloride	6	Month	$6,010	$36,060	~	~
Monthly arsenic adsorptive media replacement	6	Month	~	~	$23,610	$141,660
Long-Term Maintenance Costs						
Catalytic oxidation (Greensand plus) replacement (Mn)	0.2	Year	$16,550	$3,310	$16,550	$3,310
Non-routine analysis	6	Est	$600	$3,600	$600	$3,600
Equipment repair and replacement average annual	6	Month	$1,800	$10,800	$1,800	$10,800
Predesign-Level Annual Operation Budget Estimate			Annual Cost	**$234,100**		**$339,700**
Assuming 321.7 Acre-ft./Year production 1			$/acre-ft.	**$723**		**$1,048**
			$/1000 gal	**$2.23**		**$3.24**

5.5 Net Present Cost

A 30-year net present cost analysis with a discount rate of 3% is done to compare capital and O&M costs between trains. The capital costs are in present worth. O&M cost present worth is found with a series present worth formula.

$$\mathbf{P} = \mathbf{A}\left[\frac{(1+\mathbf{i})^{\mathbf{n}}-1}{\mathbf{i}(1+\mathbf{i})^{\mathbf{n}}}\right] \quad \text{(Equation 2)}$$

Where:
P = A present sum of money
i = Interest rate per interest period
n = Number of interest periods
A = An end-of-period cash receipt or disbursement in a uniform series continuing for n periods

The 30-year net present cost of the one-step oxidation/filtration train is $7,629,000. The 30-year net present cost for the two-step manganese removal and arsenic adsorptive filtration is $10,593,000. Oxidation filtration has a lower 30-year cost, as net present cost, and is recommended for further consideration to treat the Esposti Supply Well.

6 Conclusions

Treatment at the Esposti Supply Well for arsenic and manganese is required to comply with state and federal drinking water standards. Treatment is costly at this location due to the presence of phosphate and silica, which interfere with treatment efficacy. Two treatment trains are identified to meet or exceed design criteria: one-step oxidation/filtration or two-step manganese oxidation and arsenic adsorptive filtration. Both trains contain manganese dioxide media to facilitate the catalytic oxidation of manganese, which converts dissolved manganese in the raw water to a particulate. Oxidation/filtration is a process that relies on chemical oxidation and was originally used for iron and manganese removal. The oxidation/filtration process removes arsenic by coprecipitation with iron hydroxide, which is dosed into the water as ferric chloride. The two-step train, consisting of catalytic oxidation of manganese and arsenic adsorptive filtration, does not use iron to coprecipitate with arsenic. Instead, an iron-based media is used to adsorb arsenic. This train has the benefit of reduced sludge generation but was found to be significantly more expensive than the one-step approach considering both capital costs and O&M costs due to monthly replacement of the iron-based adsorptive media.

The one-step process is estimated to be the most economical approach. The one-step oxidation/filtration train has an estimated capital cost of $3,00,000[3], O&M cost of $230,000/year, and 30-year net present cost of $7,600,000 in 2022 dollars. The two-step catalytic oxidation of manganese and arsenic adsorptive filtration train has an estimated capital cost of $3,900,000, O&M cost of $340,000/year, and 30-year net present cost of $10,600,000 in 2022 dollars.

Trussell recommends further consideration of the one-step oxidation/filtration system. The arsenic adsorptive media is expected to require frequent media replacement, carrying high costs for the two-step manganese oxidization and arsenic adsorptive filtration system due to

[3] Quotes for the one-step treatment system differed by a factor of two. The most expensive quote was used for comparison with the two-step treatment system in this memo. However, the lower cost quotes may provide acceptable systems. Further evaluation of the equipment provider's systems is recommended to refine the Esposti Supply Well treatment cost estimate.

elevated levels of interferants in the raw water. In addition, the one-step oxidation/filtration design was modified to use smaller diameter vessels to reduce backwash flow requirements to address the concern for sanitary sewer flowrate capacity.

Trussell recommends conducting additional sampling to further characterize the Esposti Supply Well raw water quality to refine the design assumptions for treatment, particularly with respect to the need for pH adjustment. Trussell also recommends bench-scale and/or pilot-scale testing. The Esposti well has unusually high silica and phosphate concentrations. Bench-scale testing could confirm the estimated frequent replacement of arsenic adsorptive media in the two-step approach. Pilot-scale testing is recommended to verify removal efficiencies of the one-step approach, given the high ferric dose requirements due to the low iron levels in the well. Lastly, backwash reclaim systems could be further evaluated as a method to reduce wasted backwash water and loading to the sewer. Water reclamation plant operational concerns should also be explored before discharging large concentrations of iron, manganese, and arsenic. With additional data, the two feasible treatment approaches described in this TM can be reevaluated to refine the design of the preferred approach.

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8 Appendix A

Table 7 - Esposti Supply Well Design Water Quality [1]

Cations	
Hardness	120 mg/L $CaCO_3$
Ammonia	<0.50 mg/L NH_3
Calcium	22 mg/L
Magnesium	16 mg/L
Sodium	53 mg/L
Anions	
Alkalinity	220 mg/L $CaCO_3$
Bicarbonate	270 mg/L $CaCO_3$
Carbonate	<5.0 mg/L $CaCO_3$
Chloride	21 mg/L
Fluoride	0.15 mg/L
Nitrate	<0.40 mg/L NO_3
Phosphate	1.4 mg/L
Silica	50 mg/L SiO_2
Sulfate	14 mg/L SO_4
Metals	
Antimony	<6.0 µg/L
Total Arsenic	57 µg/L
Copper	<50 µg/L
Iron	<100 µg/L
Lead	<5.0 µg/L
Manganese	860 µg/L
Mercury	<1.0 µg/L
Selenium	<5.0 µg/L
Vanadium	<0.003 µg/L

APPENDIX B

Alluvial Thickness and Subsurface Texture Study

Appendix B

Investigation of Subsurface Texture in the Town of Windsor Area

INTRODUCTION

The Town of Windsor (Town) is seeking to diversify its sources of water supply, which presently derive almost entirely from surface and underflow of the Russian River. Since the early 2000s, the Town has been investigating options for construction of municipal supply wells in the Town area, east of the river alluvium. The primary impediment to that strategy is the natural occurrence of arsenic in groundwater at concentrations exceeding the maximum contaminant level (MCL) of 10 micrograms per liter (µg/L). The Groundwater Master Plan effort included new analysis to delineate the depth and texture of geologic materials that comprise the groundwater basin in and near Windsor area. This appendix documents that analysis. This study area was bounded roughly by Faught and Chalk Hill Roads to the east, Mark West Creek to the south, Eastside Road to the west and Town Limits near Arata Lane to the north, as shown in **Figure 1**. This region is referred to as the "Town area" in this discussion.

SUBSURFACE SEDIMENT TEXTURE

The Town area is located at the northern end of the Santa Rosa Plain Groundwater Basin, in a region shown on geologic maps primarily as alluvium (**Figure 2**). These surficial deposits are underlain by the Glen Ellen Formation, which crops out to the east and west of Town.

One of the original objectives for this study was to identify the contact between alluvium and the Glen Ellen Formation in well completion reports for wells in and near the Town, then contour the depth to the contact. However, geologic maps, well completion reports, and previous studies all demonstrated the difficulty of differentiating between the two formations, particularly in well logs.

Geologic Mapping

Quaternary alluvium and the Glen Ellen Formation have similar patterns of texture and strata. Both formations consist of thin local strata of clay, silt, sand and gravel. The primary differences are that the Glen Ellen Formation is more consolidated and cemented, but those differences are subtle. Evidence of the difficulty in differentiating between alluvium and Glen Ellen Formation can be found in the differences in delineating the surficial outcrops of the two formations among several recent geologic maps. **Figure 2** compares three geologic maps of the area, each of which has noticeably different delineations of the Glen Ellen Formation and alluvial formations.

- Wentworth (1997). This map from the U. S. Geological Survey's (USGS') National Geologic Map Database merged information from Wentworth (1985) and Ellen and Wentworth (1995). Map units shown as "alluvium" in the figure included eight

categories of fine, medium, and coarse-grained Pleistocene and Holocene alluvium, stream channel deposits and "unmapped colluvium". The Glen Ellen and Huichica formations were combined into a single mapping unit classified as "Quaternary-Tertiary sandstone and mudstone" by Wentworth but shown in the figure here as Glen Ellen formation.

- Delattre (2011). Map units shown as "alluvium" in the figure include Pleistocene and Holocene alluvial, basin, stream channel, alluvial fan, and other similar categories. Map units shown as Glen Ellen Formation in the figure are described as Pliocene to early Pleistocene unnamed fluvial deposits "previously mapped as Glen Ellen and Huichica formations".
- Wagner and Gutierrez (2017) mapped most of what is shown in the figure as Glen Ellen formation as older alluvium. The redesignation and simplification of map linework were done for the geologic map figure (Figure 3-4b) in the Santa Rosa Plain Groundwater Sustainability Plan (GSP).

The boundaries of the alluvium are where it is thinnest. For the objective of finding a body of low-arsenic groundwater, the thickest part of the alluvium is the most promising, and this is likely to be in the central part of the region mapped as alluvium. All three of the maps show outcrop of alluvium throughout the eastern part of the Town area, east of about Highway 101.

Review of Previous Stratigraphy Studies

As mentioned above, previous studies of stratigraphy in the Santa Rosa Plain area noted the difficulty of differentiating between alluvial deposits and the Glen Ellen Formation in borehole cuttings. For example, Cardwell (1958) concluded:

> "Because of the difficulty in distinguishing in drillers' logs between the younger alluvium, terrace deposits, and the Glen Ellen formation, the thickness of the younger alluvium is not definitely known but may have a maximum of about 150 feet. A study of the well-log and well-yield data indicates that the younger alluvium is underlain by the Glen Ellen formation or older alluvial deposits of similar character at depths ranging from a few feet to 50 feet or more on the eastern side of the Russian River south of Healdsburg, and that the younger alluvium is probably thickest, about 100 feet, on the western side near the present course of the river."

Sweetkind and others (2010) lumped the Glen Ellen Formation with the overlying alluvial deposits "because the younger surficial deposits are typically thin and difficult to differentiate in drill logs". Instead of defining subsurface stratigraphy in terms of formation names, Sweetkind and others defined it in terms of texture. They reviewed hundreds of well completion reports (WCRs) for wells throughout the Santa Rosa Plain Basin. About 317 WCRs were usable in terms of accurate location information and clarity of lithologic descriptions, and 82 of those were in or near the Town area. The authors classified drillers' terms into 19 standardized texture categories, and those were further consolidated into five categories for mapping purposes: fine, intermediate, and coarse alluvium, volcanic tuff, and basalt. Any textures including the words "sand" or "gravel" were grouped in the coarse

category. At each well location, the percent of coarse material was tabulated for depth intervals 50-100 feet thick down to over 600 feet below the ground surface.

For each depth interval, the point data at well locations were gridded over the entire basin using grid cells 660 x 660 feet in size. Interpolation to grid cells between well locations was done using a nearest-neighbor approach. A drawback to this approach is that it tends to understate the textural heterogeneity of the Glen Ellen and alluvial deposits. It produces patches of uniform texture that are large where well data are sparse. An example of the gridded texture values in the 50-100 foot interval is shown in **Figure 3**. This figure illustrates the problem with the gridding approach, resulting in large areas of continuous texture throughout the Town area. Previous studies noted that texture in the Glen Ellen Formation is "extremely heterogeneous" (Cardwell, 1958).

Fortuitously, Don Sweetkind was still reachable at the U.S. Geological Survey and kindly provided his texture database for use in this study. That enabled a new evaluation of the data as point values of percent-coarse texture for user-specified depth intervals, which is described in the next section.

New Stratigraphic Texture Analysis Using Well Completion Reports

For this study, two compilations of subsurface texture were used, both ostensibly derived from WCRs on file with the California Department of Water Resources (DWR). The first compilation was done for this study by downloading all well completion reports within a 16-square-mile area encompassing the Town area from the DWR's on-line database. The query returned 1,000 WCRs, which were assessed against multiple criteria to eliminate WCRs that could not be located or included poor quality information.

The first step was to select those WCRs for which a location could be identified. During this process only wells with PDFs of the lithology logs were considered. Coordinates of wells with address information were obtained using the geocoding tool called "Geocode Addresses". This GIS tool utilizes an address locator to match the street number, name, city, and zip code from the dataset to a location and then plots that location in a point feature class. This exercise used local road information downloaded from the County of Sonoma website to maximize accuracy and increase the number of locatable WCRs. This method provides higher location accuracy than the latitude/longitude coordinates provided by DWR's WCR database; these are very often locations based on the center of the Public Land Survey System section in which the well is located. However, the geolocator tool also has accuracy limitations because the points all fall along roadways rather than in the interior of a parcel.

The next step was to tabulate lithologic information from the WCRs with accurate location information. Reports with location information accuracy of less than 50 feet or a street address were then screened based on the quality of the lithologic descriptions. It quickly became apparent that alluvium could not be differentiated from Glen Ellen Formation in the WCRs, confirming the conclusion reached by previous investigators (Cardwell, 1958; Sweetkind and others, 2010). The range of textures and patterns of layering are similar in

both formations. Differences in compaction and cementation are difficult to discern in drill cuttings and were not noted by the drillers.

As an alternative to identifying the alluvium-Glen Ellen contact in drillers' logs and mapping its depth, the percent coarse material in the 50-200 foot depth interval was tabulated. This was considered equally useful because:

- Arsenic is thought to correlate with depth, not with formation. If so, shallower depth intervals are less likely to contain high arsenic concentrations.
- Coarse sediments are more permeable and support higher well yields.
- Coarse texture was defined for this exercise as any driller's description that did not include the word "clay". For example, "clayey sand" or "gravel with streaks of clay" would be excluded, whereas "silty sand" or "silt, sand and gravel" would be included.
- The 50-200 foot depth interval is below the minimum depth of required sanitary seals for municipal wells and deep enough to be representative of shallow aquifer conditions.

The lithology logs were reviewed and given a score from one to five based on the quality of the log **(Table 1)**. A score of 1 (highest ranking) was given to logs that used the United Soils Classification System (USCS) to describe the material and contained high quality location information. At the opposite extreme, a score of 5 was given to WCRs with little or no lithology information. Wells greater than 100 feet deep with a score of 1 or 2 were retained for texture tabulation. The percent of coarse-grained material in the 50-200 foot depth interval was calculated by summing the total length of depth intervals between 50 and 200 feet described as not containing clay and dividing by the total boring length analyzed.

Table 1: Lithologic Log Quality Scoring

Score	Criteria
1	Has location information and lithology described using USCS soil classification
2	Has location information and lithology described with coarseness of material and color
3	Has location information and lithology described with coarseness of material, no color information
4	Poor location information or lithologic description
5	No location information or very poor lithologic description

The WCR screening process winnowed the WCRs as follows:

- 246 of the 1,000 wells were greater than 100 feet deep and could be located by street address. However, as noted above street address geolocator algorithms return a location on the street itself, which can be far from the actual well location for large parcels.
- 95 of the 246 WCRs were within the Town area and had lithologic descriptions sufficiently accurate to calculate percent coarse sediments in the 50-200 foot depth interval.
- 38 wells had a coarse fraction greater than 21 percent and only 6 wells had a greater than 61 percent coarse fraction.

A map of the percent coarse material in the 50-200 foot depth interval is shown in **Figure 4**, along with similar data from Sweetkind and others (2010). Wells located in the northwest part of the Town area appear to have a higher percentage of coarse material than wells to the south or east. The relatively large coarse fraction is likely due to the proximity to the Russian River and its ancestral meander alignments. However, three wells located along Pleasant Avenue near Chalk Hill Road near the eastern edge of the Town area have relatively high coarse fractions. The coarse material at that location could be upper alluvial fan sediments deposited by the ephemeral creek draining the Shiloh Ridge area.

Reanalysis of Sweetkind and Others Texture Database

The second compilation of subsurface texture was the one completed by the U.S. Geological Survey (Sweetkind and others, 2010). They also compiled the data from WCRs on file with the California Department of Water Resources and used similar methods for identifying well locations. The texture database was obtained from Don Sweetkind and was found to contain 2,616 wells over the entire Santa Rosa Plain Basin with a combined total of 37,124 logged texture intervals. Of those wells, 126 were in or near the Town area and had usable percent coarse information. The original assignment of texture in this dataset was modified slightly to be consistent with the classification system described above. This was completed using a set of algorithms in the Excel dataset to modify how the 19 texture categories were grouped and to calculate the percent coarse thickness for any user-defined depth interval.

The Sweetkind and others database was queried for the percent coarse material in the 50-200 foot depth interval, and the resulting values are plotted on the map in **Figure 4**. One difference between the two subsurface texture compilations became immediately apparent, which was the poor match in well locations. Given that both compilations derived from approximately the same set of WCRs using similar methods, one would expect the well locations to be similar between the two efforts. They were not. This attests to the inherent uncertainty in establishing WCR well locations. There could have been differences between the street address geolocating tools used by the two studies (which was the primary location method used by both studies) or two different results produced by other methods used for some wells by Sweetkind and others (i.e. assessor's parcels, centroid of quarter-section, driller's sketch on the WCR).

For both compilations, wells with greater than 40 percent coarse material are rare and generally not clustered in certain regions. This reflects the predominantly fine-grained texture of basin deposits and the large degree of spatial variability in texture. One local area where multiple wells have above-average values of percent coarse material is at the northwest corner of the Town area, roughly bounded by Eastside Road, Highway 101 and Gumview Road (outlined in purple in **Figure 4**).

For completeness, the Sweetkind and others database was queried for 100-foot-thick depth intervals between 50 and 650 feet below ground surface. The results are shown in **Figure 5a** through **5e**. The number of data points diminishes with depth, making patterns increasingly difficult to detect. However, several local areas containing at least two wells with above-average percentages of coarse material were identified and are outlined in purple. These could be favorable locations for test wells.

Airborne Electromagnetic Survey

Another source of data that could potentially indicate alluvial depth is airborne electromagnetic (AEM) data collected by DWR in 2021. The AEM surveys were statewide, and flight lines in any given region were often far apart. The flight lines near Windsor are shown in **Figure 1**. Unfortunately, both flight lines are outside the Town area. One is along the Healdsburg Fault Zone/Rodgers Creek Fault, mostly east of mapped alluvium and where Glenn Ellen abuts Sonoma Volcanics. The other one starts west of the airport and extends south and is also not representative of conditions in the Town area. Thus, the AEM data set is not useful for identifying alluvial thickness in the Town area. It is also unclear whether the resistivities of alluvium and Glen Ellen Formation are sufficiently different to reveal the subsurface contact between the formations.

Sediment Texture Conclusions

- Sediments comprising the Glen Ellen Formation are too similar in texture and layering to those in the overlying alluvium to identify the contact between those formations in borehole lithologic logs.
- The horizontal spatial variability of texture is very high. There are few patterns evident in maps of texture data because data are sparse, and the typical lateral extent of individual deposits is probably much smaller than the typical distance between borehole logs. This spatial variability was evident in each of the 100-foot depth intervals tabulated from the well completion report, down to 650 feet below ground surface.
- Recent statewide airborne electromagnetic surveys did not include flight lines through Windsor. The nearest lines are too far away to help with interpretation of stratigraphy in the Town area.
- The new data and analysis in the present study corroborated conclusions reached by previous investigators.
- Given the tenuous identification of only a few local areas that might have above-average abundance of coarse material, the subsurface sediment texture data may

not accurately reflect textures that will be encountered at any new borehole location.

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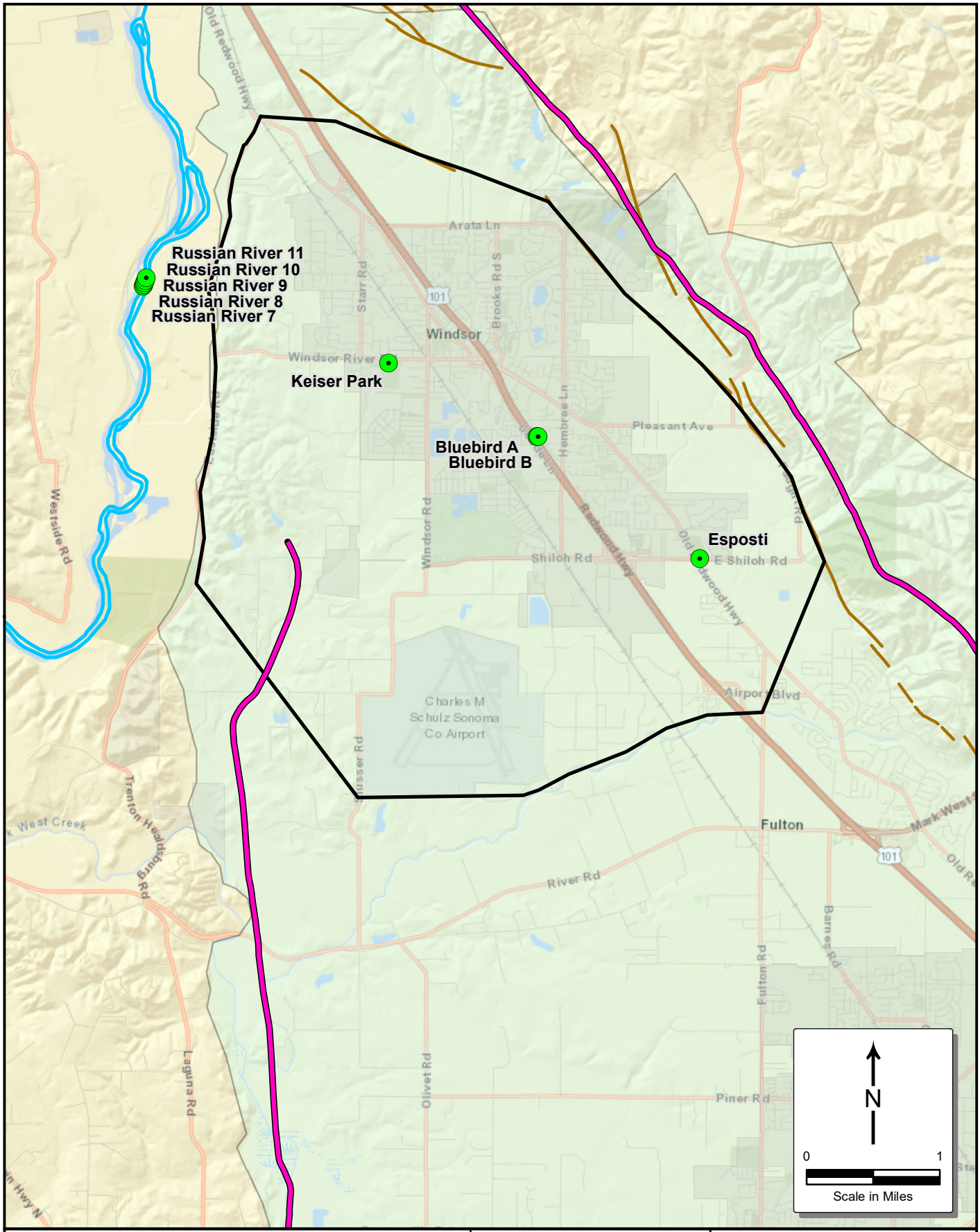
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Municipal Wells
AEM Survey Flight Line
Healdsburg & Rodgers Creek Faults
Town Area
Santa Rosa Plain Groundwater Basin

January 2023

TODD GROUNDWATER

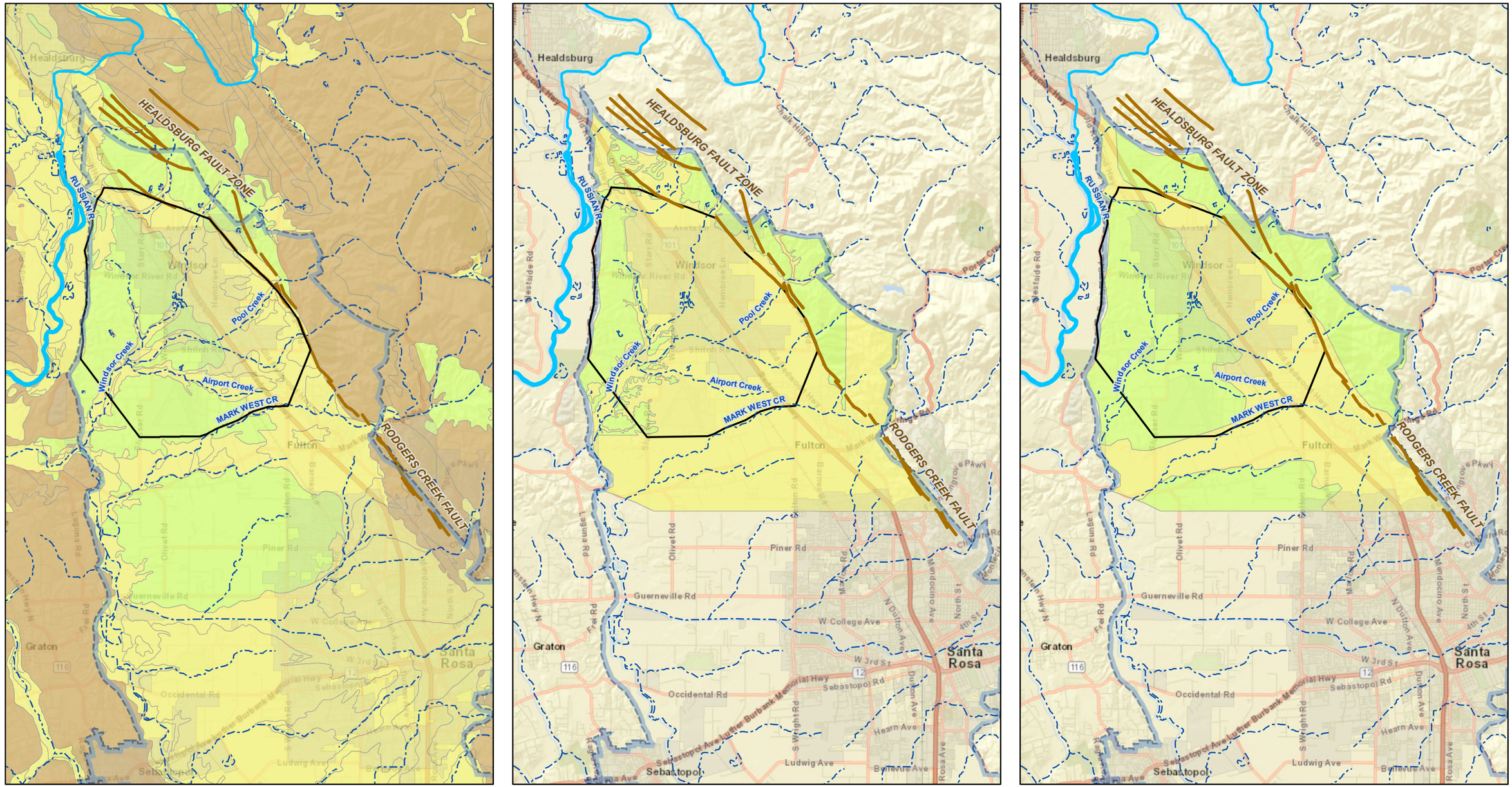
Figure 1
Town Area Boundaries

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A. Wentworth (1997)

B. Delattre (2011)

C. Wentworth and Gutierrez (2017)



Data souces:

Delattre, M.P. 2011. Preliminary geologic map of the Healdsburg 7.5' quadrangle, Sonoma County, California: a digital database. Calfornia Geological Survey. Scale 1:24,000.

