Well Station Evaluation Study

CITY OF SPOKANE

HOFFMAN, RAY STREET, AND WELL ELECTRIC

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WELL STATION EVALUATION STUDY

Welcome!

The City of Spokane (City) recently completed an evaluation of capital improvement and potential expansion options for three of its existing drinking water source facilities (Hoffman, Ray Street, and Well Electric) to help protect and ensure the long-term reliability of these facilities. The City owns and operates a total of seven well stations, which are the City's sole water supply sources and provide high-quality drinking water to its customers.

Water is delivered from these well stations via three primary pressure zones in the City's distribution system: the Low, Intermediate, and North Hill pressure zones. The well stations withdraw groundwater from the Spokane Valley–Rathdrum Prairie (SVRP) Aquifer. Some of the well stations consist of multiple, large-diameter concrete and brick-lined excavations ("caisson" wells) with multiple high-capacity pumps inside each caisson. Only one station—the Havana Street Wellfield, which is currently under construction—contains conventional vertical wells, which are commonly found elsewhere in the SVRP Aquifer and in most other groundwater-dependent regions.

This booklet summarizes findings from site investigations and reviews of existing conditions at the City's Hoffman, Ray Street, and Well Electric well stations, and provides recommendations for options to regain lost production capacity and/or expand groundwater development for greater operational and production redundancy.

Topic Summary and Study Purpose

The purpose of the evaluation was to identify the most cost-effective ways to maintain or increase the supply resiliency of the Hoffman, Ray Street, and Well Electric well stations, whether by modifying existing facilities and/or constructing additional groundwater production facilities. The overall goal is to determine the most cost-effective way to maximize the efficiency, redundancy, and resiliency of each well station.