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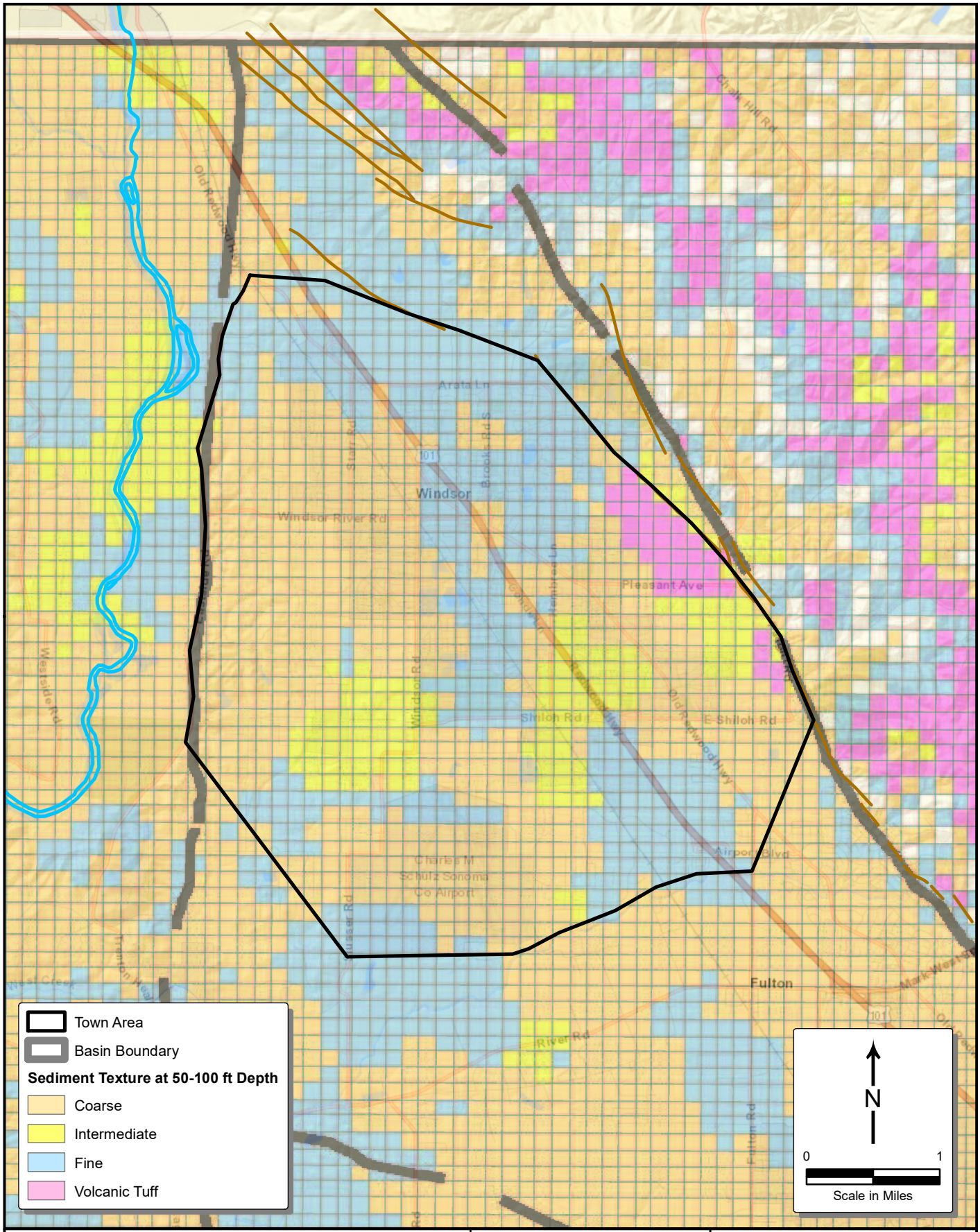
Scale in Miles

N

January 2023

TODD GROUNDWATER

Figure 2
Comparison of Geologic Maps

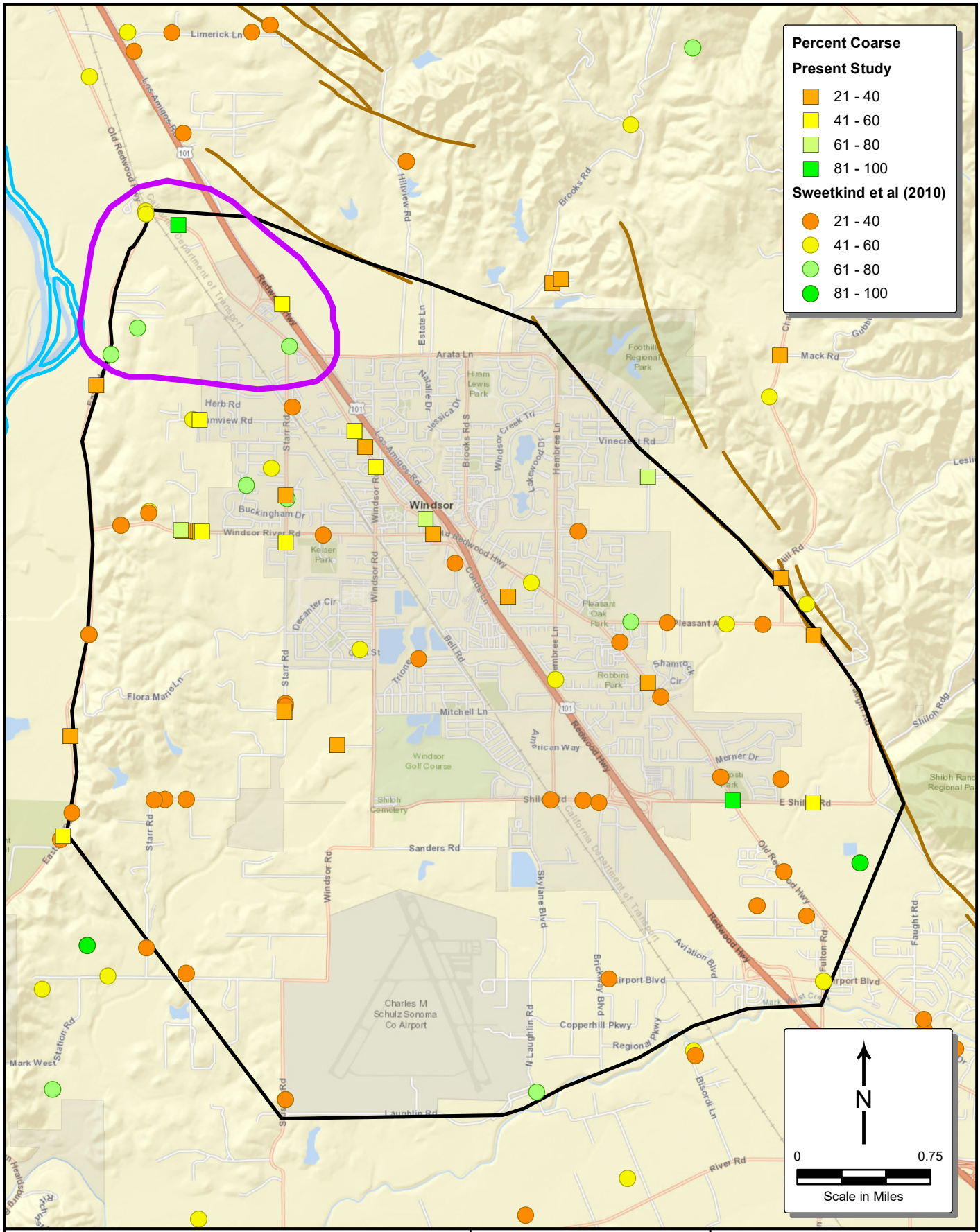


From: Sweetkind, D.S., E.M. Taylor, C.A. McCabe, V.E. Langenheim and R.J. McLaughlin. June 2010.
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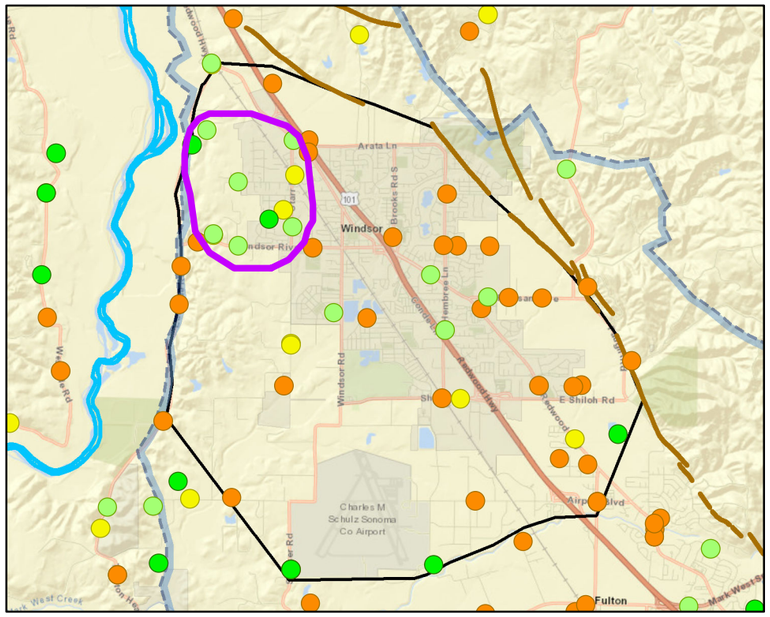
January 2023

TODD GROUNDWATER

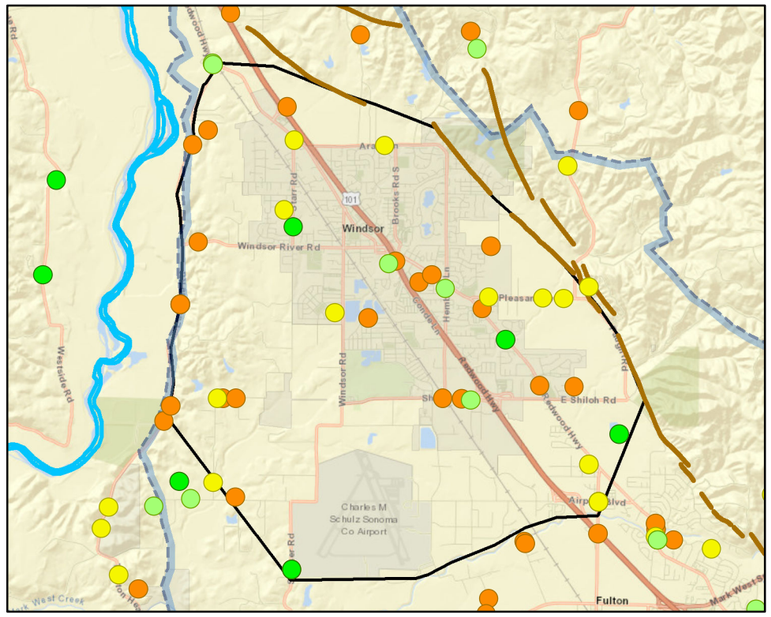
Figure 3
Gridded Texture for 50-100 Foot Depth Interval


Percent Coarse
Present Study
21 - 40
41 - 60
61 - 80
81 - 100
Sweetkind et al (2010)
21 - 40
41 - 60
61 - 80
81 - 100
Windsor
Arata Ln
Limerick Ln
Herb Rd
Buckingham Dr
Windsor River Rd
Keiser Park
Starr Rd
Windsor Rd
Los Amigos Rd
Old Redwood Hwy
Redwood Hwy
Brooks Rd
Hillview Rd
Estate Ln
Natalie Dr
Jessica Dr
Brooks Rd S
Windsor Creek Trl
Lakewood Dr
Hembree Ln
Vineyard Rd
Foothill Regional Park
Hiram Lewis Park
Mack Rd
Conde Ln
Decanter Cir
Bell Rd
Trione St
Pleasant Oak Park
Robbins Park
Shamrock Cir
Flora Marie Ln
Mitchell Ln
Windsor Golf Course
American Way
Merner Dr
Shiloh Cemetery
Shiloh Rd
E Shiloh Rd
Sanders Rd
Skylane Blvd
Aviation Blvd
Airport Blvd
Fulton Rd
Faught Rd
Brickway Blvd
Copperhill Pkwy
Regional Pkwy
N Laughlin Rd
Charles M Schulz Sonoma Co Airport
Laughlin Rd
Mark West
Station Rd
Bisordi Ln
River Rd
Shiloh Ranch Regional Park
N
0
0.75
Scale in Miles
Town Area
Russian River
Healdsburg & Rodgers Creek Faults
January 2023
TODD GROUNDWATER
Figure 4
Percent Coarse Sediment in 50-200 Foot Depth Interval
Document Path: \\todd-file\data\Projects\Windsor Plan and Well 8120\2\GIS\Maps\Figures\Fig_04 Percent_coarse_50-200ft.mxd

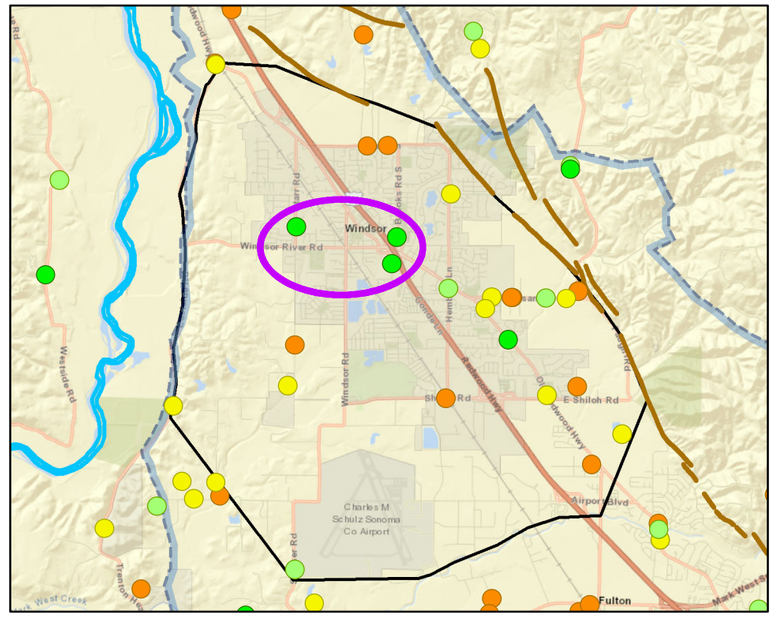
A. 50-150 Feet Below Ground Surface



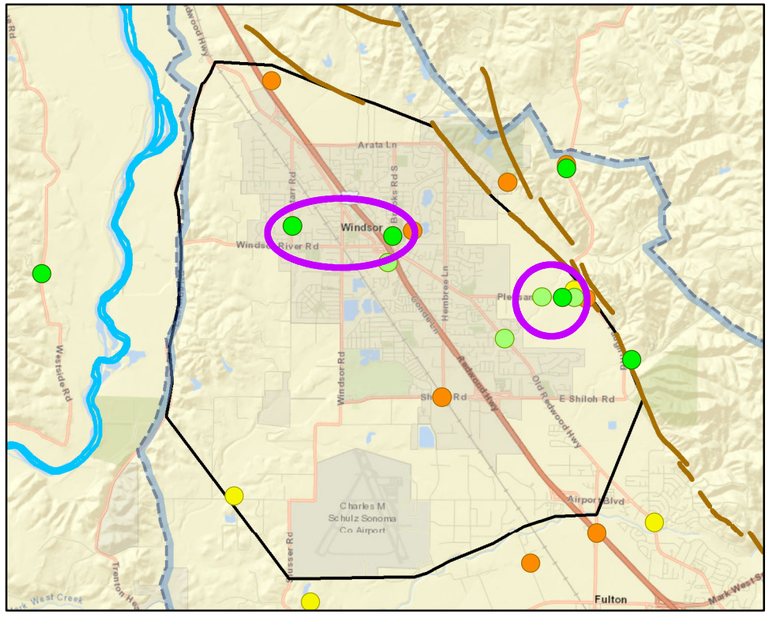
B. 150-250 Feet Below Ground Surface



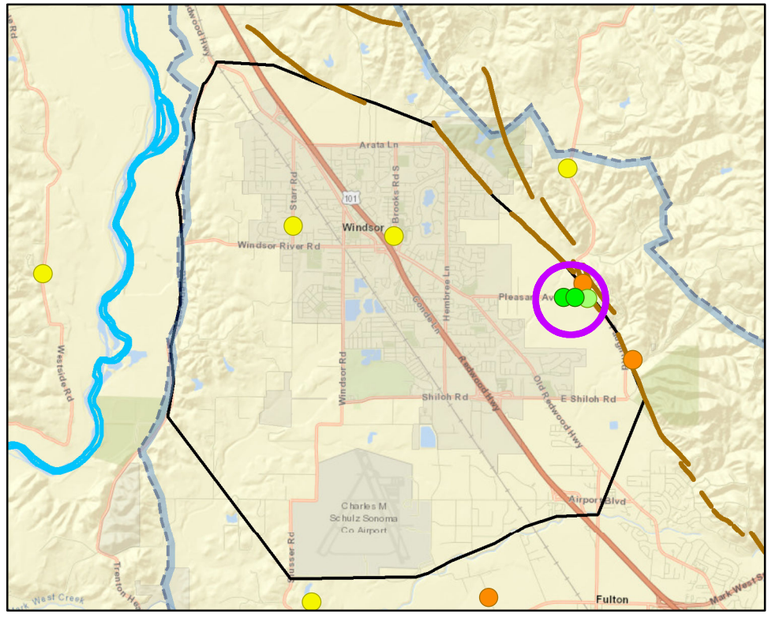
C. 250-350 Feet Below Ground Surface



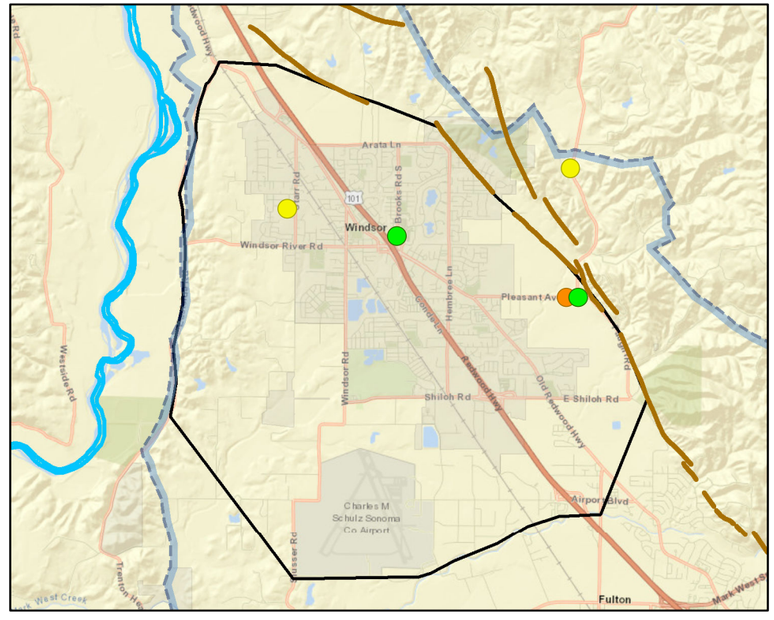
D. 350-450 Feet Below Ground Surface



E. 450-550 Feet Below Ground Surface



F. 550-650 Feet Below Ground Surface



Percent Coarse
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100

- Russian River
- Healdsburg & Rodgers Creek Faults
- Santa Rosa Plain Groundwater Basin
- Town Area

Area with realtively abundant coarse material.

Data source: Sweetkind and others (2010).

0 1.5
Scale in Miles

N

January 2023

TODD GROUNDWATER

Figure 5
Percent Coarse Material in 100-Foot Depth Intervals

APPENDIX C

Groundwater Quality Sampling and Evaluation

Appendix C: Groundwater Quality Sampling and Evaluation

INTRODUCTION

Elevated concentrations of naturally occurring arsenic and manganese in groundwater pose a major hurdle to adding off-river wells to the water supply for the Town of Windsor (Town). The Town's potable water supply presently derives entirely from surface and underflow of the Russian River. Since the early 2000s, the Town has been investigating options for construction of municipal supply wells in the Town area, east of the river alluvium. Arsenic concentrations in the Town area commonly exceed the primary maximum contaminant level (MCL) for drinking water of 10 micrograms per liter (µg/L). Manganese concentrations commonly exceed the secondary MCL of 50 µg/L.

Historical data for arsenic in groundwater were compiled in a previous study (Woodard & Curran, 2019) and revealed that available data were sparse. Additional sampling of existing wells was done for the Groundwater Master Plan project to increase the density of data and hopefully indicate regions where arsenic was generally low. In addition, two exploratory boreholes were drilled in the northwest part of Windsor (at the Herb Rd. and Arata Ln. sites), and groundwater quality was sampled at discrete depths. This appendix combines the historical data, the new sampling of existing wells and zonal sampling data from the exploratory boreholes into a comprehensive evaluation of the geographic and vertical distribution of arsenic in the groundwater basin. The study focused on groundwater conditions in the area roughly bounded by Faught and Chalk Hill Roads to the east, Mark West Creek to the south, Eastside Road to the west and Town Limits near Arata Lane to the north, as shown in **Figure 1**. This region is referred to as the "Town area" in this appendix.

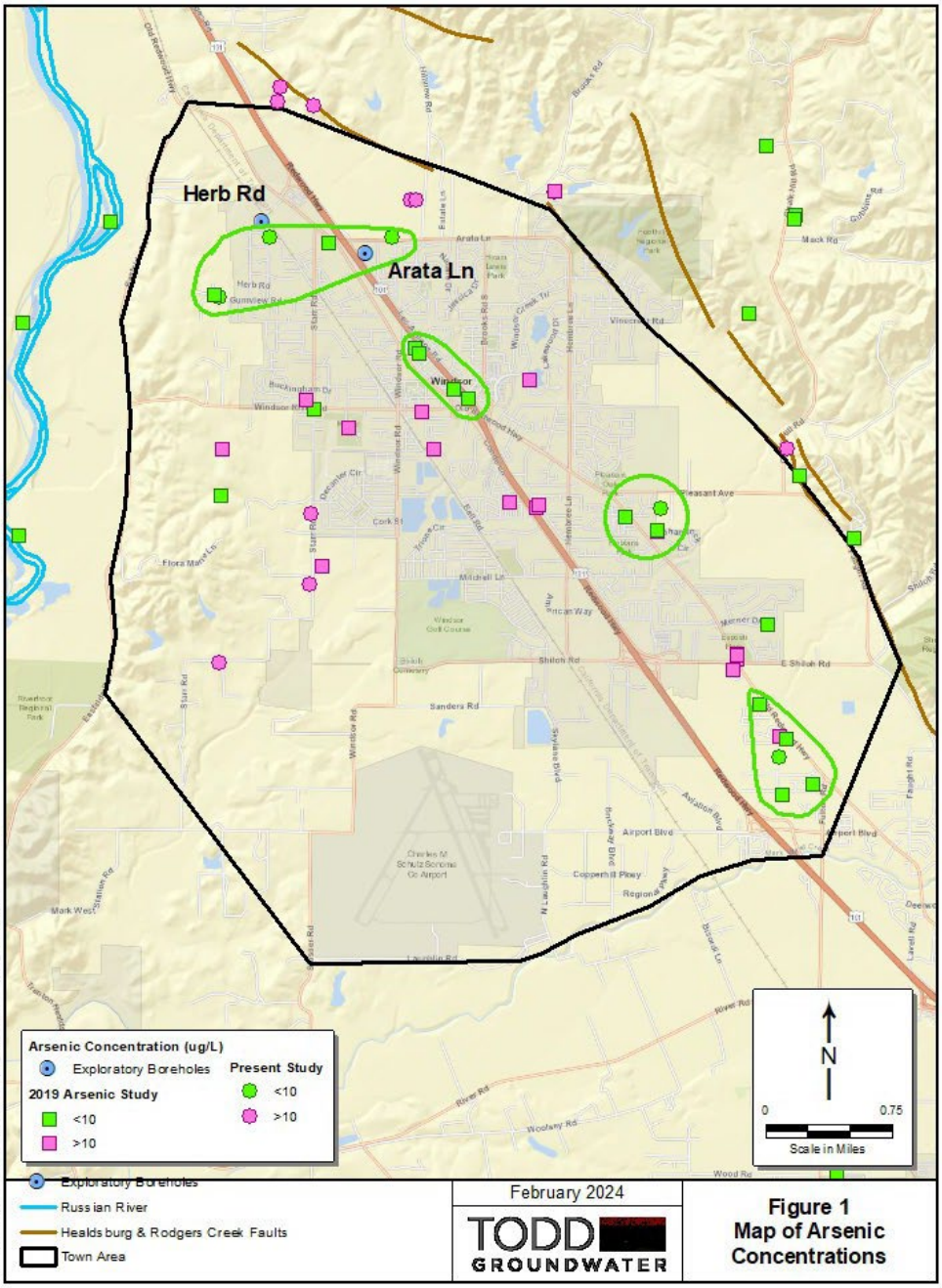


Figure 1. Map of Arsenic Concentrations in Groundwater

ARSENIC CONCENTRATION IN GROUNDWATER

High arsenic and manganese concentrations are the greatest constraints to municipal use of groundwater in the Town area because of the high cost of treatment. The two metals are chemically similar in many respects, and a single treatment process can remove both of them. Because arsenic is regulated under primary (health-based) drinking water standards, most of the focus here is on arsenic. Manganese is regulated under secondary (aesthetics-based) drinking water standards. However, concentrations are commonly several times greater than the MCL, and treatment is highly desirable.

Woodard & Curran (2019) compiled measurements of arsenic in groundwater from a number of public databases and found data for 317 wells or well screen intervals near Windsor that were sampled during 2000-2018. The number of measurements for each well or screened interval ranged from 1 to 17. A figure in that report showed a map of concentrations at 34 well locations covering 67 screened intervals in total and classified each as either above or below the MCL for drinking water of 10 µg/L. The arsenic database was obtained from Woodard & Curran for this study so that the historical data could be combined with data collected for the present study.

Sampling of Existing Wells

Existing wells were sampled for arsenic for the present study in two phases. The first focused on the Arata Lane area and the second covered the remainder of the Town area. For both phases, a list of candidate wells was prepared by selecting well completion reports with reasonably accurate location information (street address or clear location sketch), at least 100 feet deep, with detailed construction and lithology information and located in or near the Town's water distribution system. Addresses of the current owners of the parcels on which the wells were located were obtained from public agency records, and letters were sent to the owners inviting them to participate in the water quality survey. Of 42 well owners in the Arata Lane area, owners of only five wells chose to participate. In the rest of the Town area, letters were sent to the owners of 135 candidate wells, of whom ten opted to participate. A sample of the invitation is included in **Exhibit A**.

The Arata Lane wells were sampled on September 20-21, 2022 and the rest of the wells were sampled on November 17-18, 2022. Water quality parameters measured at the time of sampling included water temperature, electrical conductivity, oxidation-reduction potential (ORP) and pH. Samples were sent to Alpha Analytical Laboratories, Inc. in Ukiah, where they were measured for concentrations of arsenic, iron, manganese, and nitrate, for comparison to drinking water standards. In addition, other water quality constituents were measured that could affect the recommended method and probable cost of treating the water to remove arsenic. These included silica, calcium, magnesium, vanadium, alkalinity (all types), total dissolved solids, total organic carbon, chloride, sulfate, fluoride, and phosphate. The results of the sampling are shown in **Exhibit B**.

The arsenic sampling results for the Arata Lane and Town area wells measured for this study were combined with the 2019 arsenic database to prepare a map of arsenic concentration in groundwater. Data for all well depths and dates more recent than 2000 were classified by data source and magnitude (greater or less than the MCL), as shown in **Figure 1**. Although a relatively small number of wells were sampled for the present study, the additional data points started to reveal four regions within the Town area where arsenic is commonly low. Those regions are outlined in green on the map. Each region includes three to five wells where arsenic concentration was less than 10 µg/L. The outlines of the regions are necessarily tentative because of the low density of data points, but they are sufficiently accurate to guide the recommendation of sites for exploratory boreholes. The regions are roughly aligned along a southeast-northwest axis slightly east of the center of the Town area.

Correlation of Arsenic with Well Depth and Other Water Quality Variables

Data from around the United States show that elevated arsenic in groundwater is most commonly associated with sulfide and with ferromanganese oxide minerals, particularly in areas characterized by geothermal water or high evaporation rates in areas with hydrothermal waters (Welch and others, 2000). Of those factors, geothermal water and abundant manganese oxide minerals are present in the Windsor area. Hydrothermal waters are derived from deep within the Earth and move upward into aquifers near the land surface. At the same time recharge from rainfall, stream percolation, irrigation and other anthropogenic sources is usually low in arsenic and enter the aquifers from above, Therefore, it is reasonable to expect that arsenic concentrations in those aquifers would increase with depth and/or temperature. Also, shallow alluvium is more likely than deep deposits to be flushed by recharge from streams and rainfall, which are low in arsenic.

Correlations between arsenic concentration and well depth, water temperature and concentrations of other constituents were investigated as potential tools for finding locations and depths where arsenic concentrations are naturally low. The 2019 arsenic study investigated the relationship of arsenic with depth for three wells where screened intervals were sampled separately: the Bluebird A Well, Esposti Municipal Well and Esposti Irrigation Well (Woodard & Curran, 2019). Data for the two screens in the Bluebird A Well were too similar to demonstrate a trend. Slight correlations of arsenic with depth were visually apparent for the other two wells.

A second approach was used for this study, which was to create a scatterplot of arsenic concentration versus well depth, which is the most commonly available well construction parameter. Well depth is typically about the same depth as the bottom of the lowest well screen. However, this method incorporates inherent variability related to the number and depths of screened intervals above the bottom of the well and uncertainty related to variable rates of flow entering the well from different screened intervals. Nevertheless, if arsenic concentration generally increases with depth, that relationship should be apparent in the scatterplot. The results are shown in **Figure 2** (upper plot). The figure does not indicate any relationship between arsenic concentration and well depth. Collectively, the two approaches for correlating arsenic concentration with well depth show at best a weak

correlation. However, data from the exploratory boreholes described below show distinct variations in arsenic concentration.

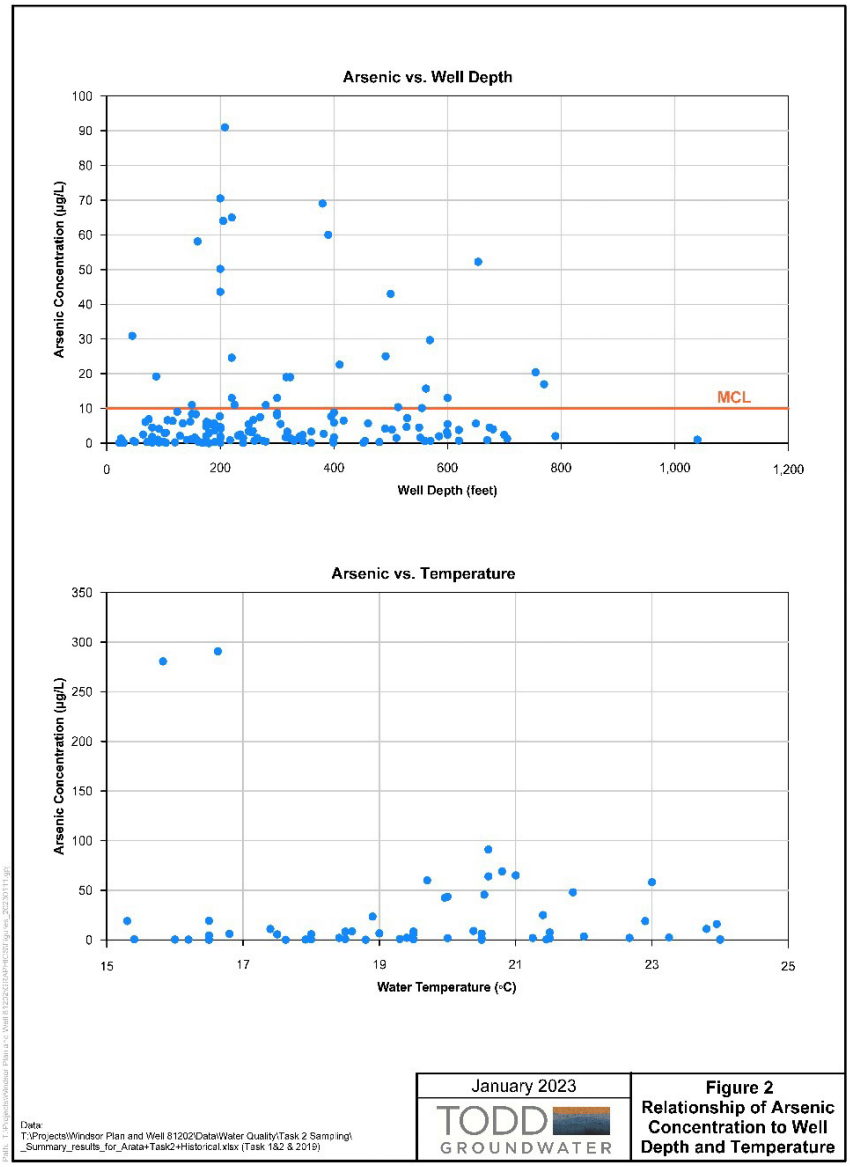


Figure 2. Relationship of Arsenic Concentration to Well Depth and Water Temperature

In contrast, the 2019 database and recent sampling show that elevated arsenic appears to be associated with higher water temperatures. A scatterplot of arsenic concentration versus water temperature for 61 wells is also shown in **Figure 2** (lower plot). Ignoring two obvious outliers, arsenic concentrations greater than 24 µg/L were all in wells with water

temperatures greater than about 19 degrees Celsius (°C), equivalent to 66 degrees Fahrenheit (°F). Groundwater temperature typically increases with depth below the ground surface, so the temperature results should be consistent with the well depth results. It is possible that the lack of apparent correlation between arsenic and well depth stemmed from long screened intervals, which cause well depth to be a poor surrogate for the depth at which water actually enters the well.

Relationships between arsenic concentration, pH, and ORP are shown in the scatterplots in **Figure 3**. The plots show that elevated arsenic concentrations are associated with pH values greater than about 6.8 and ORP values greater than about 45 millivolts (mV). These relationships and thresholds are tentative because few wells had low values of pH or ORP and one had an outlier value of ORP. These results reveal some complexity in the geochemical environment. As a simple ion, one would expect arsenic in solution to be relatively high at high pH and low ORP. Arsenic with a valence of five (As^5) is usually present as arsenic acid, and the negative charge of the acid causes it to bind with positively charged mineral surfaces. At high pH, the increased abundance of hydroxide ions (OH^-) competes for those binding sites and forces some arsenic acid molecules into solution. The Windsor data in the figure appear consistent with this mechanism. Low ORP values tend to reduce As^5 to As^3. If arsenic were present as simple ions, the decrease in the positive charge of the ion would cause some adsorbed arsenic ions to desorb from mineral surfaces and enter into solution, resulting in higher measured concentrations. However, if sulfide is present, low ORP can cause arsenic to precipitate as an arsenic sulfide mineral (e.g. orpiment), thereby decreasing the concentration in solution. Taking the scatterplot data at face value, locations and depth intervals where pH and/or ORP are low might be good candidates for finding low arsenic concentrations.

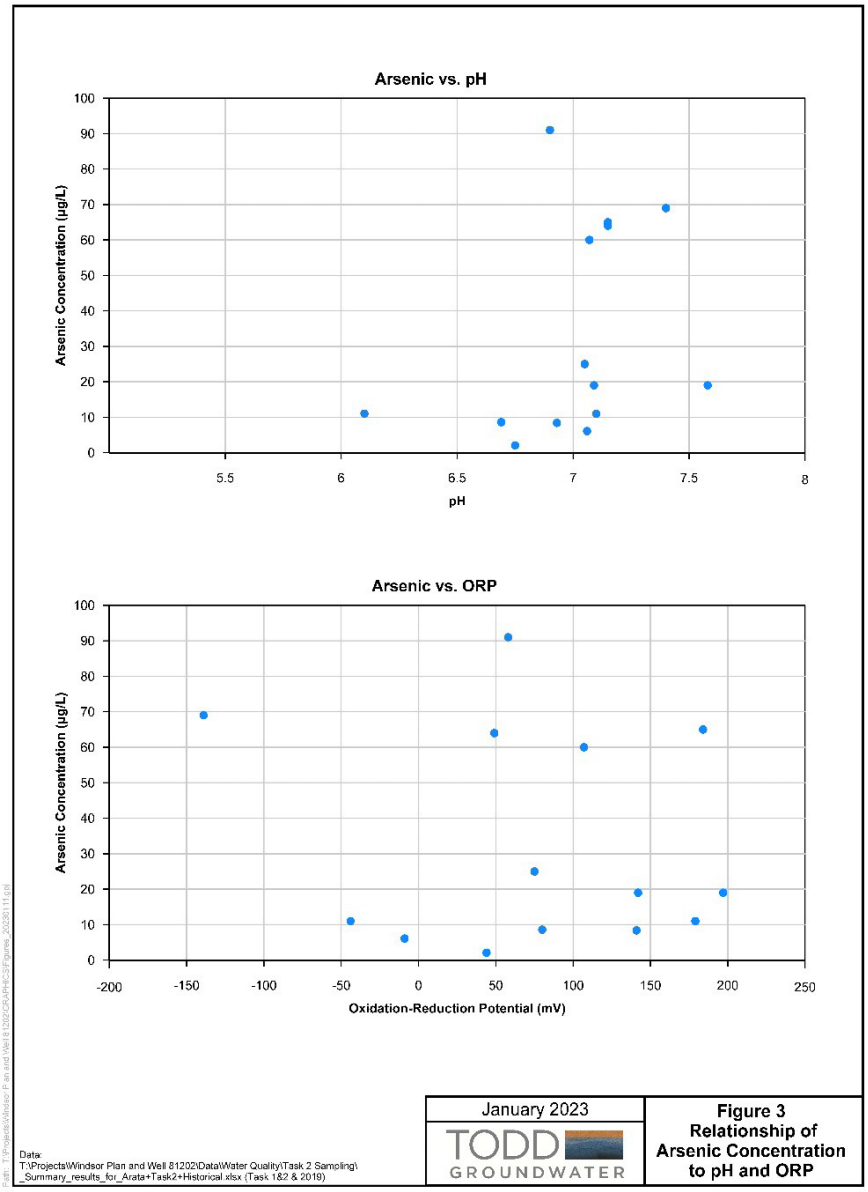


Figure 3. Relationship of Arsenic Concentration to pH and ORP

Zonal sampling of the two exploratory boreholes drilled for the Plan project in 2023 (locations shown on **Figure 1**) showed distinct variations in arsenic and manganese concentration with depth. The data (included in **Exhibit B**) are plotted in **Figure 4**. At both sites, arsenic was lowest in the shallowest zones, at depths less than 215 ft. Arsenic concentrations ranged from 6-34 µg/L. The deepest zone at the Herb Rd. site was an exception, but it was in the Sonoma Volcanics and is not representative of groundwater in

the alluvium or Glen Ellen Formation. The shallow zones are probably in the alluvium and the deeper ones (except Herb Rd. zone 1) in the Glen Ellen Formation, although the formations could not be differentiated on the basis of texture. Manganese exhibited less of a pattern with depth. Excluding the deepest Herb Rd. zone, concentrations were 360-890 µg/L, or seven to eighteen times the secondary drinking water MCL.



Figure 4. Exploratory Borehole Arsenic and Manganese versus Depth

Arsenic Speciation

As^{+3} (arsenite) is more toxic than As^{+5} (arsenate)(Gehle, 2009), and the water quality data collected for this study indicate that the arsenic atoms in the water samples are probably As^{+5}. This was inferred from the Eh-pH diagram shown in **Figure 5**. Eh is another measure of electron potential in the solution. Field measurements of ORP can be converted to Eh by adding the difference in potential between the electrode in the multi-meter and the standard hydrogen electrode, which is the basis of Eh values. The Hach Myron L 6P Ultrameter used for this study had a platinum electrode in a KCl solution. At 20 °C (the approximate temperature of most of the samples), the ORP values can be converted to Eh by adding 199 mV. The polygons bounded by red lines in the diagram indicate the arsenic molecule that is stable for that range of Eh-pH combinations. The blue fields indicate molecules with As^{+5}, and the orange fields indicate molecules with As^{+3}. The data points measured in this study all fall within the blue region, where arsenic is in the As^{+5} state.

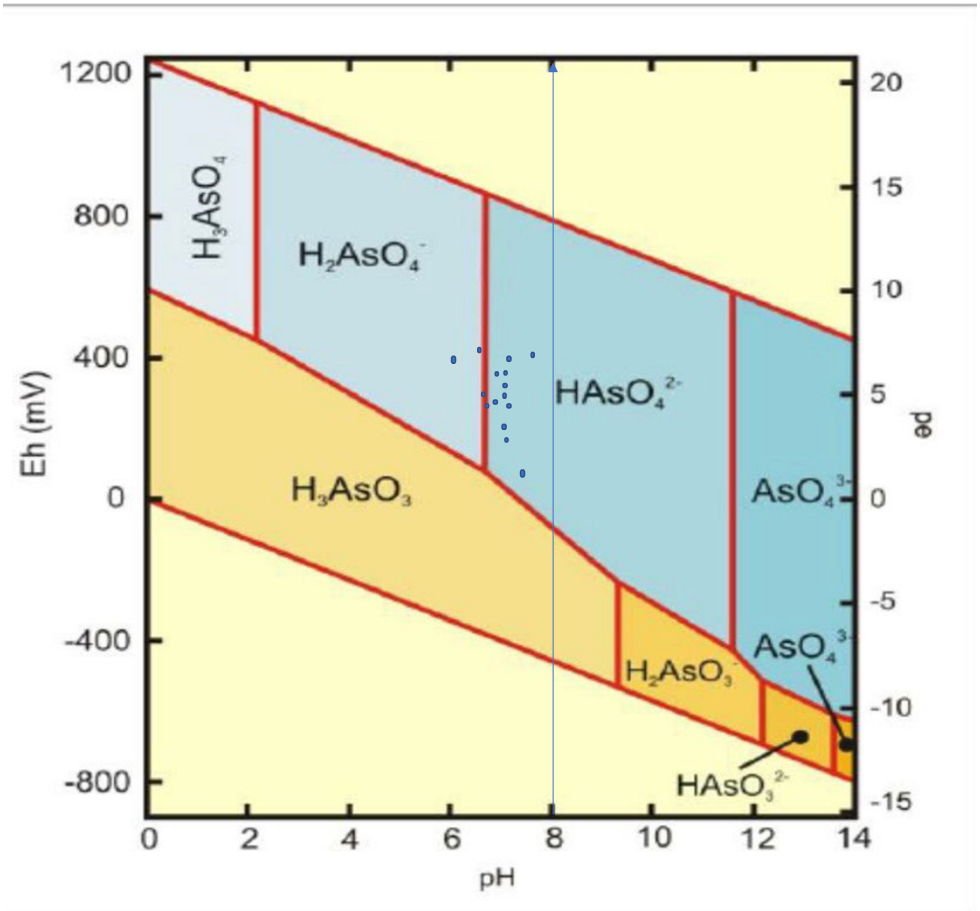


Figure 5. Eh-pH Diagram of Arsenic Samples

SITE SELECTION FOR TEST WELLS

The Herb Rd. and Arata Ln. exploratory borehole sites were selected on the basis of alluvial texture and arsenic concentration. Other factors were also considered, including land ownership, proximity to large water mains in the Town water distribution system and proximity to potential sources of contamination. Data for these additional factors were obtained and added to the maps that indicated potentially favorable texture and arsenic conditions. Candidate test well sites were selected that met four criteria:

1. In an area with relatively abundant coarse material in the subsurface
2. In an area where nearby existing well have relatively low arsenic concentrations
3. On property owned by the Town or other public agency with a usable well site of roughly 100 x 100 feet.
4. Within several hundred feet of a water main 10 inches in diameter or more

The results are shown in **Figure 6**. Polygons outline local areas with relatively abundant coarse material (purple polygons) and relatively low arsenic concentrations (green polygons). Also shown are Town-owned parcels, the alignments of water mains greater than 10 inches in diameter and the locations of sites where contamination of groundwater is known to have occurred. The contamination sites are from the State Water Resources Control Board's Geotracker database and the California Department of Toxic Substances Control's Envirostor database. Many of the sites are closed, which means that remediation has been completed. The ones nearest the candidate well sites were reviewed to see if any are still active.

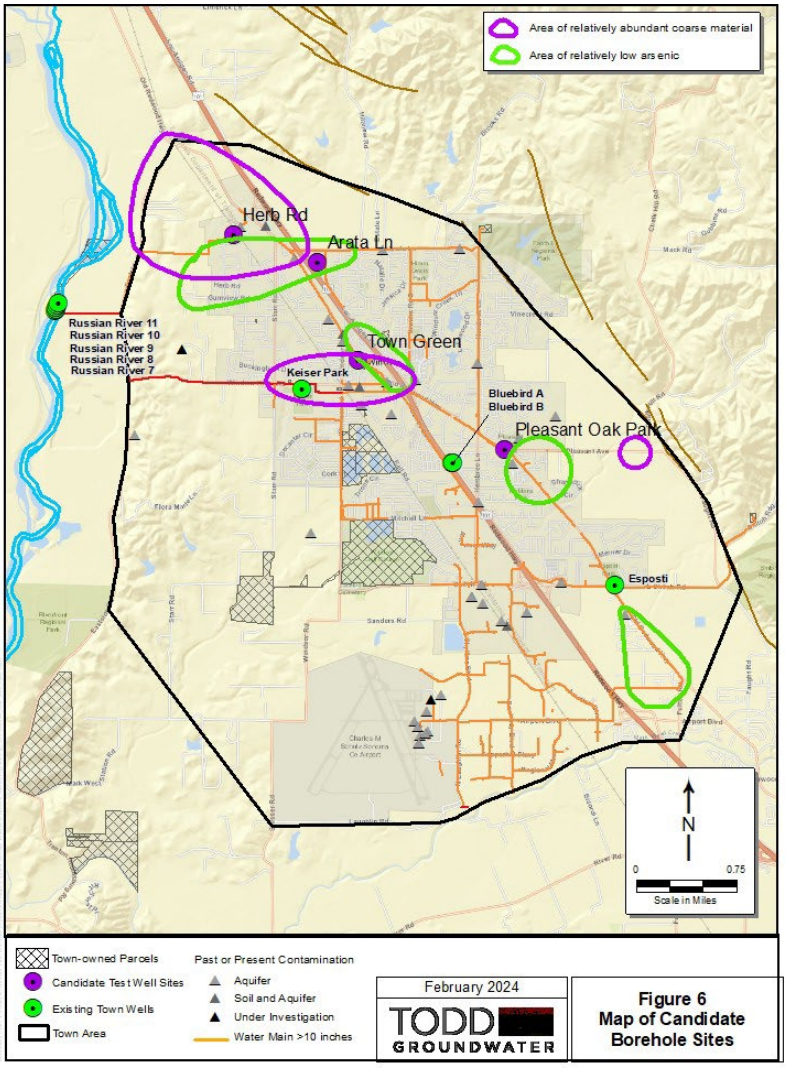


Figure 6. Map of Candidate Sites for Exploratory Boreholes

Candidate test well sites were selected by looking for Town-owned or other publicly-owned parcels in or near the green and purple polygons and also close to a large Town water main. Four candidate sites were identified. Two additional physical site characteristics were explored to see if they might be a basis for preferring some sites over others. One was the average yield of wells near each site. This evaluation was hampered by the small number of wells with yield information. Yield correlated more with the depth and intended use of the well than with its location within the basin. For example, domestic wells have small yield requirements, and wells are typically constructed, tested, and equipped accordingly. A well drilled at the same site but intended for irrigation would likely have a much higher yield achieved by greater depth, longer screened intervals, larger diameter, and larger pumping equipment. The other factor was the depths of the wells with arsenic data near the candidate test well sites. Again, the number of wells near the sites was too small to confirm any differences among the sites, although the three sampled wells near the Herb Rd. and Arata Ln. sites were slightly shallower than sampled wells near the other candidate well sites. The depths of wells with arsenic data ranged from 125 to 300 feet.

Upon reviewing the candidate sites, Town staff raised additional considerations that led to a prioritization of the sites. The Herb Rd. and Arata Ln. sites were considered the most promising sites not only because of favorable arsenic, texture, and contamination conditions but also because private landowners at or near the sites are expected to be agreeable to easements for wells and pipelines. At the Herb Rd. site, the landowner is proposing a development project that would rely on Town infrastructure, and there is an existing easement for the Town's water main across the property. The Town owns the property at the Arata Ln. site, but a pipeline easement would be needed across an adjacent parcel to the north or east to connect the well to the existing water distribution system. The owner of the parcel to the north is also proposing a development project and would likely cooperate with the Town on this water infrastructure project.

The Pleasant Oak Park site received the third-highest ranking and would be the next site to explore if the Herb Rd. and Arata Ln. sites proved not to be favorable or possible. One constraint at Pleasant Oak Park is that the park is designated a "protected area". Vegetation is maintained in a largely natural condition, including a wetland area near the middle of the park. Although a municipal well would not occupy a large footprint once it is completed, the wellhead would likely include a small building, fencing and possibly a chemical storage tank. Those facilities would contrast visually with the natural scenery in the park. The primary issue leading to a low rank for the Town Green site at the civic center is its proximity to groundwater contamination sites. If the recommended well design at that site were relatively shallow to access low-arsenic groundwater, it could potentially draw in groundwater from the nearby contamination sites.

Two other areas were dropped from consideration during preliminary phases of the site selection process. The purple circled area at the east end of Pleasant Avenue (near the eastern edge of the Town area in Figure 6) has favorable texture conditions, but no arsenic data are available in the immediate area. In addition, there would be a large cost for a 1.2-mile pipeline, and the Town would have to find a private landowner who would agree to

provide a well lot. The green-circled area near the southeast corner of Figure 6 does not have any nearby Town-owned or publicly owned property suitable for a well site. The prospects of obtaining a well lot from a private landowner in that area are unknown.

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Exhibit A. Example Well Sampling Invitation Letter

TOWSOF.
WINDSOR

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Mayor
Sam Salmon

Vice?\1...1yor
Esther Lemus

Councilmember District 3
Debora Fudge

Councilmember
Rosa Reynoza

Councilmember
Mike Wall

Town IV.fnn;1ger
Jon Davis

October 6, 2022

Name
Address
Address

RE: Free Well Water Testing by the Town of Windsor

Dear Name:

The Town of Windsor is offering to test your well water free of charge. The Town of Windsor has begun a study of arsenic levels in groundwater, which are known to be relatively high in some parts of Windsor. This information is imJX)rtant to understand groundwater quality patterns and will be used to prepare a Groundwater Master Plan for the Town. The information will not be used to regulate groundwater pumping or your use of water from your well.

The purpose of this letter is to request the collection of a raw (untreated) groundwater sample from your well by our consultant. The Town has contracted the consultant GHD Inc. (GHD) of Santa Rosa to identify and conduct well sampling this fall and would greatly appreciate your help in this effort by allowing GHD to sample your well. We will be sampling the first 10 well owners who respond in each of several areas, so please dont hesitate to call soon.

It would be a one-time sampling event, coordinated with you on a weekday, at your convenience. It is expected to take approximately 15-30 minutes for GHD to collect the water sample. The samples will be sent to a laboratory for analysis and results will be provided to you at no cost within a couple of weeks.

Elizabeth Cargay is an Environmental Program Manager for the Town of Windsor Public Works Department. Please do not hesitate to call me for further information or to answer any questions.

When ready to participate in this one-time sampling event of your well water, please contact Ryan Crawford, with GHD, at (707) 496-8070 or ryan crawford@ghd com, and he will schedule the sampling.

Thank you for your time and willingness to assist us with this important study.

Sincerely,

Town of Windsor

Elizabeth A Cargay

Elizabeth A. Cargay, PG
Environmental Program Manager

GHD Inc.

Ryan Crawford

Ryan Crawford
Senior Hydrogeologist/ Project Manager

Exhibit B. Water Quality Data

Table 1. Groundwater Quality Samples Collected for Groundwater Master Plan

Well ID	Latitude	Longitude	Sample Date	Lab ID	pH	Temperature (°C)	Specific Conductance (µS/cm)	ORP (mV)	Total Dissolved Solids (mg/L)	DWR_ID	Depth to Top of Perforations (ft)	Well Depth (ft)	Well Diameter (inches)	Well Capacity (gpm)	Arsenic (µg/L)	Manganese (µg/L)	Total Dissolved Solids Lab (mg/L)	Iron (µg/L)	Nitreate NO3-N (mg/L)	Silica SiO_2 (mg/L)	Calcium (mg/L)
365 ARATA	38.562092	-122.817573	9/20/2022	22I2709	6.75	19.4	369	44	245	61291		129	6	10	2.1	760	270	<100	2.1	85	11
10491 HILLVIEW-DOM	38.56528	-122.815588	9/20/2022	22I2683	7.05	21.4	303	75	197	993697		491	8	50	25	370	220	1,400	2.2	91	8.9
10555 HILLVIEW-IRR	38.565311	-122.815032	9/20/2022	22I2669	6.9	20.6	420	58	281			208	6	300-400+	91	1,400	270	220	<0.4	87	24
11160 LOS AMIGOS-DOM	38.5734	-122.826333	9/20/2022	22I2692	7.07	19.7	362	107	240	312294		390	6	20	60	1,700	250	<100	0	86	23
11160 LOS AMIGOS-IRR	38.573667	-122.830289	9/20/2022	22I2697	7.10	23.8	340	-44	222			150	8	50	11	330	200	310	1.2	47	17
8555 Starr Rd	38.538229	-122.826254	11/18/2022	22K3441-01	7.15	20.6	321	49	202	WCR2016-016876	182	205	5	25	64	990	220	<100	<0.4	79	12
10300 Brooks Bow	38.566091	-122.799941	11/18/2022	22K3445-01	6.10	17.4	298	179	187	e0144500		225	6	25	11	<20	250	<100	2.2	90	13
8270 Chalk Hill	38.544175	-122.774181	11/18/2022	22K3446-01	7.09	22.9	401	142	253	WCR2003-002311	169	316	5	5	19	610	260	<100	<0.4	80	14
6900 Starr Rd	38.525347	-122.836184	11/18/2022	22K3448-01	7.15	21.0	915	184	590	WCR2018-003310	95	220	5	15	65	36	570	<100	5.1	71	44
8025 Starr Rd #1	38.532116	-122.826312	11/17/2022	22K3450-01	7.40	20.8	364	-139	229	WCR2001-006368	80	380	6	~5-10	69	820	240	350	ND	77	14
11180 Los Amigos Rd	38.574906	-122.830048	11/17/2022	22K3443-01	7.58	15.3	468	197	301	WCR0160187	283	323	6	25+	19	560	310	370	<0.4	82	27
10216 Herb Rd	38.561948	-122.830959	11/18/2022	22K3442-01	6.60	15.8	481	207	309	WCR1978-001079	85	125	6	15	2.1	760	270	<100	2.1	54	22
1390 Gumview Rd	38.556785	-122.836444	11/17/2022	22K3440-01	6.93	19.5	771	141	445	WCR2003-002406	65	150	6	15	8.4	<20	510	<100	3.9	60	37
6557 Emmerson St	38.538953	-122.787884	11/17/2022	22K3452-01	6.69	18.6	304	80	191	WCR2014-015503	60	300	4	5	8.6	560	230	<100	2.2	88	8.8
5528 Kay Dr	38.517682	-122.774789	11/17/2022	22K3449-01	7.06	16.8	373	-9	236	WCR2022-001798	76	176	5	~10	6.1	840	260	<100	2.3	78	16
Herb Rd Zone 1	38.563325	-122.831801	8/17/2023	23H3323-01	6.48	n.m.	540	n.m.	354			470	6	n.a.	ND	77	340	1,900	ND	63	11
Herb Rd Zone 2	38.563325	-122.831801	8/25/2023	23H3966-01	7.4	n.m.	421	n.m.	272			320	6	n.a.	150	700	250	140	0.2	87	15
Herb Rd Zone 3	38.563325	-122.831801	8/30/2023	23H4440-01	6.95	22.2	325	n.m.	212			160	6	n.a.	34	410	190	ND	ND	58	12
Herb Rd Zone 4	38.563325	-122.831801	9/5/2023	23I0514-01	7.63	21.7	447	n.m.	298			110	6	n.a.	12	360	290	56	0.13	61	16
Arata Ln Zone 1	38.560581	-122.820277	9/25/2023	23I3852-01	6.88	n.m.	431	n.m.	282			525	6	n.a.	140	540	300	160	ND	80	13
Arata Ln Zone 2	38.560581	-122.820277	10/2/2023	23J0593-01	7.35	23.5	530	n.m.	350			400	6	n.a.	92	800	290	170	ND	74	16
Arata Ln Zone 3	38.560581	-122.820277	10/5/2023	23J1429-01	8.15	24.1	404	n.m.	266			340	6	n.a.	130	890	280	82	ND	79	16
Arata Ln Zone 4	38.560581	-122.820277	10/11/2023	23J2014-01	8.6	21.4	278	n.m.	180			205	6	n.a.	33	820	210	ND	ND	75	8.9
Arata Ln Zone 5	38.560581	-122.820277	10/13/2023	23J2424-01	8.04	21	330	n.m.	217			135	6	n.a.	6.3	630	210	80	ND	66	7.9

Well ID	Well Depth (ft)	Well Diameter (inches)	Well Capacity (gpm)	Arsenic (µg/L)	Manganese (µg/L)	Total Dissolved Solids Lab (mg/L)	Iron (µg/L)	Nitreate NO3-N (mg/L)	AsMCL	MnMCL	FeMCL	TDS_MCL	NO3-N_MCL	Silica SiO2 (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Vanadium (µg/l)	Chloride (mg/L)	Fluoride (mg/L)	Alk_OH	Total Organic Carbon (mg/L)
365 ARATA	129	6	10	2.1	760	270	<100	2.1	10	50	300	500	10	85	11	20	<20	61	0.14	<5	<1
10491 HILLVIEW-DOM	491	8	50	25	370	220	1,400	2.2	10	50	300	500	10	91	8.9	20	<20	26	<0.1	<5	<1
10555 HILLVIEW-IRR	208	6	300-400+	91	1,400	270	220	<0.4	10	50	300	500	10	87	24	21	<20	15	<0.1	<5	<1
11160 LOS AMIGOS-DOM	390	6	20	60	1,700	250	<100	0	10	50	300	500	10	86	23	20	<20	8.6	<0.1	<5	<1
11160 LOS AMIGOS-IRR	150	8	50	11	330	200	310	1.2	10	50	300	500	10	47	17	18	<20	24	<0.1	<5	<1
8555 Starr Rd	205	5	25	64	990	220	<100	<0.4	10	50	300	500	10	79	12	13	<20	24	<0.1	<5	<1
10300 Brooks Bow	225	6	25	11	<20	250	<100	2.2	10	50	300	500	10	90	13	17	<20	29	<0.1	<5	<1
8270 Chalk Hill	316	5	5	19	610	260	<100	<0.4	10	50	300	500	10	80	14	15	<20	26	<0.1	<5	<1
6900 Starr Rd	220	5	15	65	36	570	<100	5.1	10	50	300	500	10	71	44	42	<20	100	<0.1	<5	<1
8025 Starr Rd #1	380	6	~5-10	69	820	240	350	ND	10	50	300	500	10	77	14	13	<20	38	<0.1	<5	<1
11180 Los Amigos Rd	323	6	25+	19	560	310	370	<0.4	10	50	300	500	10	82	27	21	<20	18	<0.1	<5	<1
10216 Herb Rd	125	6	15	2.1	760	270	<100	2.1	10	50	300	500	10	54	22	20	<20	61	0.14	<5	<1
1390 Gumview Rd	150	6	15	8.4	<20	510	<100	3.9	10	50	300	500	10	60	37	43	<20	92	<0.1	<5	<1
6557 Emmerson St	300	4	5	8.6	560	230	<100	2.2	10	50	300	500	10	88	8.8	20	<20	33	<0.1	<5	<1
5528 Kay Dr	176	5	~10	6.1	840	260	<100	2.3	10	50	300	500	10	78	16	18	<20	29	<0.1	<5	<1
Herb Rd Zone 1	n.a.	6	n.a.	ND	77	340	1,900	ND	0	0	0	0	0	63	11	4.3	ND	15	0.38	0	ND
Herb Rd Zone 2	n.a.	6	n.a.	150	700	250	140	0.2	0	0	0	0	0	87	15	9.6	ND	16	0.08	0	0.50
Herb Rd Zone 3	n.a.	6	n.a.	34	410	190	ND	ND	0	0	0	0	0	58	12	13	ND	25	0.09	0	ND
Herb Rd Zone 4	n.a.	6	n.a.	12	360	290	56	0.13	0	0	0	0	0	61	16	22	6.7	49	0.08	0	0.38
Arata Ln Zone 1	n.a.	6	n.a.	140	540	300	160	ND	0	0	0	0	0	80	13	7.6	ND	15	0.08	0	0.45
Arata Ln Zone 2	n.a.	6	n.a.	92	800	290	170	ND	0	0	0	0	0	74	16	10	ND	17	0.1	0	0.62
Arata Ln Zone 3	n.a.	6	n.a.	130	890	280	82	ND	0	0	0	0	0	79	16	11	ND	16	0.1	0	0.51
Arata Ln Zone 4	n.a.	6	n.a.	33	820	210	ND	ND	0	0	0	0	0	75	8.9	11	ND	16	0.11	0	0.28
Arata Ln Zone 5	n.a.	6	n.a.	6.3	630	210	80	ND	0	0	0	0	0	66	7.9	14	12	38	0.13	0	0.33

APPENDIX D

Preliminary Water Supply Alternatives Analysis

TOWN OF WINDSOR California

GROUNDWATER MASTER PLAN

WATER SUPPLY ALTERNATIVES

May 2023

Trussell

GHD

TODD GROUNDWATER

2490 Mariner Square Loop, Suite 215
Alameda, CA 94501
510.747.6920
www.toddgroundwater.com

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1. INTRODUCTION

A central element of the Groundwater Master Plan is to identify and rank alternative sources of municipal water supply. The Town of Windsor (Town) presently derives almost all its water from surface and underflow of the Russian River, and it is seeking to diversify its water supply portfolio with a focus on the Town area east of the Russian River.

Two wells drilled in the Town area a decade ago have been characterized by arsenic levels exceeding the maximum contaminant level. Arsenic occurs naturally in the region and is commonly detected in wells in Sonoma County, but treatment to remove arsenic is expensive. Due to the cost of arsenic treatment, the Town seeks to fully understand all viable alternatives in the Town Area before moving forward with treatment, and is considering a broader range of conceptual water supply alternatives including: deep extraction wells, shallow extraction wells, groundwater treatment, aquifer storage and recovery (ASR) wells, and indirect potable reuse (IPR)

The water supply objective is essentially a new off-river water supply (~800 gpm) to back up the existing wells along the Russian River. All the conceptual alternatives can satisfy this objective. First, the conceptual alternatives are described generally in terms of technical feasibility, permitting feasibility, and cost. Cost is identified as the major discriminator among the alternatives. It was evaluated at a reconnaissance level and used to rank the alternatives from least to most expensive. Additional technical and permitting considerations are discussed for each of the conceptual water supply alternatives. Given that many of the conceptual alternatives involve pumping of the groundwater basin, discussion also is provided of groundwater basin budgets, basin yield, and climate change. Conclusions and recommendations are provided to meet the objective.

2. STUDY AREA

The study area for this evaluation is referred to as the "Town area" and encompasses the Town of Windsor and surrounding portions of the Santa Rosa Plain Groundwater Basin near Windsor. **Figure 1** shows the locations of existing wells owned by the Town, the alignments of large water mains (10-inch diameter or larger), recycled water mains, Town-owned property and the Town area. Generally, the boundary of the Town area investigated extends from Eastside Road and Highway 101 southeast along the Healdsburg/Rodgers Creek Fault Zone to near Shiloh Road, then south to Mark West Creek, west along the creek and southern edge of the Charles M. Shultz Airport, northwest to Eastside Road and north along Eastside Road to Highway 101. This area is 17.0 mi^2 in size, or 35 percent of the Windsor Subarea of the Santa Rosa Plain Basin as used by the US Geological Survey (Woolfenden and Nishikawa, 2014). The Town area includes three existing Town wells. The Russian River wellfield is about one-half mile to the west.

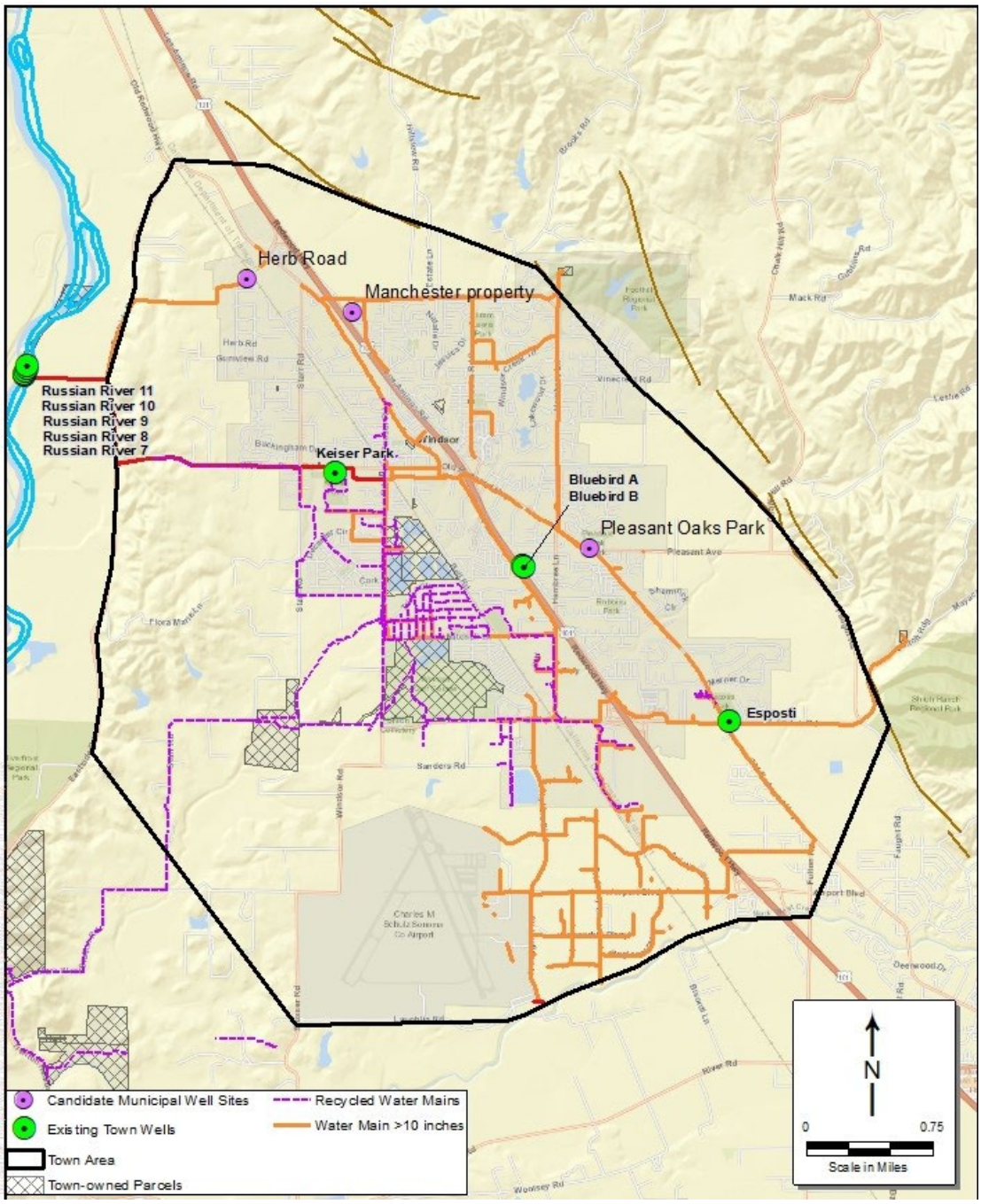


Figure 1. Location of Town Area and Facilities

3. YIELD OBJECTIVE FOR NEW WATER SUPPLY

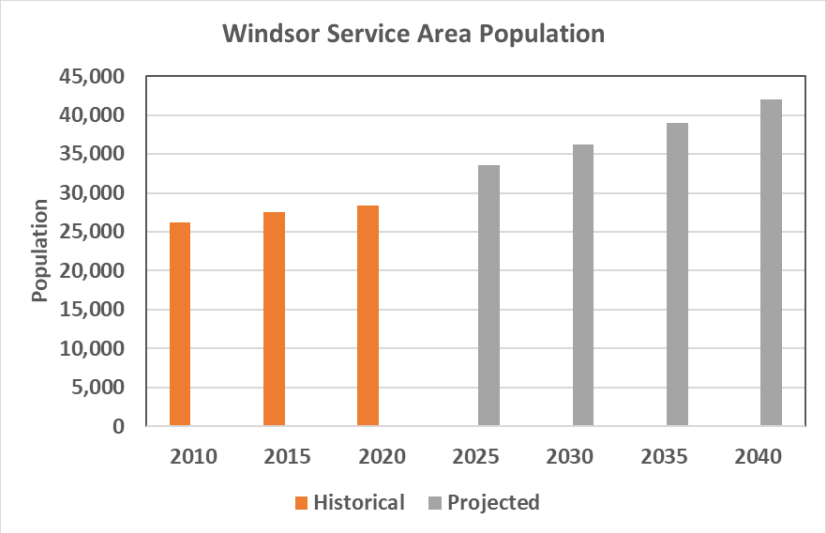
The yield objective for the new water supply can be described in terms of rates or volumes. For brief periods of use, the instantaneous or daily flow rate is most important, and for longer periods of use, the total volume produced is a more relevant metric. The starting point for planning purposes is to develop two sources of water each with a flow rate of 400 gallons per minute (gpm). All of the water supply options considered here involve wells. It is standard practice to operate wells cyclically such that they are pumping on average no more than 50 percent of the time. This allows water levels near the well to recover between pumping cycles and avoids accumulating excessive drawdown. Two 400-gpm wells each operating 50 percent of the time would provide approximately up to 1.8 acre feet (AF) per day, 54 AF per month, 322 AF over a six-month dry season, or 645 AF over a year. For context, total annual water use in the Town service area has been about 3,500 AFY in recent years. If operated all year, the capacity of the new supply would equal about 18 percent of existing water use.

The new water supply is intended to meet short-term needs of various durations, such as:

- Replacement supply for Russian River wells in the event that those wells are temporarily inoperable due to flooding, mechanical failure, contamination, or pipeline failure.
- Supplemental supply during peak demand periods in dry season.
- Supplemental supply during drought years, particularly if mandated pumping reductions are imposed on the Russian River wells.

The new supply is considered a replacement for the original Bluebird and Esposti municipal wells, which had to be removed from service as municipal supply wells when the drinking water standard for arsenic was lowered from 50 µg/L to 10 µg/L in 2001. Replacements for those two wells were drilled in 2010 under a grant, but those also failed to produce water that met the new standard. Efforts to replace those wells or treat the groundwater they produce have continued since 2010, including an evaluation of arsenic and manganese treatment and cost for the Esposti Well (GHD, 2017) and a study of arsenic occurrence in groundwater in the northern Santa Rosa Plain Basin area (Woodard & Curran, 2019a).

The new supply is not intended to provide a new increment of everyday supply to support Town growth, although the 2010, 2015 and 2020 Urban Water Management Plans (UWMPs) all projected future increases in population and water demand in the Town service area. **Figure 2** compares those projections in 5-year increments. The projections from the 2020 UWMP are based on a water demand forecasting study prepared for the Town in 2020 (EKI Environment & Water, Inc. 2020). That study resulted in projected increases in future water demand and also calculated a deficit in potable water during single year and multiyear droughts by 2030. The Town estimates that if 2 off-river wells could be installed by then, and 700 acre-feet of water were added to the system, then during droughts, the water system would be able to balance the sources of water.



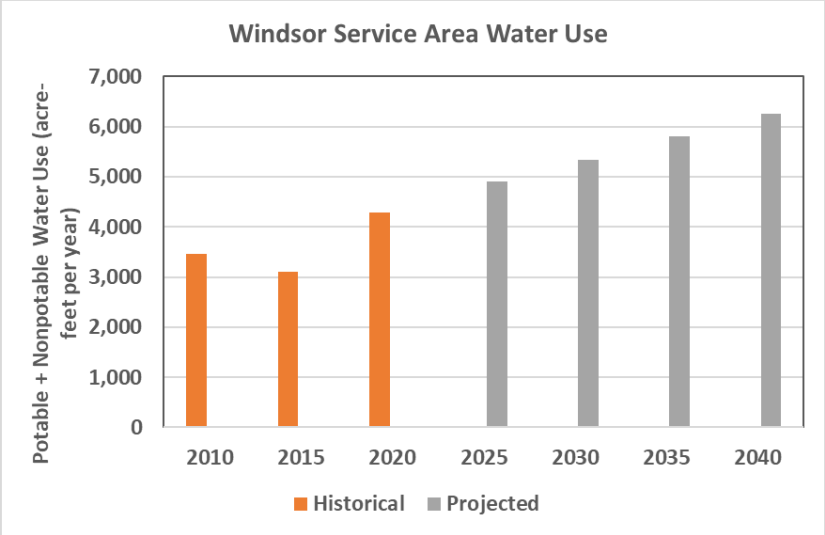


Figure 2. Projected Population and Water Use Trends

4. OVERVIEW OF WATER SUPPLY ALTERNATIVES

At a conceptual level, the water supply alternatives for Windsor consist of combinations of a small number of components, which are: extraction wells (shallow or deep), wellhead treatment of groundwater, injection wells, treatment of water for injection, and a source of supply for injection.

Each component has a cost and requires some level of permitting. Those can vary slightly based on location or site conditions, but the primary differences among the water supply alternatives have to do with which components are needed. In general, the larger the number of components, the greater the cost. The basic components of the water supply alternatives are described below, including rough order of magnitude (class 5) cost estimates and permitting requirements. This is followed by a discussion of specific alternatives and locations in the Town area.

This evaluation focuses on the following conceptual alternatives:

1. Alternative 1: Deep Extraction Wells
2. Alternative 2: Shallow Extraction Wells
3. Alternative 3: Groundwater Treatment
4. Alternative 4: Aquifer Storage and Recovery (ASR) Wells
5. Alternative 5: Indirect Potable Reuse

Several water supply alternatives previously considered by the Town are only briefly considered in this report. Imported water is impractical because there presently is no availability of excess regional water supplies from Sonoma Water facilities for importing water from distant sources besides the Santa Rosa Aqueduct. The Town obtains part of its supply from the Santa Rosa Aqueduct, but that water derives from Russian River underflow and is subject to the same risks of regulatory reduction in availability, contamination, or interruption due to natural disaster or drought as the Town's existing Russian River wells. A new deep extraction well located somewhere near the Russian River was considered but not carried forward for lack of local groundwater yield and quality data. Moving westward across the Russian River floodplain from the Mayacama Mountains east of Windsor, the formation underlying the surficial alluvial deposits transitions from Glen Ellen Formation to Petaluma Formation. The latter is typically too fine-grained to support high-capacity wells (Nishikawa, 2013). Also, the Town would have to convincingly demonstrate that water produced from a deep well near the river is distinct from river underflow and does not deplete underflow, a costly demonstration that would be difficult to prove viable. Another option that was rejected involves treating and recharging some of the recycled water that the Town presently sends to the Geysers geothermal facility. Altering the existing Geysers contract could face political and legal obstacles, and providing the additional treatment necessary to use the water for recharge would be expensive.

4.1. ALTERNATIVE 1: DEEP EXTRACTION WELLS

The Town's target yield of 800 gpm is likely to require two relatively deep wells with long screened intervals. Based on well completion reports for other wells in the area with similar yields, a depth of 400-600 feet (ft) is probably necessary. The estimated cost of Installing a deep extraction well can be broken down by item as shown in **Table 1**.

Table 1. Itemized Capital Cost Estimate for a Deep Municipal Well in Windsor

Cost Item	Central Valley (January 2020)[1]	Windsor 2023
Test hole with five zonal samples	$120,000	$220,000
Production well drilling and construction[2]	$500,000	$430,000
Well development and testing[3]	$120,000	$80,000
Land (1/4 acre)	$150,000	$0
Permitting and CEQA	$85,000	$78,000
Pump & motor (50 HP)[4]	$135,000	$170,100
SCADA equipment[4]	$100,000	$126,000
Electrical upgrades[4]	$440,000	$554,400
Subtotal	$1,650,000	$1,658,500
Engineering, permitting, administration (2	$412,500	$414,625
Subtotal	$2,062,500	$2,073,125
Suburban county cost adjustment (+30%)	$618,750	$621,938
Total	**$2,681,250**	**$2,695,063**

Assumptions: well is 500 ft deep and produces 425 gpm with pumping DTW of 50 ft

[1] SWRCB. 2021. 2021 drinking water cost assessment and gap analysis. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/results_and_methodology_cost_assessment_gap_analysis.pdf

[2] Includes mobilization and demobilization; conductor casing drilling, construction, and materials; pilot borehole drilling and geophysical logging; reaming to 24-inches; and construction of 16-inch diameter well with mild steel casing, stainless steel wire-wrapped screen, dielectric coupler, filter pack, and seal.

[3] Includes development by surging and/or airlifting and overpumping, installation and removal of development/test pump equipment, variable rate aquifer test, constant rate aquifer test, video log, and well disinfection.

[4] Windsor 2023 values estimated to equal 2021 Central Valley values multiplied by a 1.26 Construction Cost Index multiplier for 2021 to 2023.

Most of the estimates in Table 1 are derived from two recent groundwater supply guidance documents for the Central Valley prepared by the State Water Resources Control Board (SWRCB 2020 and 2021). Assumptions and adjustments for Windsor conditions in 2023 are described below:

- Land acquisition - Well sites on land already owned by the Town are obviously preferred, followed by sites owned by other public agencies. Sites on private land could be feasible if the Town has an existing easement or the owner is motivated to

sell a well lot or provide an easement. For ranking purposes, it is assumed that new wells would be drilled on Town property and that land acquisition cost is zero.

- Drilling, constructing and testing a well - This element consists of selecting a driller, mobilizing equipment, drilling to the target depth, logging the well, reaming to the target diameter, installing casing and screen, installing filter pack, developing the well, and testing the well yield and water quality. The costs for these items in Table 1 are based on recent Todd Groundwater experience and subtotal to $730,000.

- Designing and constructing wellhead facilities such as pumps, controls, disinfection equipment and plumbing - The cost estimates for these items in Table 1 are the Central Valley estimates increased by a Construction Cost Index multiplier of 1.26 for price increases from 2021 to 2023 in west coast urban areas. They subtotal $850,500.

- Constructing a pipeline connecting the well to the Town water distribution system - This cost depends entirely on the particular site selected for a new well and consequently is not included in Table 1. The SWRCB guidance document estimated that the cost of constructing a 12-inch PVC water main in 2020 would be approximately $366 per linear foot including design and engineering, permitting, general site work, installation of equipment, start-up testing, administrative, legal and contingency costs. (SWRCB, 2020). Actual construction costs for five sewer or water main pipelines in Sonoma County within the past six years ranged from $203 to $768 per foot in 2022 dollars (Sonoma Water, 2023). These were projects involving a few thousand feet of 6- to 8-inch pipeline. For the purposes of this alternatives analysis, a 2023 pipeline cost of $500 per linear foot is reasonable. The key point is that wells at sites requiring long connecting pipelines would be substantially more expensive than wells located close to existing major distribution system pipelines. Roughly speaking, one mile of pipeline would cost about as much as one 500-foot deep extraction well (both about $2.6 million).

- Permitting and CEQA.

    - A water well permit from Sonoma County Permit & Resource Management Department is required. Associated fees are likely to be $2,000-$3,000. An updated well ordinance adopted by the Sonoma County Board of Supervisors on April 18, 2023, may require an evaluation to ensure the location is not in a Groundwater Availability Area 3 or 4.
    - For CEQA compliance, a mitigated negative declaration is probably adequate. A technical memorandum addressing potential drawdown impacts on nearby wells might be needed as supporting material. Based on recent similar experience, the estimated cost of mitigated negative declaration with supporting technical analysis is about $75,000.
    - The Santa Rosa Plain Groundwater Sustainability Plan (GSP) states that water well permit applications “are required to include hydrogeologic reports to establish that groundwater quality and quantity are adequate

and will not be adversely impacted by the cumulative developments and uses allowed in the area". Groundwater quality and basin yield analyses for the Windsor area are included in this report and might suffice to meet this requirement. Accordingly, no additional cost is expected.

- The GSP also includes minimum thresholds for groundwater levels that seek to maintain groundwater levels above the depths of 98 percent of the wells in the Basin. This is a basin-wide sustainability criterion, not a site-specific criterion (Trotta, 2023). Any potential drawdown impacts on nearby wells would be evaluated in a technical study supporting the mitigated negative declaration.

The 2020 SWRCB guidance document included an adjustment factor to translate costs from the Central Valley to more expensive urban and coastal areas. For Windsor, an increase of 30 percent was indicated, and this was conservatively applied to the estimates in the right-hand column in Table 1. The resulting total estimated cost of installing a 400- to 600-ft deep municipal well in Windsor in 2023 is approximately $2.6 million, excluding pipeline costs.

Operating costs for a municipal well include energy for pumping and disinfection. The energy cost of pumping can be calculated by the following equation:

$$C = 0.746\ Q\ h\ c\ /\ (3960\ \mu_p\ \mu_m)$$

Where,

C = the cost per hour of pump operation ($/hr)
Q = pumping rate in gallons per minute
h = total dynamic head, in feet
c = cost of electricity ($/kWh)
μ_p = motor efficiency (dimensionless)
μ_m = pump efficiency (dimensionless)

Assuming a pumping rate of 400 gpm, a total head of 200 ft (lift to the ground surface plus distribution system pressure), PG&E's current industrial rate of about $0.34/kWh and pump and motor efficiencies of 80 percent, the pumping cost is $8.01/hr. The well produces 24,000 gallons during that hour, which translates to an energy cost of $109 per acre-foot of water produced.

Wells that do not need treatment to remove arsenic and/or manganese will still need to have disinfection. The disinfection-only cost is included as a line item in the discussion of Alternative 3 Groundwater Treatment below.

4.2. ALTERNATIVE 2: SHALLOW EXTRACTION WELLS

Constructing shallow wells involves all of the same cost elements as deep wells. Total well depths would likely be 150 to 400 ft and, relative to a deep well, would intersect fewer aquifer units. Assuming no variation in aquifer properties with depth the yield of a well

would increase with well depth because deeper wells intersect more aquifer units. Therefore, it is assumed for this evaluation that more shallow wells than deep wells would be required to obtain the same yield.

A conservative estimate would be that four shallow wells would be needed to obtain the 800 gpm that two deep wells could produce. Some expenses would not increase in proportion to the number of wells, such as permitting, environmental compliance, design/engineering, and driller mobilization. Other costs would increase more or less proportionately, such as land acquisition, drilling, casing, testing, pumps, controls, other wellhead infrastructure and pipelines. Thus, installing four shallow wells in lieu of two deep wells could only be cost-effective if it avoided the need to treat the produced water for arsenic, manganese or some other constituent or to minimally treat lower levels of arsenic from shallow aquifer zones.

For the purposes of this evaluation, it also is assumed that the four shallow wells are in a well field. However, if the four wells are not spaced sufficiently far apart, drawdown from one well can lower the water levels at the adjacent wells. This “well interference” leads to higher ongoing energy costs for pumping and a need for larger pumps. Assuming reasonable values of pumping rates and aquifer characteristics, two wells 500 feet apart would add several feet of drawdown at the other well after one month of pumping. Site-specific evaluation will be needed of the tradeoffs between well interference (energy costs) and additional costs for pipelines and possibly site acquisition if wells are spaced farther apart. For initial planning purposes, a minimum distance of 500 ft between wells is reasonable.

4.3. ALTERNATIVE 3: GROUNDWATER TREATMENT

Concentrations of arsenic and/or manganese commonly exceed the respective maximum contaminant levels (MCLs) or notification levels (NLs) in groundwater from wells near Windsor. In 2022, water quality samples were collected by GHD from an additional 13 domestic wells and 2 irrigation wells not previously sampled in the Town area. The results were reviewed by Trussell to identify appropriate treatment strategies to meet drinking water standards. Of those 15 wells, one would need no treatment , two would need treatment for arsenic only, one would need treatment for manganese only, and eleven would need treatment for both. All groundwater requires disinfection prior to distribution for potable supply.

Table 2 summarizes water quality and treatment requirements at the 15 sampled wells**.** These sites are used in this section as a representative sample of groundwater quality in the Town area. None of them are proposed as municipal well sites. Reactivation of the Esposti Supply well was previously considered (Trussell 2022) and is not repeated here. Treatment for that well would be costly due to challenging water quality and relatively high arsenic and manganese concentrations.

Table 2 –Water Quality and Treatment Requirements for Sampled Well Sites in 2022

Well Location	As (µg/L)[a]	Mn (µg/L)[a]	Arsenic Treatment	Manganese Treatment
365 Arata Ln.	2.1	760		X
10491 Hillview Rd. (DOM)	25	370	X	X
10555 Hillview Rd. (IRR)	91	1400	X	X
11160 Los Amigos Rd. (DOM)	60	1700	X	X
11160 Los Amigos Rd. (IRR)	11	330	X	X
8555 Starr Rd.	64	990	X	X
10300 Brooks Rd.	11	<20	X	
8270 Chalk Hill Ln.	19	610	X	X
6900 Starr Rd.	65	36	X	X
8025 Starr Rd.	69	820	X	X
11180 Los Amigos Rd.	19	560	X	X
10216 Herb Rd.	ND	ND		
1390 Gumview Rd.[b]	8.4	<20	X	
6557 Emmerson St.[b]	8.6	560	X	X
5528 Kay Dr.[b]	6.1	840	X	X

a) Red indicates exceedance of the MCL or NL for arsenic and manganese, respectively. Green indicates compliance.
b) Arsenic treatment included to provide safety factor of at least 2.
Safety Factor = MCL ÷ Acceptable Concentration
c) DOM: Domestic Well. IRR: Irrigation Well

4.3.1. Manganese Update

Guidelines for health-based advisory levels for manganese have recently been updated by the California Division of Drinking Water (DDW). On February 16, 2023, DDW proposed a revised manganese notification level (NL) of 20 µg/L (currently 500 µg/L) and response level (RL) of 200 µg/L (currently 5 mg/L), based on toxicological endpoints. NLs are health-based advisory levels established by DDW for chemicals in drinking water that lack MCLs. RLs are the benchmark where DDW recommends removal of a drinking water source from service.

Specific requirements and recommendations apply when chemicals are found at concentrations greater than the respective NL and RL. California state law requires notification to the governing body(s) by drinking water systems within 30 days of a

confirmed detection above the NL and RL in drinking water that is provided to consumers (HSC §116455). For NL exceedances, DDW recommends that the utility inform consumers about the presence of the chemical and health concerns associated with it. For RL exceedances, DDW recommends that the utility take the source out of service.

4.3.2. Treatment Technologies

Treatment technologies to remove arsenic, manganese, and iron from the contaminated wells are discussed in this section. Only treatment technologies suitable for implementation and operation by the Town were considered in this evaluation. Technologies that are infeasible due to footprint requirements or lack of market adoption were not further considered. The following general requirements for the treatment system were considered:

- Operable and maintainable by Town personnel
- Operable without the presence of fulltime staff
- Automated with a supervisory control and data acquisition (SCADA) interface
- Operated with National Sanitation Foundation (NSF) certified chemicals
- Capable of providing 400 gpm of treated water into the Town water distribution system (the steady-state flow of the well)
- Involving acceptable footprint for minimization of impact on the area
- Effective at removing manganese and arsenic to levels below California MCL and NL
- Capable of meeting disinfection and distribution requirements
- Providable by vendors in the region
- Capable of producing water that meets the Town's overall corrosion control strategy. This may require chemical addition (e.g., pH adjustment or a corrosion inhibitor) as the last treatment step prior to distribution.

The most common technologies used for manganese, arsenic and iron removal are described in the Esposti Supply Well Evaluation Technical Memorandum (TM) (Trussell, 2022). The selected technologies that are best suited for the wells in the Town area are 1) manganese catalytic oxidation/filtration, 2) arsenic adsorptive media filtration, 3) and arsenic iron coprecipitation. **Figure 3** provides an overview of the mechanisms of manganese removal, arsenic removal, and arsenic with iron removal.

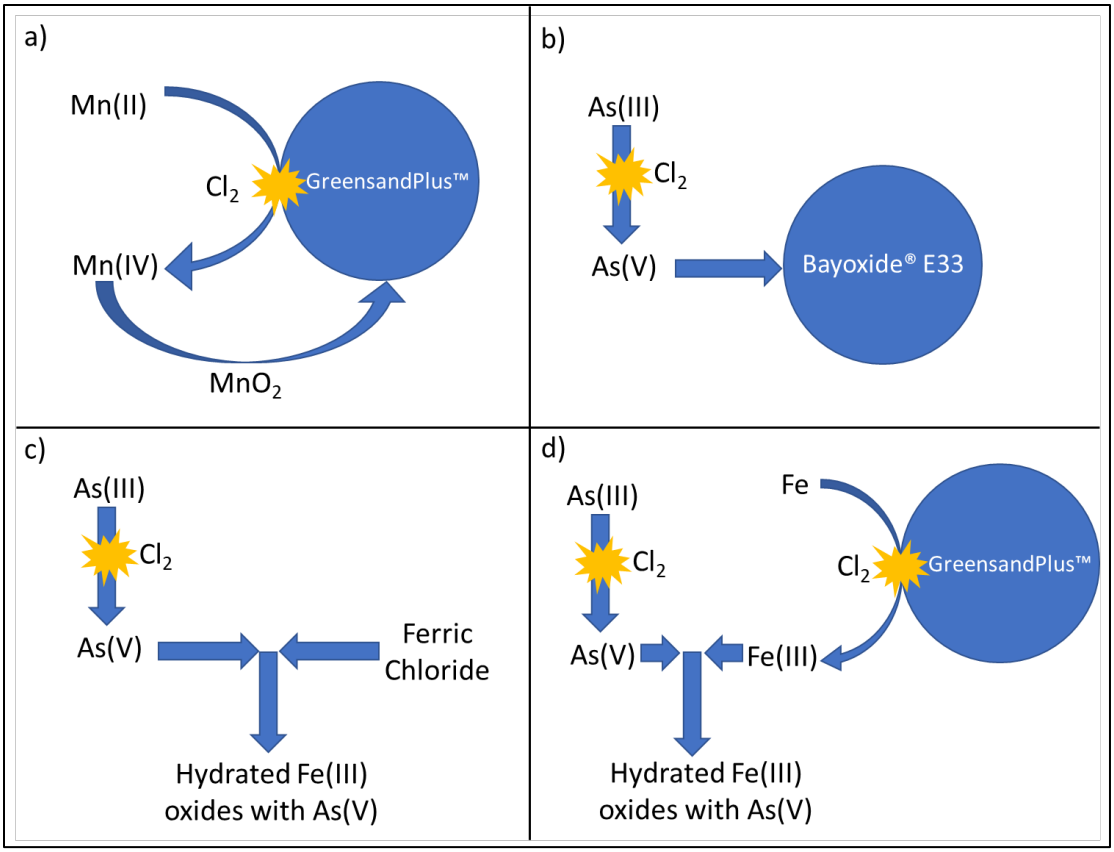


Figure 3. Process Options for Treating Arsenic and Manganese in Water

(a) Manganese catalytic oxidation/filtration, (b) Arsenic adsorptive media filtration, (c) Arsenic enhanced coagulation/filtration, (d) Arsenic iron coprecipitation.

Manganese Removal. Manganese is best removed (to appropriate levels as specified by the proposed NL) by catalytic oxidation/filtration, where chemical oxidation is achieved by free chlorine and manganese dioxide coated media, which acts as a catalyst for the oxidation reaction. Catalytic oxidation of manganese is appealing for a groundwater treatment system for the Town because it takes advantage of using free chlorine, already used as a primary and secondary disinfectant. The catalyst, a manganese dioxide coated media (commercialized as GreensandPlus™), is capable of oxidizing and filtering the incoming manganese in a pressure vessel. Once oxidized, the manganese will form additional manganese dioxide coating on the media when using free chlorine. Chemical oxidation is a form of pretreatment that varies based on water quality and is discussed in more detail in the water quality section. Another benefit is that the manganese treatment approach does not change if arsenic treatment is included in the treatment train.

Arsenic Removal. The best available arsenic removal technologies are arsenic adsorptive media filtration, arsenic iron coprecipitation, and enhanced coagulation/filtration, as described in the Esposti Supply Well Evaluation TM. These arsenic removal technologies

operate on an iron-based adsorption concept. Iron in its +3-oxidation state has a high affinity for adsorption to arsenic, which allows the arsenic to be removed via filtration or media changeout, depending on the selected technology.

Arsenic adsorptive media is housed in a pressure vessel and arsenic is retained by the media as the water flows through. The arsenic adsorptive media utilizes iron-based sorbents with a high capacity and affinity for arsenic adsorption such as granular ferric oxide (commercialized as Bayoxide® E33) or granular ferric hydroxide (commercialized as Lenntech GEH®). The media is changed out upon sufficient saturation of adsorption sites. Redundancy and vessel configuration are discussed in the "Treatment Train" section.

Arsenic and Iron Removal. GreensandPlus™ was originally developed for manganese and iron removal but has been observed to remove arsenic in waters with high levels of natural iron in a process called coprecipitation. The arsenic iron coprecipitation process relies on oxidizing existing iron in the groundwater to iron (III). Upon oxidation, the insoluble iron (III) is precipitated as hydrated iron (III) oxide and filtered out with arsenic adsorbed to it. Of the ten sampled wells that would require arsenic treatment, eight have insufficient iron for the arsenic/iron coprecipitation process. The United States Environmental Protection Agency (EPA) recommends a minimum 20:1 iron to arsenic mass ratio for effective iron coprecipitation (EPA, 2003). The actual iron to arsenic mass ratio will likely need to be higher based on well water quality and is further discussed in the "Water Quality Impacts on Treatment" section. If there is insufficient iron in the groundwater to achieve the minimum 20:1 iron to arsenic ratio, ferric chloride (commonly used as a coagulant) can be added in a process known as enhanced coagulation/filtration. The ferric chloride will not need to be oxidized and could utilize a less costly filtration media.

The listed arsenic removal technologies are compatible with the selected manganese removal technology. Arsenic adsorptive media filtration, iron coprecipitation, and enhanced coagulation/filtration technologies are further considered for implementation. Pretreatment requirements and water quality effects on treatment processes are discussed in the following section.

4.3.3. Water Quality Impacts on Treatment

Groundwater quality impacts treatment efficiency and efficacy. Some water quality parameters will decrease treatment media lifespan or require an increase of chemical feed rates, which increase operation and maintenance (O&M) costs. Additionally, water quality can affect treatment efficacy and limit the removal of arsenic or manganese. Water quality parameters like pH and oxidation reduction potential can be adjusted to ensure treatment conditions are optimal for the selected treatment technology.

Both arsenic and manganese must be chemically oxidized to facilitate removal, and so chemical oxidant pretreatment is included in all designs. Arsenic and manganese oxidation and speciation chemistry is described in the Esposti Supply Well Evaluation TM (Trussell, 2022). To summarize, oxidation prompts decreased solubility of manganese and induces arsenic charge at natural pH levels.

As discussed in the Esposti Supply Well Evaluation TM, Trussell recommends that the system use free chlorine over alternative oxidants. Free chlorine in the form of sodium hypochlorite must be dosed constantly to oxidize the compounds in the water and to maintain the oxidation-reduction capacity of the manganese dioxide coated media. Sodium hypochlorite should also be added at the beginning of the treatment train to maximize contact time with arsenic and manganese. Oxidant requirements can change based on the presence of interfering reductants and pH. The chlorine should be dosed to exceed stoichiometric oxidant demand for As(III), Mn(II), Fe(II), and H_2S. The system should have a target residual concentration of chlorine and a safety factor to ensure all constituents with oxidant demand are oxidized. The oxidation kinetics, stoichiometric oxidation demand, and presence of site-specific interfering reductants should be considered during the design of the selected treatment system.

Arsenic removal via iron-arsenic adsorption can be inhibited by non-arsenic substances. Phosphate is a compound observed to adsorb to iron oxides and compete with arsenic for these adsorption sites (Strawn 2018). High concentrations of phosphate will decrease the lifespan of arsenic adsorptive media by saturation of adsorption sites, which leads to frequent media changes and the need for an increased empty bed contact time (EBCT). Both impacts increase cost: media changes increase O&M needs and higher EBCT requires larger or more vessels. Similarly, high concentrations of phosphate can decrease the efficacy of enhanced coagulation/filtration by increasing the dose of ferric chloride needed to achieve target arsenic removal levels.

Other adsorption site competitors include chromium, vanadium, and antimony. Silica is not thought to compete for adsorptive sites, but silica indirectly prevents adsorption to sites and inhibits the formation of ferric hydroxide solids. Source water with the highest levels of phosphate and silica have been found to have the lowest media bed volume (BV) treatment capacities.

$$\boldsymbol{BV} = \frac{\boldsymbol{V_L}}{\boldsymbol{V_{AM}}} \qquad \text{(Equation 1)}$$

Where:

V_L = Volume of liquid treated

V_{AM} = Volume of adsorptive media

Iron requirements for coprecipitation treatment increase based on the presence of arsenic adsorption inhibitors. Industry feedback and academic studies on ferric chloride dosage for iron coprecipitation indicate the Fe(III):As(V) ratio may be much higher than the EPA minimum of 20:1 due to silica and phosphate interference (Ware 2013). Some of the Town's candidate well sites have insufficient levels of iron for coprecipitation to occur without supplemental iron addition. Ferric chloride is a typical chemical iron supplement, and its feed rate can be modulated to target a specific dosage needed for treatment.

The pH of the water can impact the effectiveness of the arsenic adsorption process, as it influences iron coagulation when ferric chloride is used. For successful coagulation with ferric chloride, the pH range is about 5 to 8.5. pH can also impact the efficiency of arsenic adsorption filtration. A pH of approximately 7 has been shown to maximize sorption media BV capacity. The optimum pH for iron-based sorbents is typically between 6.5 and 8 and may require adjustment for waters outside this range. The adsorption capacity of the media increases as the water approaches the lower end of the acceptable pH range (Nguyen 2011). The pH range for the candidate wells is 6.1 - 7.58. For this preliminary evaluation, it was assumed that pH adjustment would not be needed.

High levels of total dissolved solids (TDS), hardness, and alkalinity (>1000 mg/L, >350 mg/L, and >400 mg/L as $CaCO_3$, respectively) could solidify the adsorption media. Solidified media will not sufficiently re-stratify during backwash, where the water's flow is reversed in the vessel to remove accumulated particles and fluidize the media. Restratification prevents the formation of channels and voids that result in preferred flow paths. Preferred flow paths decrease the effective EBCT of the vessel and result in premature detection of arsenic in the effluent. This could prompt a media changeout and waste of media with unused treatment capacity. It could also make the media difficult to remove from the vessel and interrupt media changeouts.

Trussell recommends bench-scale and/or pilot-scale testing to confirm the effects of water quality on treatment. Bench-scale testing could better estimate the frequency of replacement of arsenic adsorptive media. Pilot-scale testing is recommended to verify removal efficiencies of arsenic and manganese with GreensandPlus™.

4.3.4. Wells with Favorable Groundwater Quality

Residential wells were sampled in 2022 to evaluate groundwater quality in the Town Area as a key factor in siting a new municipal well. To illustrate potential treatment needs for future municipal wells, Trussell identified wells with the most favorable water quality based on the considerations described in the previous "Water Quality Impacts on Treatment" section. Wells with low levels of arsenic or manganese were prioritized over wells with higher levels. The top three wells are the ones located at 365 Arata Ln, 10216 Herb Rd, and 1390 Gumview Rd. When also considering probable well yields based on alluvial texture, the 1390 Gumview Rd site may not be suitable for an efficient well. Therefore, a potential alternative well site with better aquifer characteristics (6557 Emmerson St.) was also included. **Table 3** summarizes the water quality from these four wells as of 2022.

These four well sites are considered representative of Town Area groundwater quality for planning purposes and do not necessarily represent potential municipal well sites.

Table 3. Sampled Well Sites with Desirable Water Quality

Well ID	365 Arata Ln.	10216 Herb Rd.	1390 Gumview Rd.	6557 Emmerson St.[a]
Date	9/20/22	11/18/22	11/17/22	11/17/22
pH	6.75	6.6	6.93	6.69
Conductivity (Microsiemens/cm)	369	481	771	304
ORP (mV)	44	207	141	80
As (µg/L)	2.1	ND	8.4	8.6
Mn (µg/L)	760	ND	<20	560
TDS (mg/L)	270	270	510	230
Fe (µg/L)	<100	<100	<100	<100
NO_3-N (mg/L)	2.1	2.1	3.9	2.2
SiO_2 (mg/L)	85	54	60	88
Vanadium (µg/L)	<20	<20	<20	<20
Cl (mg/L)	61	61	92	33
F (mg/L)	0.14	0.14	<0.1	<0.1
PO_4 (mg/L)	<0.5	<0.5	<0.5	<0.5
SO_4 (mg/L)	2.6	2.6	9.8	14
Total Alkalinity as $CaCO_3$ (mg/L)	88	120	160	78
TOC (mg/L)	<1	<1	<1	<1
Parameters Needing Treatment	Manganese	N/A	Arsenic	Manganese and Arsenic

a) Included as an alternative site for 1390 Gumview Rd due to conditions more conducive to pumping.

Figure 4 is a map of wells in the Town sampled for arsenic in 2019 and 2022. Vertical bars for each well show the relative arsenic concentrations measured in 2019 and 2022. Note that Highway 101 is a useful landmark to indicate the locations of well sites.

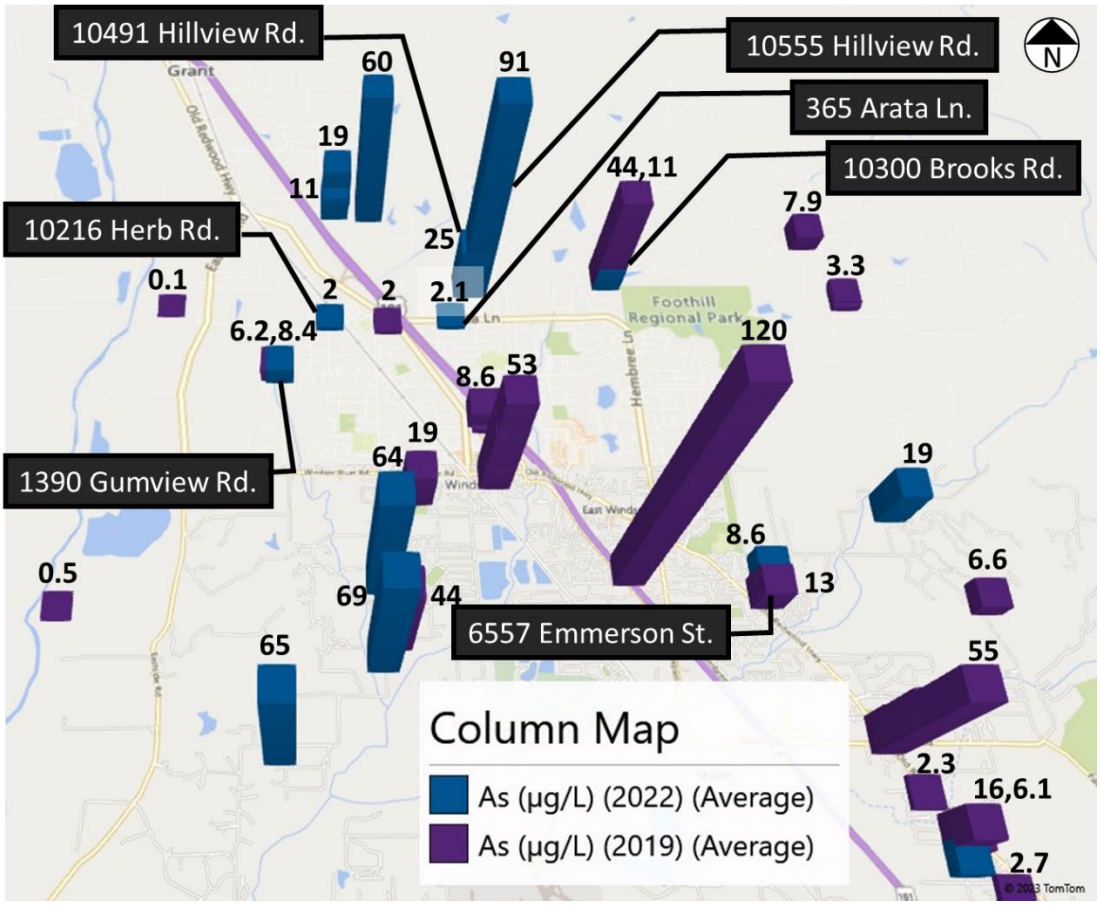


Figure 4. Arsenic map for sampled well sites from 2019 and 2022.

Review of the available 2019 and 2022 data indicate that arsenic concentrations generally are lower in the northern Town Area west of Highway 101 with less variation between the 2019 and 2022 sampling events. Higher concentrations with more spatial and temporal variability occur to the south and east. Although some wells east of Highway 101 show relatively low concentrations (e.g., 365 Arata), nearby wells may indicate high concentrations.

The detection of high levels of arsenic in close proximity to a prospective well site underscores the need to test wells at the design flow rate and depth. Given the horizontal (and potentially also vertical) variability in arsenic concentration, there is potential for pumping of a newly-installed municipal well to induce inflow of poorer quality water from surrounding areas/aquifers. As an example, the arsenic concentration in the Esposti Well (see Figure 1 for location) increased steadily from 16 µg/L to 67 µg/L during a 28-hour aquifer test with a constant pumping rate of 800 gpm. Pumping and sampling of a test well

could detect similar short-term shifts in water quality of that magnitude. Long-term trends in water quality (months to years) might be identifiable by reviewing data from wells that have been sampled periodically over a number of years.

4.3.5. Treatment Trains

Trussell (2022) identified four feasible treatment trains for removing manganese and/or arsenic, as outlined in **Table 4**. The trains are comprised of varying combinations of GreensandPlus™ and arsenic adsorption media, Bayoxide® E33. The process flow diagrams (PFD) are shown in Figure 5. as developed for the Esposti well.

Table 4. Treatment Train and Target Constituent Removed

Train: Description	**Manganese Only**: Catalytic oxidation/filtration	**One Step**: Catalytic oxidation/filtration with iron coprecipitation	**Two Step**: Catalytic oxidation/filtration with arsenic adsorptive media	**Arsenic Only**: Arsenic adsorptive media
Manganese Removal	X	X	X	
Arsenic Removal		X	X	X

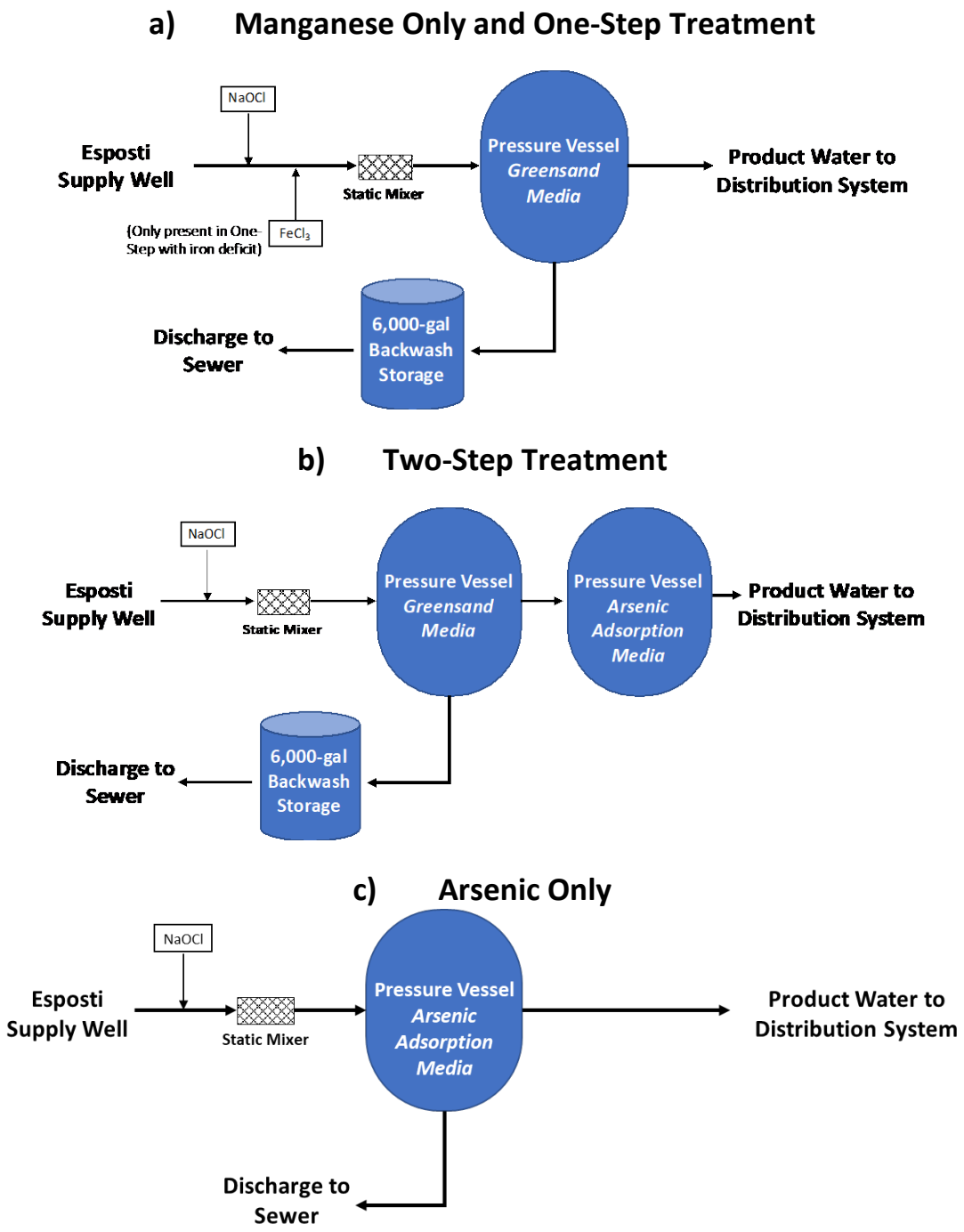


Figure 5. Example Process Flow Diagrams

(a) Manganese Only and One-Step Treatment, (b) Two-Step Treatment, (c) Arsenic Only processes.

The manganese only train (a) is a process containing oxidant pre-treatment (e.g., sodium hypochlorite addition) and granular manganese dioxide media filtration in a pressure vessel. The filtration step removes manganese through catalytic oxidation (e.g., by using GreensandPlus™ media).

The one-step train (a) also may include iron addition when needed (e.g., ferric chloride) followed by the granular media filtration in a pressure vessel. The filtration step removes precipitated iron with adsorbed arsenic and removes manganese through catalytic oxidation (e.g., by using GreensandPlus™ media). The one-step train could also be used for the treatment of source water that contains only arsenic. If natural iron is not present, iron would be supplemented with ferric chloride, which does not need to be catalytically oxidized. For this application, the media would be selected to optimize particulate removal, and so there would be a broader selection of media considered (e.g., sand and anthracite, granular activated carbon, etc.).

The two-step train (b) is a process containing oxidant pre-treatment (e.g., sodium hypochlorite), catalytic manganese oxidation and media filtration (e.g., by using GreensandPlus™ media), and arsenic adsorptive filtration. Similar to the one-step train, this process effectively removes both manganese and arsenic. A key benefit of the two-step train is that it produces less backwash waste that would need to be treated or discharged to the sewer. The main downside of the two-step train is that it may require frequent media change-out (depending on source water quality), which adds significant O&M costs due to the expensive media.

The arsenic only train (c) is a process containing oxidant pre-treatment and arsenic adsorptive media. This is an appropriate train for treating source water that is low in iron and manganese but contains arsenic.

All trains include a backwash system to fluidize and re-stratify the media. The point at which backwash is required will vary based on treatment train and water quality. GreensandPlus™ vessels have been seen to require backwash at 72-96 hours of runtime. A conservative measure of 72-hour runtime is used for the GreensandPlus™ vessels in the manganese-only and two-step trains. The one-step train is assumed to have additional loading from ferric chloride addition, and instead is assumed to have a 12-hour runtime. The Bayoxide® E33 vessels have a 6-week to 3-month runtime; for this calculation a conservative 6-week runtime is assumed.

Table 5 summarizes preliminary treatment train design criteria. Pilot testing of the treatment technology is recommended and would provide additional insight into actual backwash frequency requirements.

Table 5. Treatment Train Design Parameters

		Manganese Only	One Step	Two Step	Arsenic Only
Oxidant Addition		Sodium Hypochlorite	Sodium Hypochlorite	Sodium Hypochlorite	Sodium Hypochlorite
Iron Addition		N/A	Yes	N/A	N/A
Media Type		GreensandPlus™	GreensandPlus™	GreensandPlus™ and Bayoxide® E33	Bayoxide® E33
No. Vessels		3	3	5	2
Vessel Diameter (ft)		8	8	8 [2] 10 [3]	10
Vessel Configuration		2+1	2+1	2+1 [2] 2+0 Lead-Lag [3]	2+0 Lead-Lag
System Flowrate (gpm)		400	400	400	400
Number Backwashes per day [1]		0.67 (72 hr runtime)	4-6 (12 hr runtime)	0.67 [2] (72 hour runtime) N/A [3] (6 week runtime)	N/A (6 week runtime)
Estimated Duration of Backwash (min)		10	10	10	10
Backwash Flowrates	Gallon per day	4,000	24,000	10,000	290
	gal per backwash	6,000	6,000	6,000 [2] 12,000 [3]	12,000
	gpm during backwash	600	600	600 [2] 1,200 [3]	1,200

Notes:

1. Example calculation of backwash frequency: (1 backwash/72 Hours) * (2 vessels) * (24 hours/day) = 0.67 backwash / day
2. Manganese treatment vessels with GreensandPlus™
3. Arsenic treatment vessels with Bayoxide® E33

If a potential well does not need to oxidize arsenic, iron or manganese, sodium hypochlorite would still need to be added to maintain a chlorine residual in the distribution system. The other proposed treatment trains include sodium hypochlorite dosing and will already

provide a chlorine residual. The sodium hypochlorite dosing system would consist of a chlorine analyzer, programmable logic controller, pump skid, inline mixer, redundant chemical storage, and a canopy.

4.3.6. Planning Level Costs

This section presents an analysis of estimated planning-level capital and O&M costs for the identified treatment trains and provides a 30-yr net present cost to implement treatment. Detailed descriptions of assumptions, equations, and the approach for developing capital costs and O&M costs were included in the Esposti Supply Well Evaluation TM. **Table 6** presents updated equipment configurations and costs applicable to the three identified treatment options, plus a disinfection-only option.

Assumptions were made for developing costs for this analysis. Equipment costs are estimated from vendor-provided quotes. The highest cost quote was used where multiple quotes were available. The most expensive one-step equipment cost was obtained from MISCO Water. There are minimal differences in equipment between the one-step and manganese-only removal option (namely, ferric chloride addition is not needed for manganese-only treatment), and so the equipment cost was assumed to be the same for the two processes. The arsenic only quote was provided by Aqueous Vets for this project and is used for the equipment cost assumption. The two-step train equipment costs are assumed to be a sum of manganese-only and arsenic-only trains. With this approach, the two-step train equipment costs include the same operational redundancy and similar hydraulic loading rates to the other proposed trains.

All treatment trains were assumed to include a 6,000-gal backwash equalization tank. It was also assumed that the one-step train would utilize a GreensandPlus™ filter media and the two-step and arsenic-only trains would use Bayoxide® E33 media for arsenic removal.

Table 6. Vendor Quotes for All Treatment Train Equipment

Treatment Train	Vendor	Equipment Cost	Notes
One-Step & Manganese-Only	Tonka Water	$685,000	•Three 8-foot diameter vessels with redundancy • Updated 2023 quote
	Hungerford & Terry	$597,000	•Three 8-foot diameter vessels with redundancy •System recovery is estimated to be 94% • Updated 2023 quote
	MISCO Water	$725,000	•Three 8-foot diameter vessels with redundancy •Not updated from Esposti Supply Well Evaluation TM •System recovery is estimated to be 94%
Arsenic-Only	Aqueous Vets	$655,000	• Two 10-foot diameter vessels with no redundancy • Lead-lLag configuration
Two-Step	Composite Estimate	$1,324,000	•Based off average cost of manganese-only plus arsenic-only equipment
All	MISCO Water 6,000-gal Backwash Waste Equalization Tank	$25,000	•Slanted bottom tank with base, seismic constraints, and fittings •Bottom drain fitting allows for complete drainage of settled solids to facilitate cleaning and flushing when necessary •Not updated from Esposti Supply Well Evaluation TM •Included in all treatment train cost evaluations
No Treatment	N/A	$39,000	• Sodium hypochlorite feed system

The O&M costs for the three treatment options and the disinfection-only option include both well and treatment system (or sodium hypochlorite system) operation. The O&M costs for the two-step and arsenic-only processes are based on a modeled replacement frequency for E33 Bayoxide®. The media manufacturer estimated the capacity based on water quality of the arsenic-containing wells, i.e., 1390 Gumview Rd and 6557 Emmerson St. The estimated BV (defined in Equation 1) is 139,860 for these wells versus 24,000 for the Esposti Well as described in the Esposti Supply Well Evaluation TM. The significantly higher BV estimate for Gumview and Emmerson wells is a result of the more favorable water quality in these wells for adsorption treatment. The higher BV increases the efficiency of this treatment, which reduces the O&M cost and 30-yr net present cost.

The total capital cost was estimated using GHD's model for site development and includes preliminary design, basis of design report, detailed system design and bid package, permitting final documents, the prefabricated treatment plant, and site work and installation of the treatment plant. A 30-year net present cost analysis with a discount rate of 3% was calculated to compare capital and O&M costs between trains. The four sampled wells with the most favorable water quality are listed under the treatment trains that are applicable for treatment of the constituents identified at that site. The treatment technologies that provide the least 30-year net present cost and treats the identified constituents are manganese only (365 Arata Ln.), one-step treatment (6557 Emmerson St.), and arsenic-only treatment (1390 Gumview Rd.). The results of this analysis are shown in **Table 7** .

Table 7. Costs Associated with Treatment Trains and Applicable Sites

Treatment Train	Equipment Cost	O&M Cost (per 1000 gal)[1]	30-yr Net Present Cost	Applicable Sites	Lowest-Cost Option
Manganese-Only	$725,000	$1.89	$6,880,000	365 Arata Ln.	365 Arata Ln.
One-Step	$725,000	$2.23	$7,588,000	6557 Emmerson St. 1390 Gumview Rd.	6557 Emmerson St.
Two-Step	$1,324,000	$3.24	$8,584,000	6557 Emmerson St.	--
Arsenic-Only	$590,000	$3.21	$7,033,000	1390 Gumview Rd.	1390 Gumview Rd.
None[2]	$33,000	$1.15	$2,443,000	10216 Herb Rd.	10216 Herb Rd.

Notes
1. O&M Costs include electricity costs for operating the well pump ($0.88/1000 gal)
2. The cost shown is for a sodium hypochlorite feed system to provide disinfection

In addition to the capital and O&M costs described in this section, bench testing via rapid small-scale column tests (RSSCT) as well as pilot testing are important tools for further developing the designs for adsorptive media treatment systems. RSSCT is used for the initial design stages of arsenic-only and two-step treatment systems to inform arsenic adsorptive media selection and estimate media capacity. The planning-level estimated cost for this service is $75,000; additional information is included in the Esposti Supply Well Evaluation TM. Pilot-scale testing can also be conducted at the future treatment site using the complete treatment system (i.e., including pretreatment and backwashing capabilities if applicable). This testing will help determine the product water quality from the treatment system and confirm that the design meets all drinking water regulatory requirements. The planning-level estimated cost for this service is $75,000 - $100,000 and additional information is included in the Esposti Supply Well Evaluation TM.

4.4. ALTERNATIVE 4: AQUIFER STORAGE AND RECOVERY (ASR) WELLS

This section addresses Aquifer Storage and Recovery (ASR) wells as an option, using available water supply from the Town's Russian River wells for storage in the groundwater basin in the Town area.

Aquifer storage and recovery (ASR) is a technology involving injection of water into the aquifer and extraction through the same well. Other options exist for managed aquifer recharge, including surface percolation facilities (e.g., spreading in basins) or injection wells with recovery through other wells. In Windsor, ASR is a preferred option that was identified in previous investigations (e.g., GEI, 2013).

The surface percolation option is limited because local soils and shallow basin materials have low permeability rates and large areas of land would be required for surface spreading. As shown in **Figure 6** soils are predominantly low permeability. While channel deposits along local creeks may be very permeable, these deposits are underlain by finer-grained basin fill sediments. Any water percolated in a creek would tend to move along the creek as underflow rather than percolate downward to underlying aquifers. Also, the water table is shallow in most areas. **Figure 7** shows contours of depth to groundwater in the Town area in 2015**.** As shown, the depth to water was only about 20 feet throughout most of the Town area. This indicates that subsurface storage capacity is minimal and that percolation rates could be limited by mounding in the water table.

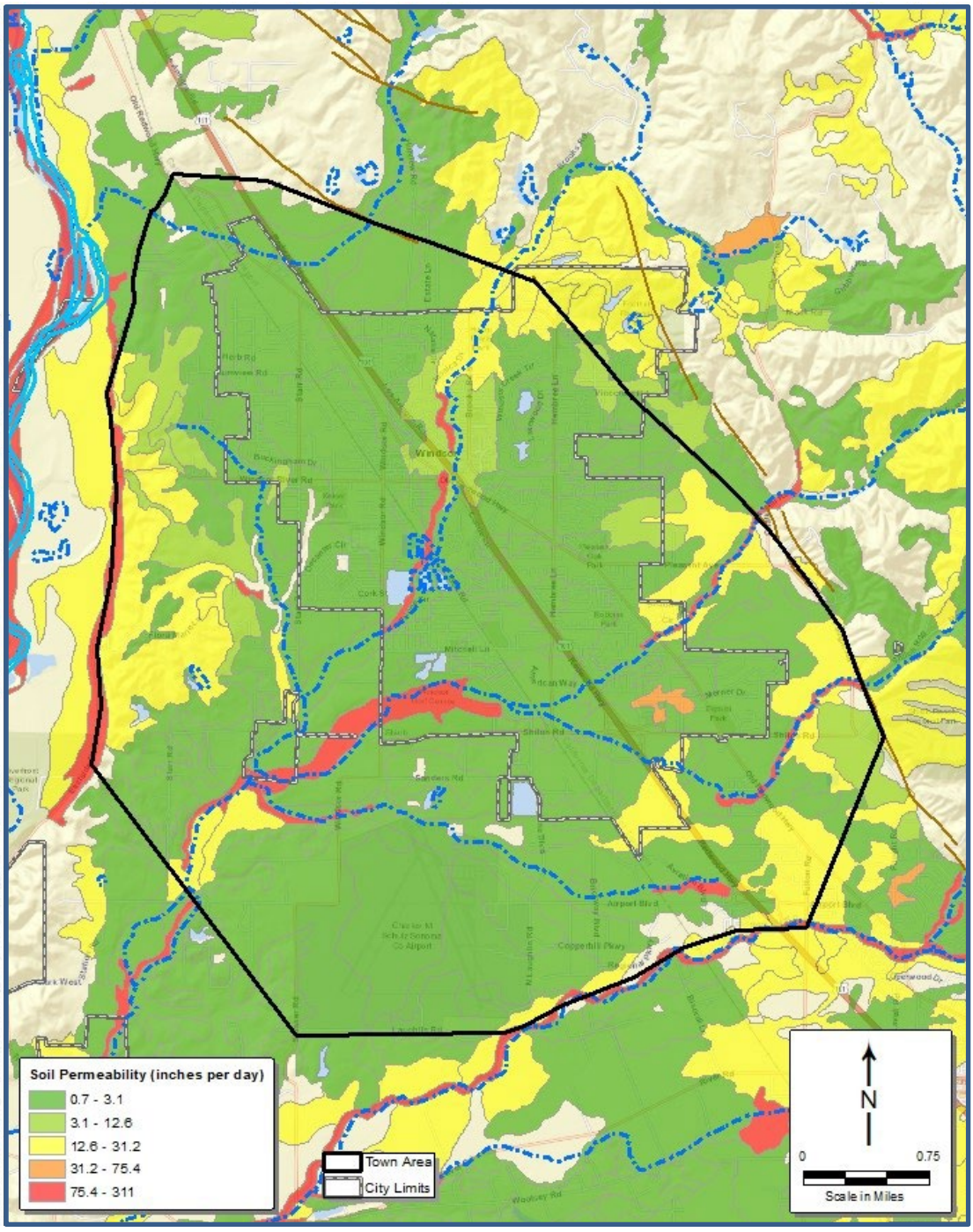


Figure 6. Map of Soil Permeability

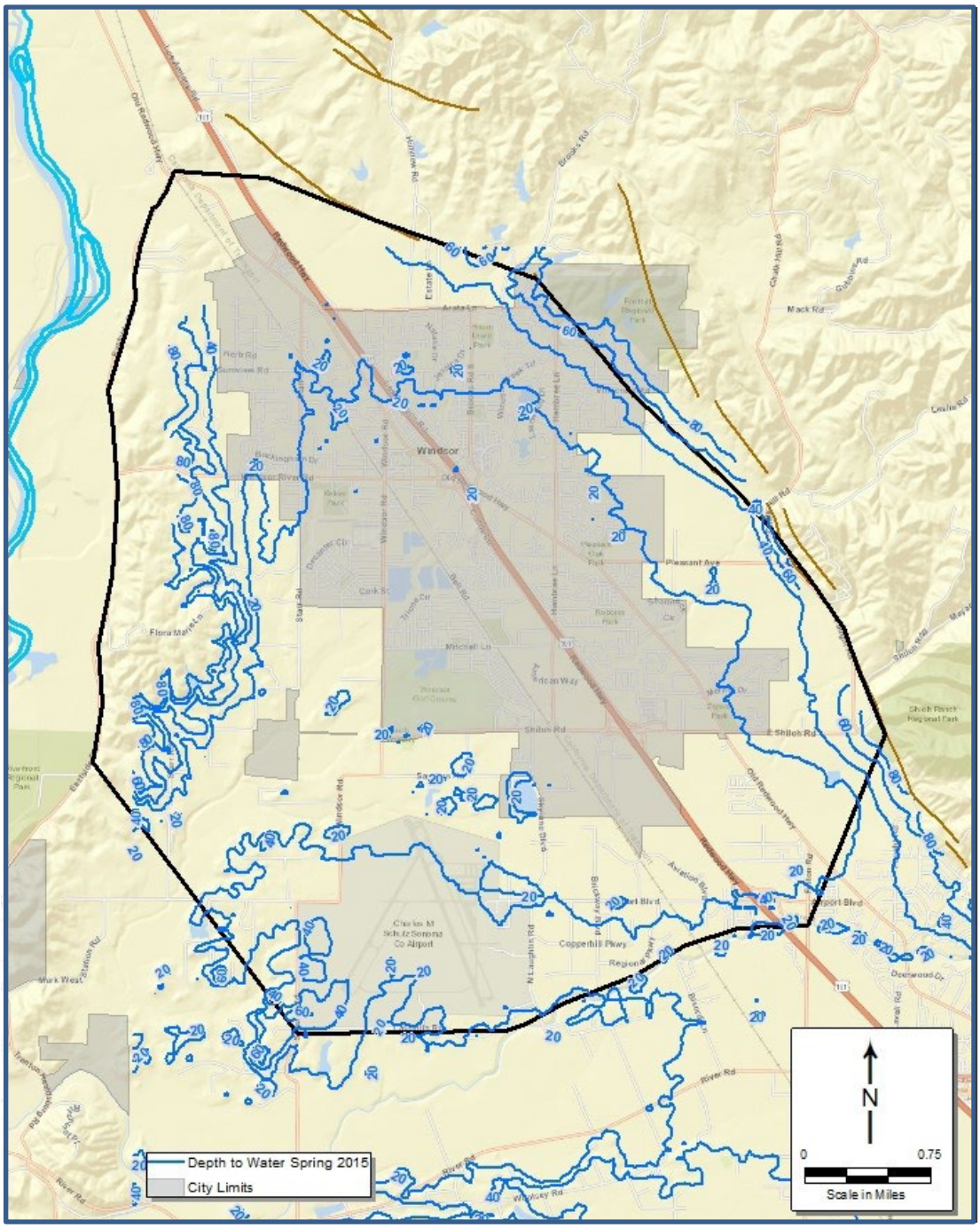


Figure 7. Depth to Groundwater in Spring 2015

The injection/extraction well pair option is not cost effective. This option requires two wells: injection at a new well and recovery through an existing or new well. As discussed previously, arsenic occurs naturally in the area, and wells with concentrations above the

MCL are common. Given that two of the three Town wells in the Town area are adversely affected, use of existing production wells for recovery is not promising. The injection well option also involves the possibility of injected water mixing with poorer quality groundwater prior to recovery. A new extraction well with suitable groundwater quality would be a water supply alternative itself.

The possibility of such mixing also exists with an ASR well, but to a much lesser extent because injection and extraction occur through the same well. The regional gradient for groundwater levels in the Town area is small, so injected water would not drift a long distance downgradient between the ASR injection and extraction phases. **Figure 8** shows contours of groundwater elevation in wells screened more than about 200 feet below ground surface in 2018 (Sonoma Water, 2021). Data were very sparse in the Town area, and contours were developed in part by groundwater modeling. Nevertheless, the contours show that the regional gradient in Windsor is quite flat (0.0016-0.0039 ft/ft). Estimates of hydraulic conductivity of the alluvium and Glen Ellen Formation based on aquifer tests and groundwater model calibration are mostly in the range of 3-50 feet per day. The Darcy Equation for groundwater flow can be applied in one dimension with those values of hydraulic conductivity and water-level gradient to estimate the amount of horizontal movement of injected water in one year, which ranges from 8 to 71 feet per year. These distances would be within the radius of influence of the ASR well when it is extracting, so the well could recover the injected water. This conclusion might not hold if the injection/extraction cycle greatly exceeds one year (for example, 8 years of injection followed by 2 years of extraction).

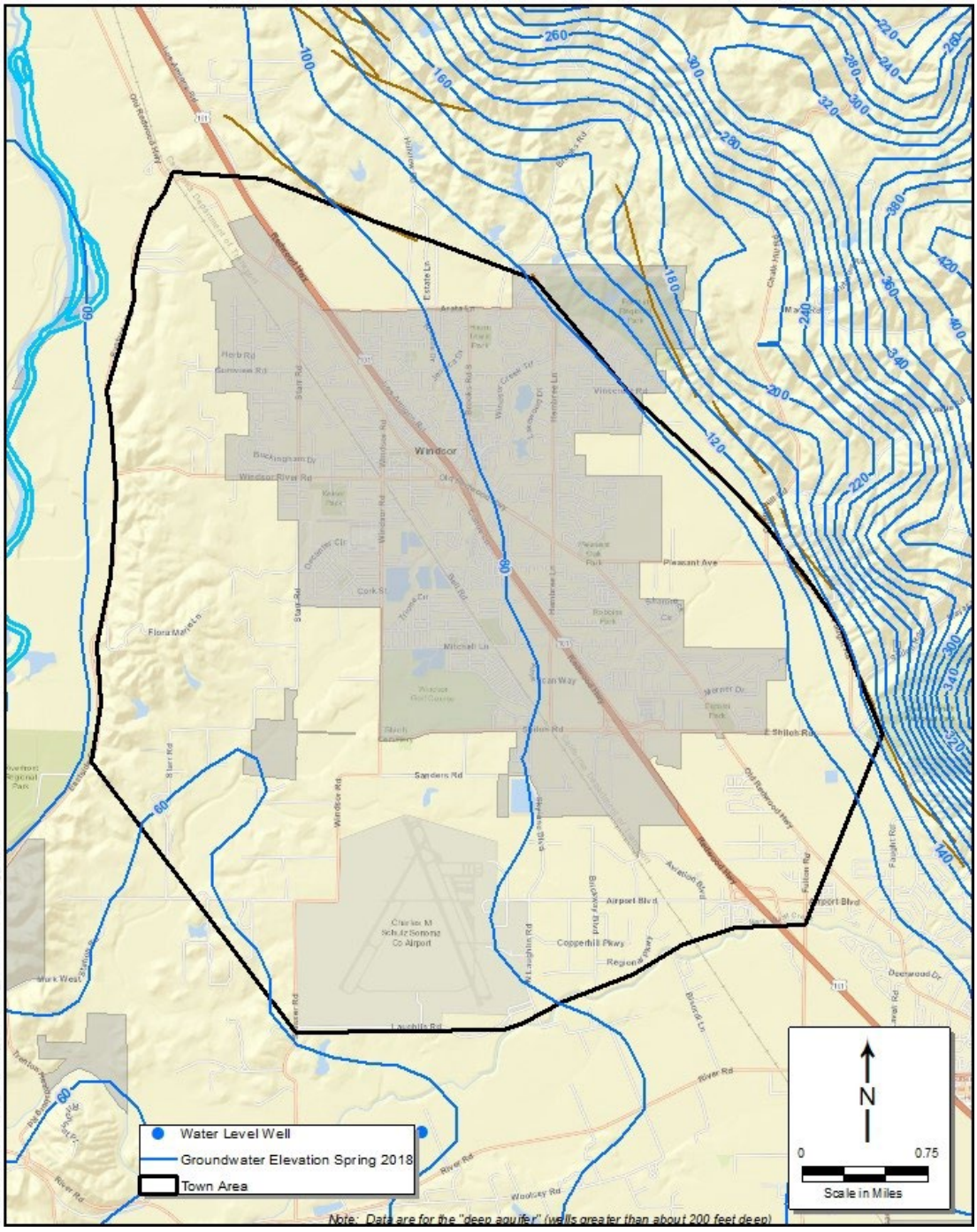


Figure 8. Groundwater Elevation in Spring 2015

The cost of an ASR well is greater than the cost of an extraction-only well. ASR wells may need to be deeper to allow vertical distance for drawdown during extraction and "draw-up"

during injection. Corrosion resistant casing and screen materials are recommended because injected water typically contains a relatively high concentration of dissolved oxygen, which promotes corrosion. Among the corrosion-resistant casing material options, stainless steel provides the best long-term performance but costs roughly three times as much as carbon steel (Pyne, 2005). ASR wells also require down-hole flow control valves to maintain positive pressure at all points within the well casing. Additional wellhead valves and pipes are needed to switch from injection to backflush operation. A means of disposing of water at the start of each backflush cycle or when starting a sustained period of extraction is also needed. For the Pure Water Monterey project in Seaside, backflush water is discharged to a percolation pond near the injection wells. Soil permeability in the Windsor area may be too low for efficient percolation, so an alternative such as discharge to the sanitary sewer system would need to be considered.

The source of water for ASR injection is assumed to be potable water from the Town distribution system derived from the Town's existing Russian River wells. The Town also obtains water from the Santa Rosa Aqueduct, but that water is relatively expensive (approximately $1,000 per acre-foot). Because the aqueduct water also derives from river diversions, it would be vulnerable to the same conditions that could limit the availability of water from the Town's Russian River wells. Water from the river wells and aqueduct is available under Sonoma Water's appropriative water right, of which 5,625 AFY is allocated to the Town. The Town's annual use of water from those sources during 2005-2019 ranged from 2,881 AFY (in 2015) to 4,331 AFY (in 2008) and was 3,300 AFY in 2019 (Woodard & Curran, 2021). Thus, at present there is roughly 2,300 AFY of water available under the Town's existing allocation of Russian River underflow to use for ASR injection. There are no other developed sources of local surface water or imported water nearby.

Injecting water into an aquifer is considered a discharge and is regulated by the North Coast Regional Water Quality Control Board (RWQCB). However, Board Order No. R1-2017-0039 provides a conditional waiver for low-threat discharges, including discharges of potable water that have no residual chlorine. The State Water Resources Control Board's Division of Drinking Water (DDW) would also need to permit the ASR operation because injected water will later be extracted for potable supply. DDW could require an analysis or pilot test of potential geochemical reactions when the source water is injected into the aquifer, such as desorption of arsenic. Desorption/dissolution studies for indirect potable reuse projects in San Jose in 2017 and Seaside in 2019 cost $160,000 and $55,000, respectively, in 2022 dollars (Pueblo Water Resources, 2017; Todd Groundwater, 2019).

For a successful ASR project, it is recommended that an extra increment of water be injected at project start-up to create a buffer zone of mixed water quality between native groundwater and subsequent injections of high-quality water (Pyne, 2005). This helps ensure that future recovery cycles retrieve high quality water not appreciably degraded by comingling with native groundwater. Water for creating the buffer zone can be injected at a time when the source supply is abundant (in winter, for example). The cost of the buffer zone water can be considered a capital cost of building the ASR project.

Successful operation of an ASR project requires close monitoring of system performance, which is usually accomplished with sensors connected to a SCADA system. Injection wells require frequent backflushing to maintain the specific injection capacity. Continuous monitoring of water levels and injection rates is used to determine an appropriate backflush frequency (e.g., weekly) and detect any sudden changes due to unanticipated changes in injection source water quality. The costs of instrumentation and staff time to monitor the SCADA information and implement backflush cycles need to be included when calculating the total cost for this alternative.

4.5. ALTERNATIVE 5: INDIRECT POTABLE REUSE (IPR) WELLS AND SOURCE WATER TREATMENT

Indirect potable reuse (IPR) via groundwater recharge consists of surface spreading or injecting highly treated recycled water into an aquifer and pumping the water out at a downgradient extraction well. IPR allows use of recycled water, a local and highly reliable source. Demand for recycled water is expected to increase in the future, such that 645 AFY to meet the yield objective of this analysis would only be available if that use is prioritized over competing uses. In 2020, the Town treated 1,643 AFY of wastewater at its treatment plant, of which 489 AFY was used for urban irrigation and 770 AFY was delivered to the Geysers for geothermal power generation. Only 384 AFY was discharged to land or Mark West Creek. The Geysers would like to increase its use of Windsor wastewater and demands for golf course and agricultural irrigation are also expected to increase. By 2040, recycled water demand for the Geysers and local irrigators (urban and agricultural) are projected to be 2,370 AFY, or 44 percent more than the total supply in 2020 (Woodard & Curran, 2021). Again, to implement the IPR alternative, the Town would need to give that use priority over some of the competing uses.

IPR is the most common type of potable reuse and has been implemented throughout California. Regulations were finalized in 2014, and there are numerous precedents that have made the project requirements and pathway to implementation clear. The IPR approach using direct injection into an aquifer is the method most suitable for the Town because it avoids the need for large areas of land that would be required for surface spreading.

Other forms of potable reuse, namely surface water augmentation (SWA) and direct potable reuse (DPR), were not evaluated for potential implementation by the Town due to several factors. Access to a large surface water reservoir would be required to implement SWA, and only one SWA project is currently permitted in California (though it is not operational yet). DPR was not considered further because the regulations are still being developed by the State Water Resources Control Board Division of Drinking Water (DDW).

To implement an IPR project in California, the following public health requirements should be considered:

- Pathogen control
- Chemical control

- Source control
- Monitoring and control
- Retention and response time
- Technical and managerial capacity

In addition to these public health requirements, other considerations related to the groundwater aquifer should be evaluated. The following subsections provide more details regarding these aspects of a direct-injection IPR project.

4.5.1. Pathogens

The California Code of Regulations for groundwater replenishment and reuse projects (GRRPs) requires advanced treatment to ensure that the concentration of infectious viruses, *Giardia*, and *Cryptosporidium* are decreased by 12, 10 and 10 orders of magnitude, respectively, before the water reaches the nearest downgradient drinking water well. Up to six logs of virus credit can be achieved via underground retention time, where one month of retention time corresponds to 1-log of virus inactivation. The other pathogen reduction requirements are achieved prior to injection. The advanced treatment criteria require that the full flow be treated by both reverse osmosis (RO) and an advanced oxidation process (AOP). This requirement is referred to as full advanced treatment (FAT). Other unit processes typically include membrane filtration, ultraviolet disinfection, chemical stabilization, and chlorination to maintain disinfection in the distribution system.

The requirement for FAT means that an RO system will need to be part of the treatment process. RO produces a concentrated waste stream that must be disposed of. Discharge to the sanitary sewer is not recommended because of the possibility of creating a closed loop of water flow with ever increasing salinity. An important aspect of determining the feasibility of implementing a direct-injection IPR project will be to identify and evaluate options for RO concentrate disposal.

4.5.2. Chemical Control

In addition to the requirements for FAT, groundwater recharge projects are required to monitor a suite of chemicals including regulated contaminants, nitrogen compounds, and unregulated contaminants.

4.5.3. Source Control

Wastewater treatment plants consider source control from the perspective of maintaining an operational facility that can meet all regulatory requirements for discharge water quality. If the facility also becomes the source water for an IPR project, the source control program must be expanded. Additional requirements are focused on further mitigation of potential contaminants entering the sewer that could eventually end up in the source water to the advanced treatment facility. The source control program for an IPR project must include the following:

- Assess the fate of site-specific chemicals through the wastewater and recycled water treatment systems,
- Monitor and investigate chemical sources,
- Develop and maintain an outreach program to manage and minimize the discharge of chemicals into the source water, and
- Inventory chemicals that may be discharged into the wastewater collection system.

4.5.4. Retention and Response Time

The minimum permissible underground retention time is two months. Retention time must be demonstrated via modeling and added tracer studies. Added tracer studies completed within the past two years in Seaside and San Jose have cost approximately $50,000 each (Todd Groundwater, 2022a and 2022b). Calibrating an existing model to the tracer study results and simulating project operations to define the Zones of Control for drinking water wells near the IPR project would involve an additional cost of about $25,000 (Montgomery & Associates, 2022).

4.5.5. Monitoring and Control

The general monitoring and control requirements for an IPR project include the following:

- Groundwater monitoring before project startup to establish baseline quality,
- Groundwater monitoring when the advanced treatment facility delivers water to the aquifer to confirm compliance with regulatory requirements,
- Online monitoring at the advanced treatment facility to confirm pathogen log reduction credits,
- Monthly performance reporting to DDW, and
- Quarterly and annual monitoring of product water and groundwater for various constituents along with reporting results to DDW.

These required monitoring and reporting activities have a significant cost. At the treatment plant, continuous or frequent monitoring of each treatment step is required to ensure that pathogen reduction targets are met. Water quality at the point of injection and at downgradient wells also needs to be monitored. Using the Pure Water Monterey project as an example, the Monitoring and Reporting Program requirements issued by the RWQCB include continuous monitoring of RO filtrate turbidity, UV dose (flow, intensity, transmittance), and product water temperature, flow and total chlorine. Daily monitoring is required for pressure integrity of the RO membrane, AOP dose, and total coliform in the product water. Weekly monitoring is required for total organic carbon in the RO filtrate. Monitoring wells must be sampled monthly for the first year for general minerals, physical parameters and inorganics with primary MCLs. Various reports must be submitted to the RWQCB and/or DDW on monthly, quarterly and annual schedules. Monitoring data must be uploaded to on-line State databases.

In addition, GRRP regulations require two monitoring wells, one located more than two weeks but less than six months downgradient of the injection well and another at least 30 days upgradient of the nearest downgradient drinking water well. The second monitoring well simply needs to be between the injection well and the nearest downgradient drinking water well, which in this case would be the extraction well installed to recover the injected water (Water Code §60320.126(a)). The monitoring wells need to be as deep as the injection and extraction wells. The cost of two 500-foot-deep monitoring wells would be approximately $240,000 based on recent costs for installing monitoring wells in other areas. This excludes costs for land acquisition and assumes that permitting was included in the permitting for the injection and extraction wells.

4.5.6. Technical and Managerial Capacity

The technical and managerial capacity of the agency or project sponsor that will lead the IPR project must be demonstrated to DDW and the Regional Water Quality Control Board (RWQCB). The agency or project sponsor must possess adequate managerial and technical capability to assure compliance with the requirements to implement an IPR project. DDW has not published the criteria they use to evaluate technical and managerial capacity, but agencies or project sponsors that have implemented IPR projects have often possessed the following:

- Experience in advanced treatment and potable reuse, and
- Established agreements with partner agencies (e.g., the agency supplying wastewater for the project) regarding roles and responsibilities.

4.5.7. Summary of IPR Alternative

This IPR alternative involves the development of an advanced treatment facility that would use source water from the Town's existing recycled water distribution system. After treatment, the water would be conveyed via short pipelines to two nearby injection wells with subsequent withdrawal of the water at two downgradient extraction wells. The three existing municipal supply wells in the Town area all have high arsenic concentrations that might not be sufficiently diluted by upgradient injection of recycled water. Thus, it is assumed that this alternative would require construction of two pairs of injection and extraction wells plus the construction of the advanced treatment facility. A study of water system costs in California in 2016 found that the cost of water produced by small indirect potable reuse projects was $2,000-$2,700 per acre-foot (Cooley and Phurisamban, 2016). Applying a Construction Cost Index multiplier of 1.64 to inflate 2016 dollars to 2023 dollars produces a current cost estimate of $3,280-$4,428 per acre-foot.

In addition to the public health requirements described in this section, the project would also need to maintain compliance with environmental regulations. In particular, the requirement for FAT means that an RO system will be part of the treatment process. RO produces a concentrated waste stream for which disposal is not yet resolved. Discharge to the sanitary sewer can create a closed loop of recycled water flow with progressively rising

salinity levels. An important aspect of determining the feasibility of implementing a direct-injection IPR project will be to identify and evaluate options for RO concentrate disposal.

5. RANKING OF CONCEPTUAL WATER SUPPLY ALTERNATIVES

All of the alternatives are conceptually feasible from a technical and permitting standpoint and all can satisfy the basic yield objective of 800 gpm or 645 AFY. Therefore, the primary basis for ranking them is cost, and cost generally reflects the number of components required for each alternative. For example, the cost of an extraction well would be about the same for all alternatives, but some alternatives require additional components such as well upgrades for injection, additional extraction wells, and treatment of injected or extracted water. An initial ranking of conceptual alternatives can be made on the basis of the components included in the alternative.

Table 8 lists six conceptual alternatives (columns) and the cost components that would be included in each of them (rows), as indicated by the dot symbols. The simplest alternative consists of two deep extraction wells, each capable of producing 400 gpm of water that does not require treatment for arsenic or manganese. As indicated, the cost components are limited to the top rows for that alternative. The other alternatives involve additional components and therefore greater expense. For example, the IPR alternative (far right column) entails the most cost components and likely greatest costs. In cases where an alternative would require a larger quantity of a component, multiple dots are shown.

Table 8 shows that alternatives requiring more components will be more expensive than ones with fewer components. This means that the cost estimates for each component do not have to be highly accurate to roughly determine whether one alternative would be more expensive than another. Nonetheless, variations or combinations of alternatives would require more detailed and site-specific design and cost analysis to determine ranking. For example, two shallow wells not requiring treatment might be more or less expensive than one deep well producing the same amount of water needing treatment to remove one constituent. Similarly, an ASR well might be less expensive than an extraction well requiring treatment, depending on the cost and type of treatment.

Table 8. Cost Components of Conceptual Water Supply Alternatives

Cost Component	Two Deep Extraction Wells w/o Treatment	Four Shallow Extraction Wells w/o Treatment	Two Deep Extraction Wells with Single Treatment	Two Deep Extraction Wells with Dual Treatment	Two Single ASR Wells w/o Treatment	Two IPR injection/Recovery Well Pairs w/o Treatment
Extraction Well						
Property acquisition	●	●●	●	●	●	●●
Permit for drilling	●	●●	●	●	●	●●
Drilling, testing and construction	●	●●	●	●	●	●●
Wellhead infrastructure design and construction	●	●●	●	●	●	●●
Connecting pipeline to distribution system	●	●●	●	●	●	●●
Groundwater Treatment Equipment						
Arsenic teatment: capital and O&M			●	●		
Manganese treatment: capital and O&M				●		
ASR Injection/Extraction Well						
Additional well cost for injection capability					●	●
Source water for injection					●	●
Pre-treatment of injected water					●	●
Permitting for injection (RWQCB, CEQA)					●	●
Energy cost for injection					●	●
Disposal of backflush water					●	●
Indirect Potable Reuse Well Pair						
Advanced treatment of recycled water: capital and O&M						●
Additional permitting (DDW)						●
Two or more monitoring wells						●
Tracer study						●
Monitoring of product water and groundwater per GRRP regs						●

Based on these cost factors and item costs presented earlier, the ranking of conceptual water supply alternatives from least to most expensive is:

1. Two deep extraction wells without treatment
2. Four shallow wells without treatment
3. Two deep ASR wells (without treatment)
4. Two deep extraction wells with treatment for one constituent
5. Two deep extraction wells with treatment for two constituents
6. Two pairs of IPR injection and extraction wells.

6. ADDITIONAL CONSIDERATION OF CONCEPTUAL ALTERNATIVES

6.1. TWO DEEP EXTRACTION WELLS WITHOUT TREATMENT

The challenge with this alternative is the moderately low probability of encountering low-arsenic groundwater at any given location. In the 2019 arsenic study, only 19 of 50 wells (38 percent) in the Town area had arsenic concentrations at or below the drinking water MCL of 10 µg/L. Of the 15 wells sampled for this Groundwater Master Plan, 5 (33 percent) had arsenic concentrations less than 10 µg/L. In both sets of samples, the average depth of wells with high arsenic was greater than the average depth of wells with low arsenic. Therefore, the probability of successfully installing a deep well that does not require arsenic treatment is less than one in three. The probability of achieving two successful sites is less than one in nine.

To improve the odds of success, exploratory borehole sites within the Town area were identified where available data indicated above-average likelihood of encountering low arsenic or high permeability or both. That effort further narrowed the search to three sites near existing water mains and on Town-owned property (or with an existing easement). The arsenic and permeability data used to guide site selection were sparse—especially for wells greater than 300 feet deep—so the improvement in the odds of success may be small. The exploratory boreholes are expected to be drilled in 2023.

This alternative could theoretically include the concept of deep wells near the Russian River. Wells screened below the river alluvium would arguably tap percolating groundwater rather than river underflow and thus not be subject to surface water appropriation rules and water rights. Several practical impediments were encountered for this option. First, no well completion reports or water quality samples were found for existing deep wells near the river. The river alluvium affords high well yields, so there has been no reason to drill deeper. The nearest deep wells are along Eastside Road at the eastern edge of the alluvium. None of the well owners opted to participate in water quality sampling for this groundwater master plan. Second, the alluvium near the river is thought to lie directly over the Petaluma Formation, which consists predominantly of fine-grained sediments that would not support high well yields (Nishikawa, 2013). Third, the burden of proof could be on the Town to convince Sonoma Water that well screens at any given depth extract only percolating groundwater without depleting the overlying river underflow. Existing water quality and short-term pumping tests of deep test wells would not definitively resolve that issue.

6.2. FOUR SHALLOW EXTRACTION WELLS WITHOUT TREATMENT

The 2019 arsenic study and the present study found that low-arsenic wells were shallower on average than high-arsenic wells. However, the depth ranges overlapped, and there was no particular depth associated with a transition from low to high arsenic. If exploratory boreholes encounter a situation where only shallow aquifer zones have low arsenic, then installing four shallow wells instead of two deep wells could be the best option. In particular, the two identified sites in the northwestern part of the Town area (the Herb Road and

Manchester sites) are in a region where five sampled wells had low arsenic and were also less than 160 feet deep.

6.3. TWO DEEP EXTRACTION WELLS WITH SINGLE TREATMENT

Six of the 15 wells sampled for this study (40 percent) would need treatment for arsenic or manganese but not both. Thus, there is a reasonable probability that this situation will be encountered at test well sites. Treatment equipment requires additional space at the wellhead for tanks, piping and controls. It is assumed that sites on Town-owned parcels would be large enough to accommodate the additional equipment. Access to the sanitary sewer system to discharge backflush water would also be needed. Sewer and water mains are commonly co-located, and both are available near the three sites currently under consideration (Herb Road, Manchester and Pleasant Oaks Park). The tanks needed for water treatment are often large (8-10 ft in diameter and at least that long, for example), which can be visually unappealing if the well is in a park or natural area. Wellhead infrastructure would be particularly noticeable at Pleasant Oaks Park, for example, which is one of the candidate test well sites and is managed as a natural area. Visual impacts can be addressed by planting vegetation that provides visual screening or installing tanks partially below grade.

It is possible that the exploratory boreholes will result in one deep well that does not require treatment and one that does. Assuming each well needing treatment has its own wellhead equipment, the cost of a single well needing treatment would simply be half the cost of two wells needing treatment.

6.4. TWO DEEP EXTRACTION WELLS WITH DUAL TREATMENT

The considerations for treating water for two constituents are qualitatively the same as for one constituent. The site footprint, number of tanks and amount of equipment would probably be larger. There is the possibility that the exploratory borehole sites will include one not needing treatment and one needing dual treatment. In that case, treating the existing Esposti Well might be less expensive than drilling a new well also needing dual treatment.

6.5. TWO ASR WELLS

The advantage of ASR wells is that they are not constrained by existing groundwater quality. Potable water would be injected into the aquifer, creating a “bubble” of high-quality water around the well that would be pumped out later. A larger number of sites are thus potentially feasible. Aquifer transmissivity would become the primary criterion for choosing among sites, assuming all candidate sites are on Town-owned property near large water mains.

Water from the Town’s existing Russian River wells would be available during low-demand seasons to establish the buffer zone and then store water for future extraction. The seasonal peaking factor for water demand in recent years is 1.43, which is the ratio of

maximum month demand to annual average demand (Woodard & Curran, 2019b). This means that the maximum-month demand is about 2.5 times greater than the minimum-month demand. The minimum demand occurs in winter when additional pumping would not adversely impact Russian River flows. Under agreements with Sonoma Water, the Town is entitled to annual withdrawals of 4,725 AFY from its Russian River well field and 900 AFY from the Santa Rosa Aqueduct, for a total supply of 5,625 AFY. Potable water demand since 2015 has ranged from 2,800 to 3,300 AFY. The 2020 Urban Water Management Plan projects that potable water demand will increase due to population growth and exceed 5,625 SFY sometime around 2030 (Woodard & Curran, 2021). Until then, surplus winter supply should be available in low-demand months from the Russian River well field for ASR storage.

ASR wells in the Windsor area might need to have sealed wellheads capable of holding pressure because the depth to water in the region is only about 20 ft. If the wellhead cannot be pressurized, the maximum injection pressure by gravity flow would be only about 8 pounds per square inch (psi), which might not be sufficient to inject water at a reasonable rate. Sealing of wellheads to allow pressurized injection is common, with pressures in rare cases as high as 70 psi (Pyne, 2005).

In 2013, the Town participated in a regional evaluation of the potential for ASR in the Santa Rosa Plain Basin (GEI and others, 2013). The study concluded that ASR appears generally feasible and that pilot projects should be pursued. This recommendation was reiterated in the Santa Rosa Plain Basin GSP (Sonoma Water, 2021). Those studies focused on ASR as a means of preventing chronic declines in groundwater levels and storage. For Windsor, the primary objective would be overcoming water-quality limitations of local groundwater. For the 2013 study, the Town provided a water sample from Russian River Well #11 for detailed water quality analysis. The results indicated that the general mineral quality was suitable for injection, but there was a potential for bromate precipitation and for microbial growth stimulated by phosphorus used in the Town's water treatment process. Cores or cuttings from exploratory boreholes at prospective well sites need to be chemically analyzed to support comprehensive chemical equilibrium modeling that combines the injected water, native groundwater and aquifer minerals.

6.6. TWO IPR WELL PAIRS

IPR is the lowest-ranked option due to its high capital and operating costs. However, like ASR, it offers flexibility in location because low-arsenic water would be injected into the aquifer and later extracted. If a small advanced-treatment plant is constructed near the injection wells, it could be supplied by tapping into an existing nearby recycled water distribution pipeline. **Figure 1** shows the locations of existing recycled water pipelines. Advanced treatment involves reverse osmosis and produces a waste brine for which disposal is not yet resolved. Although there is some flexibility in locating the two injection wells, each injection well needs a companion extraction well located in the downgradient direction with respect to the regional gradient. A minimum travel time of 2 months is required, and more may be desirable to obtain additional virus LRV credits.

At present, all recycled water mains are west of Highway 101. None are located upgradient of the Keiser Park, Bluebird or Esposti Wells. Therefore, those existing wells could not be used as downgradient extraction wells without constructing a lengthy extension to the recycled water distribution system, which could cost more than installing a new well for extraction.

One of the difficulties in planning well locations, stems from uncertainty in subsurface travel time between the injection and extraction wells. Groundwater typically flows primarily through relatively permeable layers, or “preferential flow paths”. These result in much faster travel times than would be estimated by applying a Darcy Equation or groundwater flow model that assumes flow is through the full thickness of a given depth interval. The decrease in travel time due to flow through preferential flows paths cannot be reliably estimated without implementing a tracer test.

7. GROUNDWATER BUDGETS, SUSTAINABLE YIELD AND CLIMATE CHANGE

Most of the supply options involve pumping native groundwater. An important issue is how the hydrologic system will respond to the increase in pumping and whether the increase will be within the sustainable yield of the basin. A related question is how climate change will impact the groundwater budget and the ability of the basin to sustain the additional pumping.

7.1. GROUNDWATER BUDGETS

Average annual groundwater budgets for areas within the Santa Rosa Plain Groundwater Basin were estimated by the U.S. Geological Survey as part of a groundwater and surface water modeling study (Woolfenden and Nishikawa, 2014). The study evaluated numerous hydrologic processes using linked rainfall-runoff, stream flow and groundwater flow models. Average annual groundwater budgets for water years 1976-2010 were simulated for four subareas within the Basin. The Windsor Subarea covers 47.8 mi^2 at the northern end of the Basin and includes the Town of Windsor. The Town area used for this study is 17.0 mi^2 in size, or 35 percent of the Windsor Subarea used by the USGS.

Table 9 shows the estimated average annual groundwater budget for the Town area under climate and land use conditions present during 1976-2010. The entries are simply 35 percent of the Windsor Subarea values in the USGS modeling report. This reflects an assumption that groundwater recharge per square mile in the Town area is similar to that for the USGS Windsor Subarea, which is reasonable given similar geology, soils, land use and stream network density. Average annual inflows to the Windsor Subarea during 1976-2010 were equivalent to a recharge rate of 0.59 ft/yr from all sources, on a per-area basis. Applying that recharge rate to the Town area produces an estimated average annual recharge of 6,437 AFY.

[Point out that the 4% imbalance doesn't necessarily indicate overdraft]

The response of the groundwater system to an increase in extraction can be inferred by identifying which inflows and outflows are essentially fixed in magnitude and which are head-dependent, meaning that the flow varies depending on water levels. In **Table 9**, 54 percent of inflows and 43 percent of outflows were "fixed"; the magnitudes would not be affected by a change in pumping. These include rainfall recharge and groundwater pumping. Note that the USGS model did not include recharge from irrigation return flow, pipe leaks or septic systems. Those would also be fixed. All other budget items were head-dependent and would adjust to a change in pumping. These include seepage to and from streams and inflows and outflows across internal and external basin boundaries.

Table 9. Estimated Average Annual Groundwater Budget for the Windsor Town Area

Inflows and Outflows	Flow (acre-feet per year)
Inflows	
Deep percolation of rainfall	3,450
Percolation from streams	1,814
Inflow from outstide Basin	711
Inflow from other Basin subareas	462
Total inflows	**6,437**
Outflows	
Wells	2,916
Evapotranspiration	925
Discharge to streams	1,280
Surface leakage	391
Outflow to Healdsburg Basin	1,031
Outflow to other Basin subareas	178
Total outflows	**6,722**

Source: Average values during 1976-2010 values for Windsor Subarea (Woolfenden and Nishikawa (2014) multiplied by 0.356 area ratio to estimate values for Town area.

An increase in groundwater extraction would be balanced by shifts in the head-dependent boundary fluxes. Two 400-gpm wells each pumping half the time would increase total groundwater outflows from the Town area by 645 AFY, or about 10 percent. Water levels near the wells would decline slightly, then stabilize at a new "equilibrium" level as head-dependent boundary flows compensate for the increase in extraction. The USGS simulated an extreme scenario in which historical pumping was decreased to zero, and the results confirmed this pattern. Comparing the water budgets for the with- and without-pumping scenarios, the USGS found that 53 percent of the groundwater pumping was derived from a reduction in stream flow (increased percolation from streams and decreased groundwater discharge to streams), about 25 percent from a reduction in evapotranspiration, 13 percent from a decrease in storage and about 8 percent from changes in net boundary flows (Woolfenden and Nishikawa, 2014).

Applying the USGS results to the Town area, 53 percent of a 645 AFY increase in groundwater pumping equals 342 AFY. Most of the pumping effect on stream flow manifests as a decrease in groundwater discharge to streams. For example, if 100 AFY became an increase in percolation from streams, it would correspond to a 6 percent increase in stream percolation. At the same time, if the remaining 242 AFY of pumping increase became a decrease in groundwater discharge to streams, it would correspond to a decrease of 19 percent. The USGS results also indicated that about 25 percent of a change in pumping is absorbed by a change in groundwater consumption by phreatophytes. In this case, 25 percent of 645 AFY is 161 AFY, which corresponds to 17 percent of phreatophyte

ET. Those changes in stream flow and phreatophyte ET are large enough to potentially have ecological impacts.

The groundwater basin in the Town area could physically sustain a 10 percent increase in outflows. Whether such a shift in the water balance is sustainable from the perspective of the Sustainable Groundwater Management Act (SGMA) depends on how it would affect each of six sustainability indicators defined in the Santa Rosa Plain GSP (Sonoma Water, 2021). In this situation, the most relevant are the criteria related to water quality, water levels and depletion of interconnected surface water. The minimum threshold for water quality states that no more than two municipal wells should experience increases in arsenic, nitrate or TDS above the drinking water MCLs. Because the Town wells would be new, with water treatment to meet all drinking water standards, the wells would not cause an exceedance of the minimum threshold.

The water level minimum threshold states that water levels should remain above the historical low (adjusted downward for an additional 4 years of drought) and above the depths of 98 percent of the wells in the Basin. This criterion is presented in the GSP as a basin-wide metric; it is not intended to be applied at a local scale for individual production wells (Trotta, 2023). Instead, drawdown impacts of new municipal wells on nearby existing wells would be evaluated as a potential impact during CEQA review.

7.2. CLIMATE CHANGE EFFECTS

The GSP included an extensive evaluation of the effects of climate change. The GSP Technical Advisory Committee reviewed ten global circulation models (GCMs) and selected the HadGEM2-ES model because it reproduced historical conditions in the Russian River watershed well and produced less extreme results than the other models. The model was paired with RCP 8.5, which is a “worst-case” representative concentration pathway (RCP) for future greenhouse gas emissions. This pathway was warmer than historical conditions throughout the 2021-2070 analysis period. It was wetter than historical from 2021-2050 and mostly dry from 2051-2070. The evaluation of climate change also incorporated projected changes in land use.

Predictably, the modeling showed higher stream flows during the first part of the scenario and lower stream flows during the second part. There was a consistent shift to greater net stream percolation, however, due to the assumed increase in groundwater pumping and the relatively wet conditions during the first half of the scenario. The simulated cumulative change in groundwater storage shows the net effect of all the changes in all the groundwater budget items. The basinwide cumulative storage change was essentially flat during the historical 1976-2020 period. It remained essentially flat during 2021-2040, when greater pumping was accompanied by relatively wet climatic conditions. During 2050-2070, however, a combination of greater pumping and chronically dry conditions produced a steady decrease in basinwide storage of 3,100 AFY.

A previous climate change analysis using the same groundwater model was done in 2014 (Woolfenden and Nishikawa, 2014). That study used an "ensemble" approach, comparing results for two GCMs paired with two RCPs. Three of the four resulting scenarios produced decreases in long-term average precipitation, and all of them produced greater precipitation variability. Basinwide groundwater pumping increased by about 26 percent compared to the 1981-2010 average due to urban growth and warmer summer temperatures that increased irrigation demand. All elements of the groundwater budget changed, but stream flow gains and losses absorbed most of the net changes in rainfall recharge and pumping.

Stream flows are sensitive to assumptions about future precipitation, and net stream percolation is sensitive to groundwater pumping. Thus, stream flows are likely to exhibit the largest hydrologic response to increased pumping—including new Town wells—combined with climate change.

8. SUMMARY AND CONCLUSIONS

The Town is seeking a new increment of water supply that is independent of its existing Russian River supplies. The yield objective for the new increment is an instantaneous flow rate of 800 gpm and an annual yield of 645 acre-feet. This could be provided by two deep wells, if hydrogeologic conditions at the well sites are reasonably favorable.

Five conceptual alternatives were selected for evaluation. Sufficient information was available to indicate that all of them could be capable of meeting the target yield and would be feasible from a permitting and construction standpoint. The five alternatives are deep wells, shallow wells, groundwater treatment, aquifer storage and recovery, and indirect potable reuse.

The primary discriminator for ranking the alternatives is cost. Rough cost estimates were developed for generic examples of each alternative, without details related to specific sites or designs. It became clear that alternatives involving fewer components would usually be less expensive than ones with more components. For example, a deep well not requiring treatment and drilled on Town-owned property would be the lowest-cost option. Other alternatives require additional components, such as additional wells, treatment to remove one or more contaminants (manganese and/or arsenic), pipelines, or treatment to bring injected water up to regulatory requirements. Each additional component adds to the overall cost of each alternative. On this basis, the ranking of conceptual alternatives in descending order is two deep wells not requiring treatment, four shallow wells not requiring treatment, two deep ASR wells, two deep wells with treatment for one constituent, two deep wells with treatment for two constituents, and two pairs of IPR injection and extraction wells.

Groundwater not needing treatment is clearly the lowest-cost option. However, the probability of encountering high-quality groundwater at any given location is relatively low. Therefore, final selection and design of an alternative must wait until site-specific water quality and yield information becomes available. A program is currently underway to obtain that information at three potential well sites: Herb Road, Manchester and Pleasant Oaks Park.

Given the variability of local groundwater conditions, the final water supply project will likely include multiple elements, such as a combination of deep wells, shallow wells, treatment and/or ASR.

9. RECOMMENDATIONS

1. Drill exploratory boreholes at the Herb Road and Manchester property sites. If both locations have low arsenic and adequate permeability, analyze drawdown and potential water level impacts on nearby wells. Construct two deep wells at those locations. Design and operate the wells to avoid significant drawdown impacts or mitigate the impacts.

2. If a deep well at one or both sites requires treatment, drill an exploratory boring at the Pleasant Oaks Park site. If sampling indicates that a deep well at that location would not need treatment, analyze potential drawdown impacts at nearby wells. Construct a deep well at that location designed and operated to minimize drawdown impacts. Mitigate impacts if needed.

3. If steps 1 and 2 fail to achieve two deep wells not requiring treatment, evaluate the next tier of options. Based on the lithologic and water quality results from the boreholes indicating a need for treatment, calculate and compare three costs:

    a. If any of the sites have arsenic in deep strata and low arsenic in shallow strata, estimate the feasibility and cost of drilling two shallow wells at that site. The feasibility analysis should consider land acquisition and pipeline costs associated with spacing the wells far enough apart to reduce interference to an acceptable level. Evaluate potential drawdown impacts on nearby wells and plan to avoid or mitigate those impacts.

    b. Based on water quality zonal sampling results, estimate the cost of treating the water from a deep well at that site to remove arsenic and/or manganese. This feasibility analysis also needs to confirm whether the quality of backflush water will allow it to be discharged to the sanitary sewer system.

    c. Based on water quality and lithology, estimate the feasibility and cost of installing ASR wells at one or more of the sites. The feasibility analysis should consider the longest injection/extraction cycle and whether injected water would drift away from the well before the extraction phase. It should also consider geochemical reactions in the aquifer, the long-term availability of source water for injection, the need for a pressurized wellhead, disposal of backflush water and similar technical details. If the extraction cycle follows the injection cycle, there should be no drawdown impacts at nearby wells.

4. Proceed with the lowest-cost option from steps 3a, 3b and 3c.

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APPENDIX E

Drilling and Zonal Testing of Exploratory Boreholes

TOWN OF WINDSOR ZONAL TESTING TECHNICAL MEMORANDUM

HERB RD. AND ARATA LANE SITE BOREHOLES

January 2024

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1. INTRODUCTION

This report documents the drilling, logging, design, temporary zone construction, development, and sampling of two exploratory boreholes for the Town of Windsor in Sonoma County, California. The exploratory borehole sites, designated Herb Road Site and Arata Lane (Manchester property) Site, are located on the northwestern and northern end of town, respectively (**Figure 1**). These exploratory boreholes were drilled, constructed, sampled, and destroyed to gain insight into local aquifer layering and water quality to support a broader groundwater master planning project.

Todd Groundwater was retained by the Town of Windsor to assess the town's potential water supply options. This report documents the field activities associated with task three of this assessment: drilling and sampling two test boreholes.

The scope of work addressed herein included the preliminary design, planning, drilling, logging, and aquifer zone interval testing of the two boreholes. Tasks associated with this work are summarized as follows:

- Observation during borehole drilling and reaming, including contractor coordination, soil logging, and geophysical logging
- Design and implementation of an aquifer zone interval testing program for depth-specific water quality assessment
- Final documentation report preparation

This report presents summary documentation of all aspects of the work described above.

1.1. TECHNICAL APPROACH

Initial planning for each borehole included a 600-foot depth based on available nearby water well data and known alluvial aquifer units overlying the basin bottom Franciscan Complex. Borehole locations were selected based on regional water quality and available parcels the Town either owns or has existing agreements for access. Boreholes were to not exceed 12 inches in diameter for zonal sampling with the intent of making development and obtaining of a representative aquifer zone sample easier and less time consuming.

Technical specifications for the construction, development, and testing of the wells were prepared by Todd Groundwater staff and reviewed by Town of Windsor staff. These specifications contained detailed instructions for mobilization, drilling, construction, development, testing, borehole abandonment, and site cleanup for both sites. The specifications were used as the basis for the Town of Windsor to solicit bids from drilling contractors. Multiple bids were received, and Weeks Drilling and Pump Co. of Santa Rosa, California was selected.



Figure 1: Borehole Locations in Town of Windsor

Field staffing was split between Todd Groundwater and GHD, another consulting firm participating in the overall groundwater master planning project. Generally, Todd staff observed and coordinated the drilling, logging, and first zone construction, and GHD staff stepped in to supervise latter zones once the details of the process were determined.

2. PILOT BOREHOLE DRILLING AND AQUIFER ZONE INTERVAL TESTING

Drilling of both boreholes was conducted using the reverse rotary method using limited quantities of drilling additives. Drilling fluid consisted primarily of water and small amounts of bentonite or other drilling fluids when necessary to maintain circulation, stabilize the borehole, and facilitate the removal of formation cuttings. Field equipment consisted of a top driven reverse rotary drilling rig, pumps, hoses, air compressor, generator, submersible pump, and mud shaker.

Initial drilling activities for each borehole included the drilling of 11-inch diameter boreholes and installation of 10-inch diameter, mild steel temporary conductor casings to depths of 10 feet. The purpose of the conductor casings was to stabilize the boreholes near the ground surface during drilling and to provide a protective surface seal to prevent surface water from migrating into the borings.

After the conductor casings were installed at each site, pilot borehole drilling was conducted using an 8.75-inch diameter tricone (milled and button) drill bit. Drilling operations were conducted during daylight hours on weekdays for both sites. Drilling fluid properties were checked routinely during drilling for consistency. Drilling fluids were circulated through a mobile mud filter (referred to in this document as a shaker) to remove drill cuttings and recycle mud into the system. After completing each borehole, drilling fluids and cuttings were disposed of by spreading onsite.

The contractor was in routine communication with Todd Groundwater or GHD staff regarding drilling operations. This included correspondence at least twice a day in the morning and evening. A geologist from the technical advising team visited the site at various points of the drilling process of both sites to confirm that the technical specifications were being followed and to log soil samples for the preparation of lithologic logs of each borehole. Formation samples were collected at five-foot intervals directly from the shaker throughout drilling. Samples were cleaned by wet-sieving with a No. 200 mesh sieve and logged in the field by a Todd Groundwater geologist. Formation samples were evaluated for grain size distribution, shape, color, and source material. Sample descriptions were generally based on sediment grain-size classifications (e.g., Shepard 1954) and modified to nomenclature in the Unified Soil Classification System (USCS) (ASTM 2000). A small sediment sample from each interval was collected and retained by Todd Groundwater.

Prior to drilling, a projected total depth of 600 feet was estimated based on local well logs and the deepest aquifer used locally. Pilot drilling was anticipated to penetrate the entire thickness of the Quaternary Alluvium and Glen Ellen Formation. Drilling would stop if the Franciscan Complex bedrock that underlies the basin were encountered at a depth less than 600 feet. Other basin-fill formations that were potentially present beneath the Glen Ellen Formation included the Sonoma Volcanics and Petaluma Formation.

Upon reaching total depth in each borehole a suite of standard geophysical measurements was collected. Geophysical logging of each borehole included electrical resistivity, spontaneous potential, and natural gamma radiation measurements along the full depth of the borehole. The combination of geophysical logs and lithologic logs was used to evaluate the subsurface geology, identify zones for aquifer zone interval testing, and design temporary zone construction details.

Following pilot drilling and logging, each borehole was reamed to a 12-inch diameter which involved removing the temporary conductor and retracing the borehole with a 12-inch bit to the depth of the lowest zone selected for testing.

Aquifer zone interval testing is a method for collecting depth-specific samples from a borehole without permanent well construction. This process involves constructing temporary test wells with a 10 to 20-foot (ft) section of perforated casing at the bottom of a string of casing, developing the zone until the turbidity of the produced water is less than 10 nephelometric turbidity units (NTU), pumping to purge water for at least two hours, and the collecting groundwater samples for laboratory analyses. The aquifer zone intervals tested in each borehole were selected based on the lithology and geophysical signatures in the borehole, focusing on those intervals that contained coarser materials suitable for screening in a production well. Testing began at the deepest interval in each borehole by sealing the bottom of the interval with bentonite, placing the perforated casing, surrounding the perforated casing and ten feet above the perforations with filter pack, then sealing above the filter pack with bentonite to a depth corresponding to fine-grained material in the borehole. This temporary well was then developed and purged by pumping before samples were collected from the pump discharge. After sample collection in a zone interval the temporary well casing was pulled from the borehole with the drill rig and cleaned prior to being used in the next interval. Testing of each subsequent interval followed the same procedures.

Samples from each aquifer zone interval were collected by a geologist on the technical advising team, stored on ice, and sent to Alpha Analytical, Inc., laboratory for analysis. Each sample was analyzed for total dissolved solids (TDS), total organic carbon (TOC), sulfate, nitrate, fluoride, phosphate, chloride, alkalinity, manganese, arsenic, iron, vanadium, magnesium, silica and calcium. This suite of chemical constituents was selected because of high concentrations observed in wells within the subbasin.

Once the final zone was sampled in each borehole, all tools were removed and the borehole was abandoned in accordance with state and local best practices by grouting from bottom to top of the remaining open borehole with neat cement.

Field activities began with mobilization to the Herb Rd. site on July 25, 2023, and concluded with demobilization from the Arata Lane site on October 17, 2023. A general construction timeline is presented in **Figure 2.** Selected photographs of drilling and aquifer zone testing field operations are included in **Appendix A**.

TASK	START	END	DAYS
Herb Rd. Mobilization	7/25/2023	7/25/2023	1
Herb Rd. Pilot Drilling	7/26/2023	8/4/2023	10
Herb Rd. Geophysical Logging	8/7/2023	8/7/2023	1
Herb Rd. Reaming	8/8/2023	8/15/2023	8
Herb Rd. Zone 1	8/16/2023	8/22/2023	7
Herb Rd. Zone 2	8/24/2023	8/28/2023	5
Herb Rd. Zone 3	8/29/2023	8/31/2023	3
Herb Rd. Zone 4	9/1/2023	9/5/2023	5
Manchester Mobilization	9/6/2023	9/6/2023	1
Manchester Pilot Drilling	9/7/2023	9/14/2023	8
Manchester Geophysical Log	9/15/2023	9/15/2023	1
Manchester Reaming	9/18/2023	9/21/2023	4
Manchester Zone 1	9/22/2023	9/28/2023	7
Manchester Zone 2	9/29/2023	10/4/2023	6
Manchester Zone 3	10/5/2023	10/10/2023	6
Manchester Zone 4	10/11/2023	10/12/2023	2
Manchester Zone 5	10/13/2023	10/16/2023	4
Demobilization	10/17/2023	10/17/2023	1

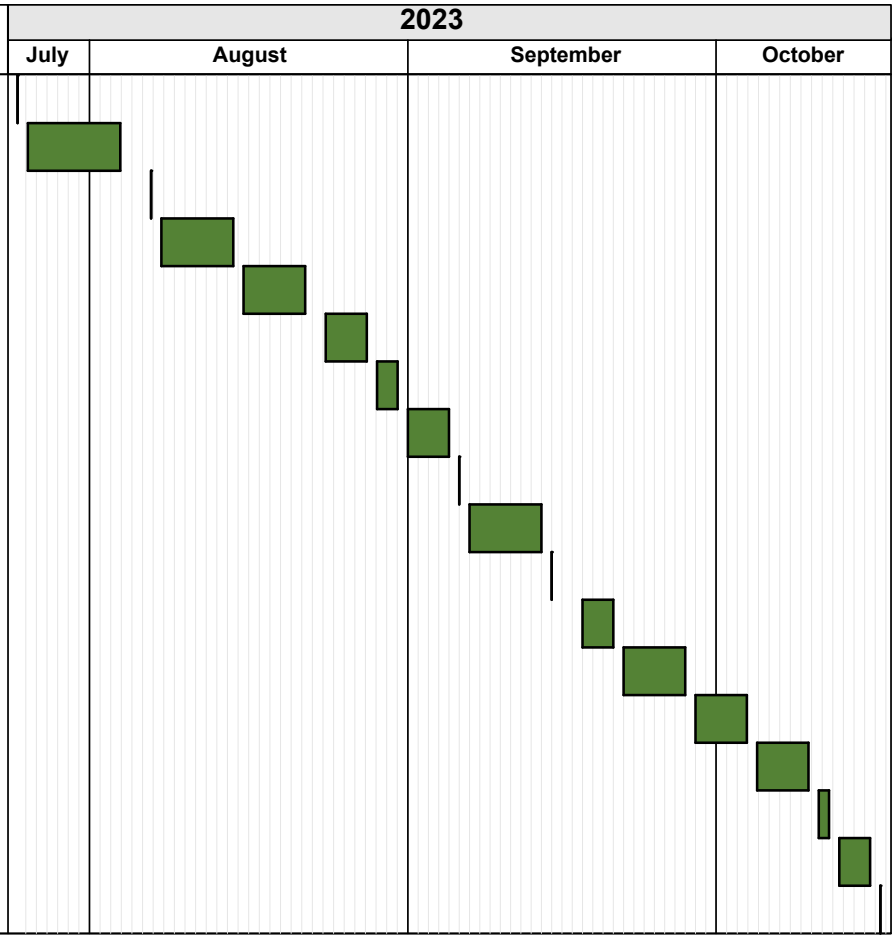


Figure 2: Construction Timeline

2.1. HERB RD. BOREHOLE DRILLING AND AQUIFER ZONE INTERVAL TESTING

2.1.1. Pilot Borehole Drilling

Weeks mobilized a reverse rotary drilling rig to the site starting July 24, 2023, and pilot borehole drilling began on July 26, 2023. Drilling proceeded during daylight hours, approximately 10 hours per day, five days a week. Drilling fluids were limited to bentonite. A Todd Groundwater geologist visited the site on July 26, 2023, at the beginning of drilling to confirm that methods aligned with the technical specifications. The technical advising team monitored drilling remotely by checking in with the driller daily to monitor progress. On August 3, 2023, the Weeks driller reported slow drilling at 565 feet below ground surface (ft-bgs) in blue and green well-cemented material. On August 4, 2023, a GHD geologist visited the site and confirmed that the lithologic samples resembled the Franciscan Complex, and ended the borehole at a total depth of 580 ft-bgs. Following completion of pilot drilling the borehole was prepared for geophysical logging. This included circulating the borehole fluids to remove all cuttings and provide consistent borehole fluid properties. Finally, all drill pipe was removed in preparation for logging. A Todd Groundwater geologist was on-site to log the remaining samples and observe the geophysical log on the following Monday, August 7, 2023.

2.1.2. Lithologic and Geophysical Logging

Lithologic samples were collected at five-foot intervals from 10 feet to total depth during pilot borehole drilling. Samples were examined, described, and archived with the boring designation, date, and depth. A lithologic log for the Herb Rd. borehole is provided in **Figure 3**.

Due to the nature of open hole drilling, depth-specific samples may be contaminated with sediments from shallower depths that have fallen from upper portions of the open borehole. Additional problems of sample integrity are related to rotary methods and include the loss of fine-grain formation material into the drilling fluid and the addition of bentonite, which may be difficult to differentiate from subsurface clays. The drilling method also skews the samples with regard to cobbles and boulders, since these materials are broken up into gravel and sand size particles during drilling. For these reasons, lithologic samples were used primarily as a qualitative guide to subsurface materials, while the geophysical logs were used to determine the exact depths where stratigraphic changes occurred. The geophysical log for the Herb Rd. borehole is provided in **Appendix B**.

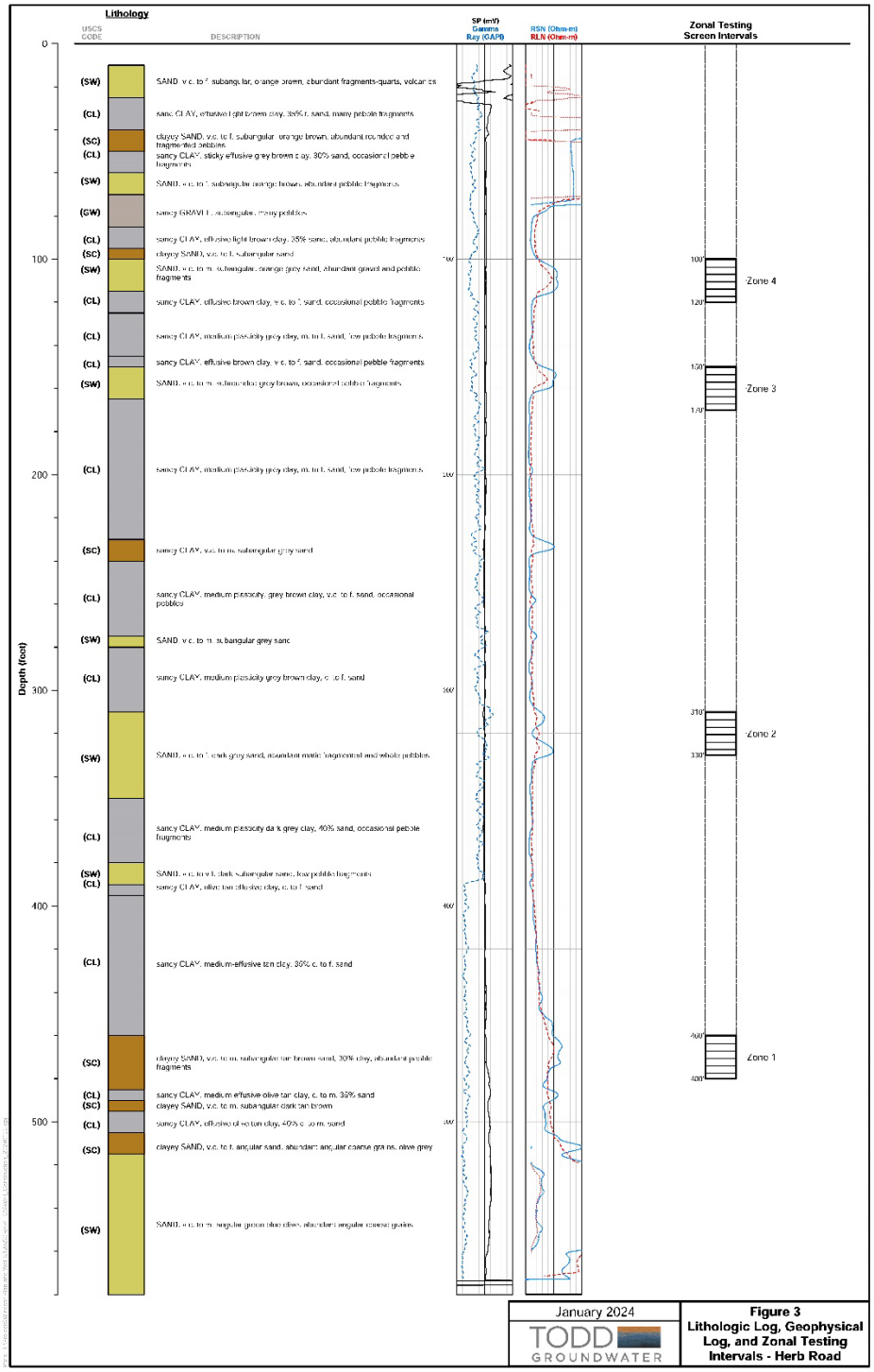


Figure 3: Lithologic, Geophysical Logs, and Zone Intervals, Herb Rd. Borehole

The geophysical logging program was designed to supplement the lithologic logs in evaluating the subsurface geology for the purpose of zone design. Stewart Well Logging Service ran the geophysical logs on August 7, 2023. Data were provided in paper and electronic formats. The logging program included an electrical resistivity log, spontaneous potential, and natural gamma radiation. The geophysical and lithologic logs are in general agreement, though the lithologic log does not capture the exact depth of every lithologic change (**Figure 3**).

2.1.3. Pilot Borehole Data Analysis

The lithologic and geophysical logs were analyzed to interpret the subsurface materials and select the intervals for aquifer zone interval testing. These analyses consisted of a comparative review of lithologic changes encountered during drilling, grain size distribution, and geophysical properties. The lithologic and geophysical data were used to identify distinct intervals with high resistivity and coarse material, which correlate with higher hydraulic conductivity. These zones were targeted for testing by the zone design put forward by the technical design team.

Todd Groundwater geologists identified four zones for testing and numbered them from deepest to shallowest to track the order in which they would be constructed, developed, and tested, shown in **Table 1**.

Table 1: Herb Rd. Zone Design

Zone	Upper Seal (ft-bgs)	Gravel Pack (ft-bgs)	Screen (ft-bgs)	Lower Seal (ft-bgs)
1	439-450	450-490 510-580	460-480	490-510
2	290-300	300-340 360-439	310-330	340-360
3	135-145	145-170 290-190	150-170	170-190
4	70-90	90-130	100-120	130-135

The shallowest aquifer zone (zone 4), spanning from 100 to 120 ft-bgs, consisted of orange-grey gravely subangular sand. Above this interval consists of interbedded light brown sandy clays and orange-brown poorly sorted clayey sands lacking substantial clean coarse beds. Below zone four from 120 to 150 ft-bgs, effusive brown sandy clays were encountered with occasional angular fragments of what were likely pebbles before being broken down in the drilling process. The third deepest zone consisted of grey-brown very coarse to medium subrounded sand spanning from 150 to 165 ft-bgs. Below zone three through 310 ft-bgs consisted of grey-brown effusive sandy clays interbedded with rare thin beds of gravely sands which were evident in pebble and gravel fragments as observed above. One of these

beds shows in the short normal resistivity log at 235 ft-bgs on **Figure 3** but was not substantial enough to be represented in the lithologic log. The second deepest zone (310 to 330 ft-bgs) consisted of dark grey very coarse to fine sand with abundant apparent mafic gravel and pebble fragments. Below zone two the borehole encountered dark grey sandy clays through 390 ft-bgs, at which point tan-brown sandy clay was encountered through 450 ft-bgs. The deepest aquifer zone of interest for sampling (zone 1 at 460-480 ft-bgs) consisted of tan-brown clayey very coarse to fine subangular sand with abundant pebble fragments. Below zone one interbedded olive tan sandy clays and clayey sands were present until 515 ft-bgs, after which the borehole encountered green-blue-olive very coarse to medium grained angular sand which appears to be Franciscan Complex broken up by the drilling process. The elevated resistivity values in this lowest portion of the borehole are consistent with a well-cemented highly lithified rock.

2.1.4. Aquifer Zone Interval Testing, Herb Rd. Borehole

The aquifer zone intervals were tested as described above with the seals, gravel, and screens placed as outlined in **Table 1**. Todd Groundwater staff conveyed the zone design to Weeks by email on August 7, 2023.

Construction of the bottom zone began upon completion of reaming the borehole to a 12-inch diameter to a depth of 510 ft-bgs on August 15, 2023. The perforated tool was set into place, and gravel and bentonite were added on August 16, 2023. The upper seal was revised at request of the driller from a twenty to a ten-foot thickness due to concerns around tool removal. The top of the seal was tagged to confirm thickness on the morning of August 17, 2023, which showed the bentonite had swelled an additional foot making an eleven-foot upper seal. Airlift development was started after confirming seal thickness, producing about 5 gallons per minute (GPM) of visibly turbid water. Airlift development continued through Friday, August 18 then the submersible pump was installed for pumping development on Monday, August 21, 2023. Pumping development produced 25 GPM of turbid water around 80 NTU which did not decrease with repeated pumping and stopping. Zone 1 sample was collected by Todd geologist on August 22, 2023, after two days of pumping development with little improvement in turbidity. This sample was collected after decreasing pumping rate to 2.5 GPM in hopes of reducing turbidity, but to little effect. Following sampling, all tools were removed from the borehole, the screen was washed, and zone two was constructed. Removal of zone one required all 40,000 pounds of lifting force Weeks was capable of with the equipment on site, reaffirming the decision to shorten the upper seal thickness.

Construction of zone two took place on August 24, 2023, following the dimensions outlined in **Table 1**. Zone two was airlifted for approximately five hours, producing an estimated 100 GPM, before the submersible pump was installed and pumping development began on August 25, 2023. Pumping development continued a second day on Monday, August 28, 2023, and developed quickly, allowing sampling by Todd geologist that afternoon with turbidites below 10 NTU.

Zone three construction went ahead on August 29, 2023, with no complication. This zone was airlifted August 30, 2023, producing an estimated 100 GPM. The submersible pump was installed, and pumping development achieved outflow below 10 NTU turbidity, allowing for GHD geologist to sample on August 31, 2023.

Zone four was constructed September 1 according to the dimensions on **Table 1**, airlifted September 4, pump-developed and sampled by GHD geologist on September 5, 2023. This zone was similarly productive as zones two and three, cleaning up and producing low turbidity water relatively quickly. The Herb Rd. borehole was sealed with neat cement on September 7, 2023, and Weeks began mobilization to the second site, the Arata Lane property.

2.1.5. Aquifer Zone Testing Results, Herb Rd. Borehole

Laboratory sample results for all zones of the Herb Rd. Borehole are tabulated in **Table 2.** These results are evaluated in a separate groundwater master planning report.

Table 2: Herb Rd. Laboratory Results

Well ID	As (ug/L)	Mn (ug/L)	TDS (mg/L)	Fe (ug/L)	NO3N(mg/L)	V (mg/L)	SiO2 (mg/L)	Ca (mg/L)	Mg (mg/L)	Alk_CaCO3 (mg/L)	Cl (mg/L)	F (mg/L)	PO4 (mg/L)	SO4 (mg/L)	TOC (mg/L)
MCL	10	50	500	300	10										
Herb Rd Zone 1	ND	77	340	1900	ND	ND	63	11	4.3	240	15	0.38	0.3	5.6	ND
Herb Rd Zone 2	150	700	250	140	0.2	ND	87	15	9.6	170	16	0.08	2.8	14	0.496
Herb Rd Zone 3	34	410	190	ND	ND	ND	58	12	13	120	25	0.09	1.2	4.1	ND
Herb Rd Zone 4	12	360	290	56	0.13	6.7	61	16	22	140	49	0.08	0.51	12	0.38

A dual transducer system was utilized during zone pumping development in order to record water levels throughout development and sampling with atmospheric pressure variation removed. These data were analyzed to glean insights into relative zone productivities. While development pumping and sample pumping directly following development is a poor estimation of a pumping test, it does provide the potential for relative aquifer zone productivity so long as seals effectively restrict flow and the temporary perforations and pumping equipment remain unchanged from one zone to the next. These data for the Herb Rd. borehole are presented in **Table 3** as specific capacities (SC) for each zone below, which is a measure of the GPM per foot of drawdown.

Table 3: Herb Rd. Zonal Pumping Data

Zone	Specific Capacity (GPM/ft-dd)	Duration (hours)	Pumping Rate (GPM)
1	15.0	3.25	10
2	1.86	8	25
3	11.6	6.7	25
4	28.7	4.25	24

It should be noted that these specific capacities are not entirely representative of each aquifer's hydrogeologic characteristics for a number of reasons. First, the low pumping rates of these pumping events are not likely to stress the aquifer over a large enough area to provide a representative transmissivity value. Second, the small thickness of most of these aquifer units means that storage releases from underlying and overlying confining units could contribute much of the observed outflow during short duration pumping events, which could lead to an overestimate of specific capacity. As can be seen in **Table 3**, these pumping events are fairly variable in their duration and pumping rates, making relative comparison more fraught.

2.2. ARATA LANE BOREHOLE DRILLING AND AQUIFER ZONE INTERVAL TESTING

2.2.1. Pilot Borehole Drilling

The reverse rotary drilling rig was moved from the Herb Rd. site to the Arata Lane site on September 7, 2023, and began drilling that same day. Drilling was slightly delayed due to minor rig repairs but reached the total depth of 600 ft-bgs after six days of drilling on September 14, 2023. Drilling remained on the same daylight weekday schedule as was adhered to for the Herb Rd borehole. A GHD geologist checked in on drilling methods and progress periodically during pilot drilling. A Todd Groundwater geologist visited the site to observe the geophysical logging, process drilling cuttings, and draft the lithologic log on September 15, 2023.

2.2.2. Lithologic and Geophysical Logging

Lithologic samples were collected at five-foot intervals from 10 to 600 ft-bgs during pilot borehole drilling. Samples were examined, described, and recorded with the date and depth. **Figure 4** shows the log next to the geophysical log.

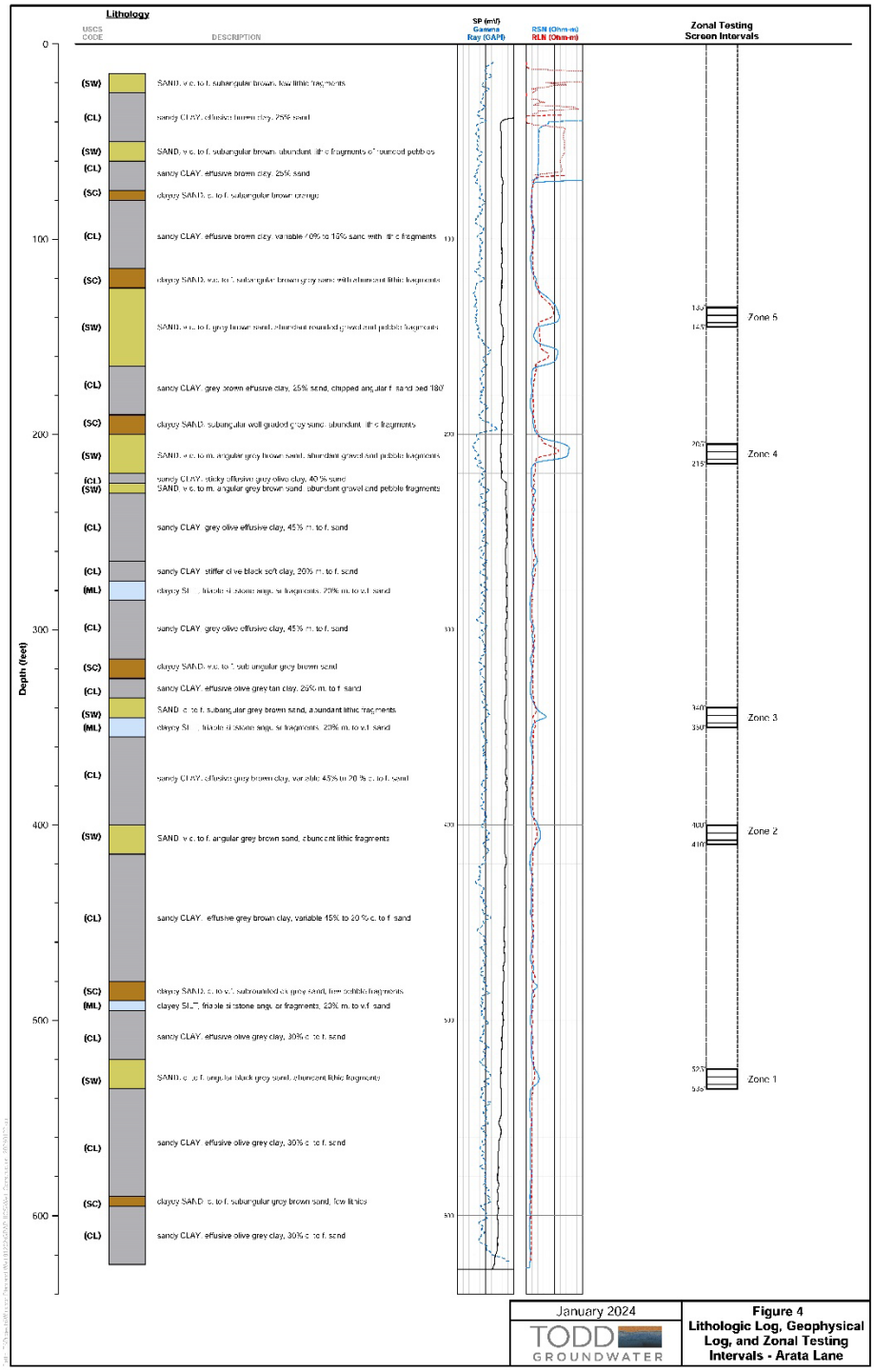


Figure 4: Lithologic, Geophysical Logs, and Zone Intervals, Arata Lane Borehole

As described in section 2.1.2, the lithologic samples may not align directly with the depths marked on each sample bag. The geophysical log provided a more accurate guide to the depths at which lithologic changes occurred. The Arata Lane Borehole geophysical log is provided in **Appendix B**.

Stewart Well Surveys ran the geophysical logs on September 15, 2023. Data were provided in paper and electronic formats. The logging program included electrical resistivity, spontaneous potential, and natural gamma radiation.

2.2.3. Pilot Borehole Data Analysis

The lithologic and geophysical logs were analyzed to interpret the subsurface stratigraphy and select the intervals for aquifer zone interval testing. The lithology of the Arata Lane borehole is characterized by interbedded coarse alluvial gravels and sands with sandy clays within the shallowest 220 feet and predominantly sandy clays below 220 ft-bgs with three noteworthy coarser sand units approximately ten feet thick or narrower at 345, 405, and 530 ft-bgs.

Todd Groundwater and GHD geologists identified five zones of interest and drafted the zone sampling design outlined in **Table 4**. It was determined that a ten-foot screen section would better isolate the narrow aquifer units encountered in this borehole. Weeks was able to modify their perforation tool to accommodate this setting.

Table 4: Arata Lane Zonal Design

Zone	Upper Seal (ft-bgs)	Gravel Pack (ft-bgs)	Screen (ft-bgs)	Lower Seal (ft-bgs)
1	513-523	523-537	525-535	537-557
2	385-395	395-412 432-513	400-410	412-432
3	328-338	338-352 372-385	340-350	352-372
4	193-203	203-217 237-328	205-215	217-237
5	123-133	133-147 167-193	135-145	147-167

The upper 130 feet of the borehole encountered interbedded poorly sorted clayey sands and gravels in thicker beds of sandy effusive brown clay beds. The fifth deepest, or shallowest zone (130 to 165 ft-bgs) consisted of a thin less resistive unit approximately five feet thick at 150 ft-bgs based on the geophysical log, as seen on **Figure 3**. This thin low resistivity bed in the middle of the unit was not represented in the lithologic log, which is not unusual for rotary mud drilling. The lithology of this shallowest zone consisted of poorly

sorted grey-brown sand with abundant gravel and pebble fragments which showed rounded faces and apparent fresh fractures assumed to be caused by the drilling process. Below this unit more sandy effusive brown clays were encountered through 200 ft-bgs, but with the addition of occasional pebble fragments. The fourth deepest aquifer zone (200 to 220 ft-bgs) and was comprised of angular grey-brown very coarse to medium sand with abundant gravel fragments as seen above. From 220 to 265 ft-bgs sandy clay was encountered with a similar grey-brown color as above, which transitioned to a stiffer olive-grey to black color through 275 ft-bgs. A semi-lithified friable olive-black sandy, clayey, silt was encountered from 275 to 285 ft-bgs. From 285 to 335 ft-bgs the borehole encountered olive grey effusive sandy clay with varying sand content from 10-45% of total volume. The third deepest aquifer zone identified for testing consisted of poorly sorted grey-brown sand with abundant angular fragments of darker lithics spanning from 345 through 345 ft-bgs. Friable olive grey sandy clayey silt similar to that encountered above was seen from 345 to 355 ft-bgs. More grey-brown effusive sandy clay with sand content varying from 20 to 45% total volume was seen from 355 to 400 ft-bgs. The second deepest aquifer zone identified for sampling consists of poorly sorted angular grey-brown very coarse to fine sand spanning from 400 to 415 ft-bgs. Grey-brown effusive sandy clay was encountered from 415 to 480 ft-bgs, followed by coarse to very fine dark grey subrounded sand with rare pebble fragments as above to 490 ft-bgs. A friable sandy silt similar to silts encountered above was seen from 490 to 495 ft-bgs. Sandy effusive olive grey clay was seen from 495 to 520 ft-bgs. The deepest aquifer unit identified for testing spanned from 520 to 535 ft-bgs and consisted of coarse to fine angular black grey sand with abundant angular fragments. More sandy effusive olive grey clay was encountered from 535 to total borehole depth of 625 ft-bgs.

2.2.4. Aquifer Zone Interval Testing, Arata Lane Borehole

The lithologic and geophysical logs were analyzed by the technical advising team and identified the five zones shown on **Table 4**. This design was conveyed to Weeks the following Monday after geophysical logging September 18, 2023.

Reaming past 557 ft-bgs and construction of zone one was completed on September 22, 2023, with dimensions as noted in **Table 4**. Airlift development of zone one began Monday, September 25, 2023, and the submersible pump was installed the following day. Variable high turbidity and pumping water level fluctuations caused concern of seal bypass, so approximately five more feet of bentonite and gravel was added to the upper seal and allowed to hydrate for two hours before resuming pumping. Unexpected water level fluctuations and surges in water turbidity decreased, but the submersible motor shorted out the morning of September 27, 2023. A new motor was installed and sampling by Todd Groundwater geologist with turbidity below 10 NTU was achieved on September 28, 2023.

Zone two was constructed the following day, airlifted October 2, 2023, and submersible pumping development began the following day. Sampling of zone two was completed by a GHD geologist on October 4, 2023, after decreasing the pumping rate to 5 GPM to decrease turbidity below 10 NTU.

Zone three was constructed October 5, 2023, and airlift development continued through the next day. The submersible pump was installed and a sample was collected by a GHD geologist on October 9, 2023 while outflow had a turbidity of 30-40 NTU. It was decided to sample this zone despite the elevated turbidity due to diminishing returns in turbidity decreases with successive pumping cycles.

Weeks constructed zone four on October 10, 2023, under GHD geologist observation and achieved a 6.5 NTU sampling the morning of October 12, 2023, following a very rapid development. Zone five was constructed the afternoon of October 12, 2023, and developed through the next day. A GHD geologist was able to sample the following Monday, October 16, 2023, after another very quick development. Airlifting of zone five was estimated to produce 80 GPM with stable water levels, though the method of flow measurement was less than reliable. The Arata Lane remaining open borehole was grouted from bottom to top with neat cement on October 17, 2023.

2.2.5. Aquifer Zone Testing Results, Arata Lane Borehole

Laboratory sample results for all zones of the Arata Lane Borehole are tabulated in **Table 5.** These results are evaluated in a separate groundwater master planning report.

Table 5: Arata Ln. Laboratory Results

Well ID	As (ug/L)	Mn (ug/L)	TDS (mg/L)	Fe (ug/L)	NO3N(mg/L)	V (mg/L)	SiO2 (mg/L)	Ca (mg/L)	Mg (mg/L)	Alk_CaCO3 (mg/L)	Cl (mg/L)	F (mg/L)	PO4 (mg/L)	SO4 (mg/L)	TOC (mg/L)
MCL	10	50	500	300	10										
Arata Lane Zone 1	140	540	300	160	ND	ND	80	13	7.6	180	15	0.08	1.6	13	0.446
Arata Lane Zone 2	92	800	290	170	ND	ND	74	16	10	160	17	0.1	1.6	11	0.619
Arata Lane Zone 3	130	890	280	82	ND	ND	79	16	11	160	16	0.1	1.6	9	0.514
Arata Lane Zone 4	33	820	210	ND	ND	ND	75	8.9	11	110	16	0.11	0.87	1.9	0.28
Arata Lane Zone 5	6.3	630	210	80	ND	12	66	7.9	14	95	38	0.13	0.35	5.2	0.326

The same dual transducer system was used to capture the Arata Lane site water level trends during development and sampling. The specific capacities from these data were analyzed by a GHD geologist and are presented in **Table 6** below.

Table 6: Arata Lane Zonal Pumping Data

Zone	Specific Capacity (GPM/ft-dd)	Duration (hours)	Pumping Rate (GPM)
1	0.14	5.75	24
2	0.12	1.7	6
3	NA	NA	NA
4	7.82	3.5	24
5	NA	NA	NA

Transducer data was not collected for zones 3 and 5, making comparison of apparent capacity of these more productive zones not possible aside from anecdotal measurements of airlifting flow volumes. As mentioned in section 2.1.5, these data are not to be treated as proper pumping test data.

APPENDIX A

Herb Rd. and Arata Lane Boreholes Drilling and Testing Photographs



Herb Rd. pilot borehole drilling



Building zone 1 on Herb Rd. Site



Filter pack material on Herb Rd. Site



Herb Rd. equipment during drilling



Perforated section used on both sites



Coated bentonite pellets for seals



Turbidity testing nearing completion on Arata Ln. Site



Zone construction casing

TODD GROUNDWATER

Town of Windsor Arata Ln. Zonal Testing

APPENDIX B

Herb Rd. and Arata Lane Boreholes
Geophysical Log

STEWART
WELL LOGGING SERVICE

ELECTRIC - GAMMA RAY-TEMPERATURE LOG

Stewart Well Logging Service
· Phone: (530)908-6928 · Email: STEWARTWELLLOGGING@GMAIL.COM

Filing No.

Job No.
1420

COMPANY **Weeks Drilling & Pump Co.**

WELL **Town Of Windsor Herb Rd. Well**

FIELD **Windsor**

STATE **California** COUNTY **Sonoma**

LOCATION:

SEC: **02** TWP: **08N** RGE: **09W** LAT.: **38.5632792** LONG.: **-122.8317649**

OTHER SERVICES:
None

Permanent Datum: **Ground Level** Elev.: **141** Ft. Elevs.: K.B. ____ Ft.
Log Measured From: **Ground Level** , **0** Ft. Above Perm. Datum D.F. ____ Ft.
Drilling Measured From: **Ground Level** G.L. **141** Ft.

Run	**One**			
Date	**Aug 07, 2023**			
Depth-Driller	**580** Ft	Ft	Ft	Ft
Depth-Logger	**578** Ft	Ft	Ft	Ft
Top Logged Interval	**10** Ft	Ft	Ft	Ft
Btm Logged Interval	**578** Ft	Ft	Ft	Ft
Casing-Driller	**10** In @ **10** Ft	In @ Ft	In @ Ft	In @ Ft
Casing - Logger In@Ft	**10** In @ **10** Ft	In @ Ft	In @ Ft	In @ Ft
Bit Size	**8.75** In @ **580** Ft	In @ Ft	In @ Ft	In @ Ft
Time On Bottom	**1115**			
Type Fluid in Hole	**Bentonite**			
Density / Viscosity				
pH / Fluid Loss	ml	ml	ml	ml
Source of Sample	**Lift Pump**			
Rm @ Mea. Temp	**14** @ **75** °F	@ °F	@ °F	@ °F
Rmf @ Mea. Temp	**14.3** @ **75** °F	@ °F	@ °F	@ °F
Rmc @ Mea. Temp	**9.3** @ °F	@ °F	@ °F	@ °F
Source Rmf / Rmc	**Meas.**			
Rm @ BHT	**82** @ °F	@ °F	@ °F	@ °F
Time Since Circ.	**1** Hr	Hr	Hr	Hr
Max. Rec. Temp.	**83** °F	°F	°F	°F
Van No. / Location	**SWLS-2** **WOODLAND**			
Recorded By	**Stewart**			
Witnessed By	**Tim**			

This Eagle Plot Heading Conforms To API RP 31A

Weeks Drilling & Pump Co.
Town Of Windsor Herb Rd. Well
Aug 07, 2023

ELECTRIC - GAMMA RAY-TEMPERATURE LOG

Single Page

DEPTHS
(Feet)

0 Gamma Ray(api) 200
< - S.P. (10 mV/div) S.P. + >

100 64 Inch Normal (ohmm²/m) x10 1000
0 64 Inch Normal (ohmm²/m) 100
100 16 Inch Normal (ohmm²/m) x10 1000
0 16 Inch Normal (ohmm²/m) 100

75 Temperature (°F) 85
0 Single Point(ohms) 100

50'
100'
150'
200'
250'
300'
350'
400'
450'
500'
550'

Log Depth 578'

STEWART
WELL LOGGING SERVICE

ELECTRIC - GAMMA RAY-TEMPERATURE LOG

Stewart Well Logging Service
· Phone: (530)908-6928 · Email: STEWARTWELLLOGGING@GMAIL.COM

Filing No.

Job No.
1486

COMPANY **Weeks Drilling & Pump Co.**

WELL **Arata Lane**

FIELD **Windsor**

STATE **California** COUNTY **Sonoma**

LOCATION:

SEC: **11** TWP: **08N** RGE: **09W** LAT.: **38.5607459** LONG.: **-122.8212181**

OTHER SERVICES:
None

Permanent Datum: **Ground Level** Elev.: **138** Ft. Elevs.: K.B. ____ Ft.
Log Measured From: **Ground Level** , **0** Ft. Above Perm. Datum D.F. ____ Ft.
Drilling Measured From: **Ground Level** G.L. **138** Ft.

Run	**One**			
Date	**Sep 15, 2023**			
Depth-Driller	**630** Ft	Ft	Ft	Ft
Depth-Logger	**630** Ft	Ft	Ft	Ft
Top Logged Interval	**10** Ft	Ft	Ft	Ft
Btm Logged Interval	**630** Ft	Ft	Ft	Ft
Casing-Driller	**10** In @ **10** Ft	In @ Ft	In @ Ft	In @ Ft
Casing - Logger In@Ft	**10** In @ **10** Ft	In @ Ft	In @ Ft	In @ Ft
Bit Size	**8.75** In @ **8.75** Ft	In @ Ft	In @ Ft	In @ Ft
Time On Bottom	**1140**			
Type Fluid in Hole	**Bentonite**			
Density / Viscosity				
pH / Fluid Loss	ml	ml	ml	ml
Source of Sample	**Circ.**			
Rm @ Mea. Temp	**12.6** @ **75** °F	@ °F	@ °F	@ °F
Rmf @ Mea. Temp	**12.7** @ **75** °F	@ °F	@ °F	@ °F
Rmc @ Mea. Temp	**8.6** @ °F	@ °F	@ °F	@ °F
Source Rmf / Rmc	**Meas.**			
Rm @ BHT	**78** @ °F	@ °F	@ °F	@ °F
Time Since Circ.	**1** Hr	Hr	Hr	Hr
Max. Rec. Temp.	**79** °F	°F	°F	°F
Van No. / Location	**SWLS-2** **WOODLAND**			
Recorded By	**Stewart**			
Witnessed By	**Tim**			

This Eagle Plot Heading Conforms To API RP 31A

Weeks Drilling & Pump Co.
Arata Lane
Sep 15, 2023

ELECTRIC - GAMMA RAY-TEMPERATURE LOG

Single Page

DEPTHS
(Feet)

0 Gamma Ray(api) 200
< - S.P. (10 mV/div) S.P. + >

100 64 Inch Normal (ohmm²/m) x10 1000
0 64 Inch Normal (ohmm²/m) 100
100 16 Inch Normal (ohmm²/m) x10 1000
0 16 Inch Normal (ohmm²/m) 100

75 Temperature (°F) 85
0 Single Point(ohms) 50

50'
100'
150'
200'
250'
300'
350'
400'
450'
500'
550'
600'

Log Depth 630'

APPENDIX F

Estimated Cost Tables for Water Supply Alternatives

Itemized cost estimates were prepared for each water supply alternative that was considered logistically feasible. The cost estimates are presented in the tables below and are considered Class 5 (rough order of magnitude) cost estimates. This level of accuracy was sufficient to support a ranking of the alternatives. Details of estimated operation and maintenance costs for all alternatives are presented in a separate table at the end. All costs are in 2023 dollars. The green-highlighted items are permitting and design items requiring near-term funding.

Table F-1. Cost Estimate for Esposti Well Treatment Plant

Cost Estimate for Esposti Supply Well Treatment Plant			
DESCRIPTION	**ONE STEP: OXIDATION/FILTRATION**		
	ESTIMATE		
	GHD Fee	**Trussell Fee**	**TOTAL**
Site Survey[1]	$110,000		**$110,000**
System Design and Bid Package			**$770,000**
Basis of Design Report[2]	$30,000	$75,000	$105,000
30% Design Drawings and Specifications	$150,000	$80,000	$230,000
60% Design Drawings and Specifications	$250,000	.	$250,000
90% Design Drawings and Specifications	$100,000	$30,000	$130,000
Bid Documents	$40,000	$15,000	$55,000
Permitting[3]	$45,000	$70,000	**$110,000**
Well Pump Development[4]	$40,000		**$40,000**
Piloting and Bench Scale Testing[5]		$60,000	**$60,000**
Engineering Support	$60,000	$40,000	**$100,000**
Prefabricated Treatment Plant			**$840,000**
Contractor Site Work			**$600,000**
General Conditions (8%)			**$120,000**
Bond / Insurance (2%)			**$30,000**
O&P (18%)			**$260,000**
Construction Management	$150,000		**$150,000**
Subtotal			**$3,100,000**
Predesign-Level Estimating Contingency (30%)			**$930,000**
Predesign-Level Project Budget Estimate			**$4,120,000**
Net present value of O&M costs			**$4,230,000**
Total project net present value			**$8,350,000**

1. Costs are in 2023 dollars, rounded to nearest $5,000.
2. Site surveying includes location selection, surveying, geotechnical evaluation, visual and noise impact assessments, sewer capacity evaluation, field verification, and power connection evaluation.
3. Report to compile predesign results and finalize treatment process
4. Includes CEQA Plus analysis, DDW application, and sewer discharge permit application.
5. Installation of permanent pump for 400 gpm system
6. Includes pilot testing of Cat. Oxidation (Mn & As) - field trailer and well pumping
7. Net present value assumes 30-year period and 3% discount rate.
8. See Table F-6 for O&M cost details.

Table F-2 Cost Estimate for Single Deep Well

Cost Estimate for Single Deep Well	
Cost Item	**Estimated Cost[1]**
Pre-Construction Costs	
BODR, 30-60-90-100% design, bid documents	$326,000
Initial studies, CEQA, DWSAP and Local Permitting	$122,000
Engineering support during bidding	$10,000
Subtotal pre-cnstruction costs	**$458,000**
Construction Phase Costs	
Production well drilling and construction[2]	$520,000
Well development and testing	$100,000
SCADA equipment	$120,000
40 HP pump & motor, installed[3]	$60,000
Contractor site work[4]	$224,000
Subtotal construction costs	**$1,024,000**
General Conditions (8% of contractor site work)	$18,000
Bond / Insurance (2% of contractor site work)	$4,000
O&P (18% of contractor site work)	$40,000
Construction Management	$76,000
Subtotal capital costs	**$1,620,000**
Predesign-Level Estimating Contingency (30%)	$486,000
Predesign-Level Capital Cost Estimate	**$2,106,000**
Net present value of O&M costs	$1,999,000
Predesign-Level Total Cost Estimate	**$4,105,000**

Assumptions: well is 500 ft deep; 400 gpm; 40 ft static depth to water

[1] Costs are in 2023 dollars

[2] Based on construction cost for similar-sized municipal well at San Juan Oaks in 2021. Includes mobilization and demobilization; conductor casing drilling, construction, and materials; pilot borehole drilling and geophysical logging; reaming to 24-inches; and construction of 16-inch diameter well with mild steel casing, stainless steel wire-wrapped screen, dielectric coupler, filter pack, and seal. Well development cost listed separately.

[3] Interpolation of 2024 Franklin Electric 40 HP submersible pump price at R.C. Worst Co.) and SWRCB 2020 cost estimate for 25 HP deep well turbine pump for 800' static DTW.

[4] Assume equals 70% of Esposti treatment plant estimate because no treatment equipment or sewer connection

See Table F-7 for O&M cost details.

Table F-3. Cost Estimate for Two Shallow Wells

Cost Estimate for Two Shallow Wells	
Cost Item	**Estimated Cost[1]**
Pre-Construction Costs	
BODR, 30-60-90-100% design, bid documents	$360,000
Initial studies, CEQA, DWSAP and Local Permitting	$135,000
Engineering support during bidding	$10,000
Subtotal pre-construction phase	**$505,000**
Construction Phase Costs	
Production well drilling and construction[2]	$660,000
Well development and testing	$160,000
SCADA equipment	$150,000
Two 25 HP pumps & motors, installed[3]	$65,000
Contractor site work[4]	$335,000
Subtotal construction phase	**$1,370,000**
General Conditions (8% of contractor site work)	$30,000
Bond / Insurance (2% of contractor site work)	$5,000
O&P (18% of contractor site work)	$60,000
Construction Management	$80,000
Subtotal capital costs	**$2,050,000**
Predesign-Level Estimating Contingency (30%)	$615,000
Predesign-Level Capital Cost Estimate	**$2,665,000**
Net Present Value of O&M Costs	$2,235,000
Predesign-Level Total Cost Estimate	**$4,900,000**

Assumptions: two 230-foot deep wells; 200 gpm each; 40 ft static depth to water

[1] Costs are in 2023 dollars, rounded to nearest $5,000.

[2] Weeks Drilling rough estimate of "less than $500,000" for each shallow well at Los Amigos site, including development and testing (3/26/2024). Subtracted $50,000 to reflect carbon versus stainless steel casing and screen.

[3] 2024 price for two Franklin electric 6-inch, 25HP, 200 gpm submersible pumps and motors at R.C. Worst, Inc. ($35,000) plus installation ($30,000)

[4] Same items as for single deep well but increased by 50% to include the second

[5] See Table F-7 for O&M cost details.

Table F-4. Cost Estimate for Two Shallow Wells with ASR

Cost Estimate for Two Shallow Wells with ASR	
Cost Item	**Estimated Cost[1]**
Pre-Construction Costs	
BODR, 30-60-90-100% design, bid documents	$395,000
Initial studies, CEQA, DWSAP and Local Permitting	$135,000
Design and permit ASR pilot study	$10,000
Engineering support during bidding	$10,000
Subtotal pre-construction phase	**$550,000**
Construction Phase Costs	
Production well drilling and construction[2]	$780,000
Well development and testing	$160,000
SCADA equipment	$170,000
Two 25 HP pumps & motors, installed[3]	$65,000
Contractor site work[4]	$390,000
Subtotal construction phase	**$1,565,000**
General Conditions (8% of contractor site work)	$30,000
Bond / Insurance (2% of contractor site work)	$10,000
O&P (18% of contractor site work)	$70,000
Construction Management and Inspection	$80,000
Subtotal capital costs	**$2,305,000**
Predesign-Level Estimating Contingency (30%)	$690,000
ASR pilot study for RWQCB[5]	$165,000
Predesign-Level Capital Cost Estimate	**$3,160,000**
Net Present Value of O&M Costs	$3,450,000
Predesign-Level Total Cost Estimate	**$6,610,000**

Assumptions: two 230-foot deep wells; 200 gpm each; 40 ft static depth to water

[1] Costs are in 2023 dollars, rounded to nearest $5,000.

[2] Equals the estimate for two shallow extraction wells adjusted to add stainless steel casing and the injection drop pipe.

[3] 2024 price for two Franklin electric 6-inch, 25HP, 200 gpm submersible pumps and motors at R.C. Worst, Inc. ($35,000) plus installation ($30,000)

[4] Same items as for single deep well but increased by 50% to include the second well. For ASR, includes costs for additional valves, flow meters and pressure gages for injection/extraction switching at each well, and excavation of small percolation basins for injection backflush water. Includes only on-site infrastructure; additional pipelines will be needed to connect to off-site Town water and sewer mains.

[5] Includes $108,000 for installing one monitoring well.

[6] See Table F-7 for O&M cost details.

Table F-5. Cost Estimate for Indirect Potable Reuse

Cost Estimate for Indirect Potable Reuse	
Cost Item	**Estimated Cost[1]**
Capital Costs[2]	
Advanced water treatment plant (800 gpm; 1.2 MGD)	Included in total
Initial studies, CEQA, and Local Permitting	Included in total
State permitting (DDW, RWQCB)	Included in total
Four deep wells (2 injection; 2 extraction)	Included in total
Two monitoring wells	Included in total
Recycled water pipelines to injection wells	Included in total
Predesign-Level Capital Cost Estimate[3]	**$30,000,000**
Net Present Value of O&M Costs[4]	$57,230,000
Predesign-Level Total Cost Estimate	**$87,230,000**

Assumptions: 800 gpm advanced water treatment plant with reverse osmosis; two 600-foot deep injection wells each with 200 gpm capacity; two 600-foot-deep extraction wells each with 400 gpm capacity; two 600-foot-deep monitoring wells.

[1] Costs are in 2023 dollars, rounded to nearest $10,000.

[2] List of capital cost items is illustrative, not exhaustive.

[3] Estimated from cost-versus-capacity regression equation from survey of "medium sized" IPR plants in inland locations in the United States (Herman, 2017), adjusted to 2023 dollars.

[4] Estimated annual O&M cost for 1.2 MGD treatment plant is $2.92 million from Herman (2017) adjusted to 2023 dollars. Net present value based on 30 years at 3% discount rate.

[5] Includes $108,000 for installing one monitoring well.

[6] See Table F-7 for O&M cost details.

Table F-6. Cost Estimate for Esposti Well Treatment Plant Operation and Maintenance

Annual O&M Costs for Esposti One-Step Treatment				
Description	Quantity		Estimate	
	Number	Unit	Unit Cost	Annual Cost
Monthly Costs				
Electricity	6	Month	$16,650	$99,900
Disinfection/oxidation	6	Month	$3,350	$20,100
Staff labor	6	Month	$4,780	$28,680
Sampling and analysis	6	Month	$2,000	$12,000
Ferric chloride	6	Month	$6,010	$36,060
Long-term Maintenance Costs				
Greensand Plus media replacement	0.2	Year	$17,870	$3,574
Non-routine analysis	6	Month	$650	$3,900
Equipment repair and replacement	6	Month	$1,940	$11,640
Total Pre-Design Level O&M Cost Estimate				**$216,000**

Table F-7. Estimated Operation and Maintenance Costs for Water Supply Alternatives

O&M Cost Item	Esposti Treatment[1]	Single Deep Well[2]	Two Shallow Wells[3]	Two Shallow ASR Wells[4]	Indirect Potable Reuse[5]
Electricity[6]	$99,900	$81,000	$76,000	$114,000	$614,433
Disinfection	$20,100	$1,000	$1,000	$1,000	Included in total
Labor	$28,680	$8,424	$13,000	$26,000	$482,000
Sampling and analysis	$12,000	$10,000	$20,000	$30,000	Included in total
Ferric chloride	$36,060	n.a.	n.a.	n.a.	n.a.
Greensand filter media	$3,574	n.a.	n.a.	n.a.	n.a.
Reverse osmosis brine disposal	n.a.	n.a.	n.a.	n.a.	Included in total
Non-routine analysis	$3,900	n.a.	n.a.	n.a.	Included in total
Equipment repair and replacement	$11,640	$2,000	$4,000	$5,000	Included in total
Total annual O&M cost	$216,000	$102,000	$114,000	$176,000	$2,920,000
Net present value of O&M cost	$4,234,000	$1,999,000	$2,234,000	$3,450,000	$57,233,000

Notes:

All estimates are in 2023 dollars. Inflation from prior years calculated using the California Construction Cost Index.

[1] Costs from Trussell (2022) in Appendix A, as itemized and updated by Trussell in 2024.

[2] Pumping cost assumes flow of 400 gpm, total dynamic head of 310 feet, wire-to-water efficiency of 0.60, electricity cost of $0.45/kWh.
Disinfection cost per well is half of Russian River well cost due to 6 months/year operation.
Labor estimated at $27/hr, 6 hr/wk, 52 wk/yr.
The Town's current annual laboratory cost per well for water quality monitoring is approximately $10,000.

[3] Electricity cost for pumping lower due to smaller static depth to water at the Los Amigos site.
Labor cost assume equal to 150% of single well cost because of smaller travel time per well (both wells at one site).

[4] Water quality monitoring cost estimate higher than for two shallow extraction-only wells due to inclusion of a monitoring well, additional constituents, and possibly more frequent sampling.

[5] Overall O&M cost estimate for a 400 gpm (0.6 MGD) IPR plant is from a cost-versus-capacity regression line based on a survey of IPR plants all larger than 0.6 MGD (Herman, 2017). Power and labor costs are major components of O&M, and independent estimates are show for illustration. The typical energy cost for wastewater reverse osmosis is 221 kWh/m3, evaluated here at $0.49/kWh. Advanced wastewater treatment plants require 24/7 staffing by Level 3 or higher operators, for which a pay rate of $55/hr is typical (Guzman, 2024).