INTRODUCTION TO THE AQUIFER

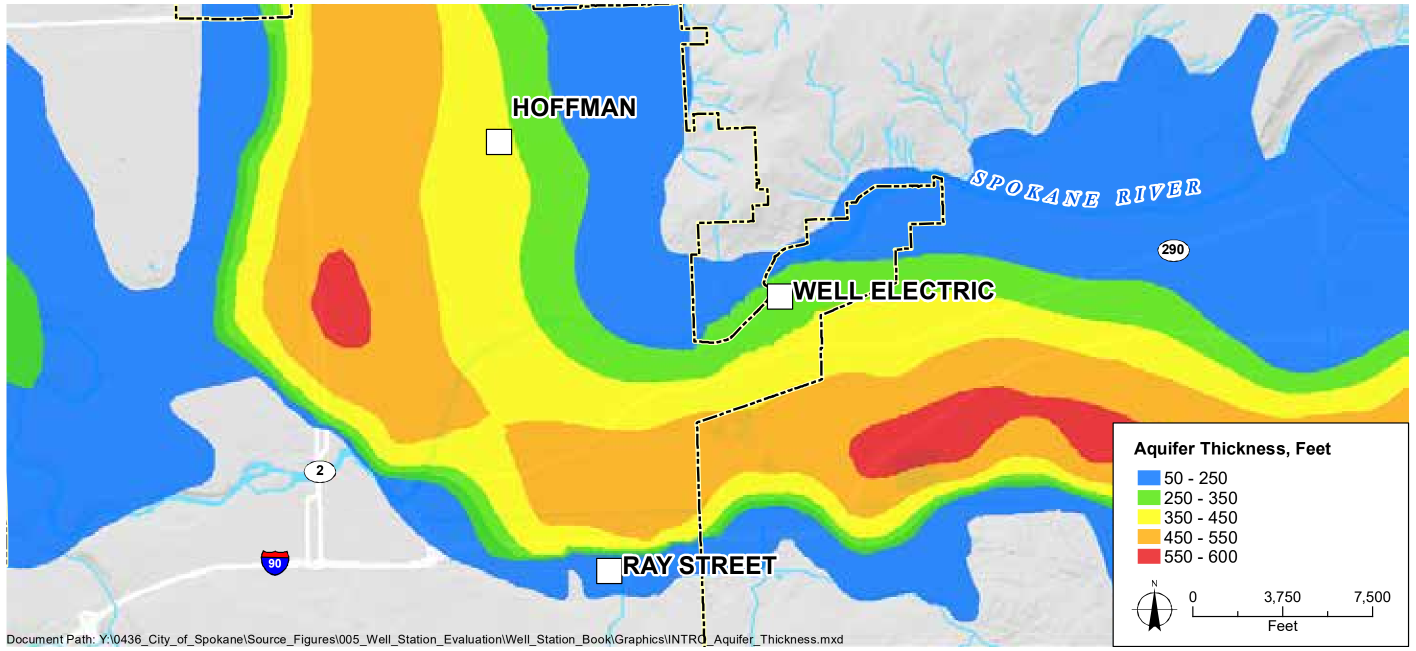

Figure 1. Contour map of estimated aquifer thickness (contour interval 50 feet). Courtesy of GSI Water Solutions, Inc.

Overview

The SVRP Aquifer underlies the eastern, central, and northern portions of the City and is the exclusive source of water supply for the City and the majority of the Spokane/Coeur d'Alene metropolitan region. The SVRP Aquifer largely consists of a single sand and gravel unit that is underlain and laterally bounded by granites, basalts of the Columbia River Basalt Group (CRBG), and low-permeability clay (Latah Formation). The SVRP Aquifer is unconfined and generally characterized as highly productive and highly transmissive.

Caisson wells completed in the aquifer are known to produce up to tens of millions of gallons per day with minimal drawdown, commonly less than 10 feet. Aquifer tests conducted by the City during the 1990s in the caissons for the Central and Nevada well stations produced aquifer transmissivity estimates ranging from approximately 600,000 to 1,300,000 square feet per day (feet^2/day) and hydraulic conductivity estimates ranging from 2,500 to 3,000 feet/day. More recent tests at other well stations—including the Havana Well Station under construction—have produced hydraulic conductivity estimates as high as 15,000 feet/day.

What We Know

Within the portion of the SVRP Aquifer underlying the City, groundwater primarily flows from the east to the west and north, following the general topographic surface of the Spokane Valley and Hillyard Trough. Regionally, groundwater levels range in elevation from approximately 1,500 feet North American Vertical Datum of 1988 (NAVD88) at the confluence of the Spokane and Little Spokane Rivers northwest of the City to approximately 2,000 feet NAVD88 at the Washington/Idaho state line, and to nearly 2,100 feet NAVD88 at the upgradient margins of the aquifer near Lake Pend Oreille and Coeur d'Alene Lake in Idaho.

Recharge of the SVRP Aquifer is primarily from infiltration of rainfall and snowmelt runoff from these lakes, from tributary runoff entering the valley from higher elevations in the watershed, and as recharge from the Spokane River over portions of the aquifer. Natural groundwater discharge is primarily to gaining sections of the Spokane River that are located just east of the eastern City limits (near Sullivan Road) and between Upriver Dam and the Greene Street Bridge.

Natural discharge also occurs as subsurface discharge into the valley containing the Little Spokane River. Human-derived groundwater withdrawal from the SVRP Aquifer occurs in the form of municipal and irrigation pumping. A portion of the pumped groundwater that is used indoors returns to the river after treatment at wastewater treatment plants owned and operated by the City of Spokane, Spokane County, and municipalities in Idaho. The remainder of the pumped groundwater is used outdoors; some of this outdoor water is lost to evaporation and plant water uptake, while the remainder infiltrates downwards to the aquifer and thereby provides a certain amount of "return flow" recharge to the local aquifer system.

What Uncertainties Remain?

Because of the aquifer's extremely prolific water-bearing capacity, most production wells penetrate only 50 to 100 feet into the water table, and only a small number of drilled holes (electrical grounding wells) have penetrated more than half of the aquifer's total thickness (Figure 1). Accordingly, the lithology, depth, and saturated thickness of the aquifer are not precisely known in most locations and are only generally known from the grounding well data, regional-scale geologic mapping studies, and airborne geophysical (gravity) surveys.

Additionally, the aquifer is thought to consist of a single thick aquifer (Figure 2) in most areas except in Hillyard Trough (Figure 3), where it appears to consist of separate upper and lower systems.

Recent exploratory drilling at the Well Electric Well Station site also identified the existence of a deep sand unit lying underneath the gravel-dominated deposits that are observed at most locations in the aquifer. Most wells in the region are too shallow to provide a full understanding of these subsurface conditions.

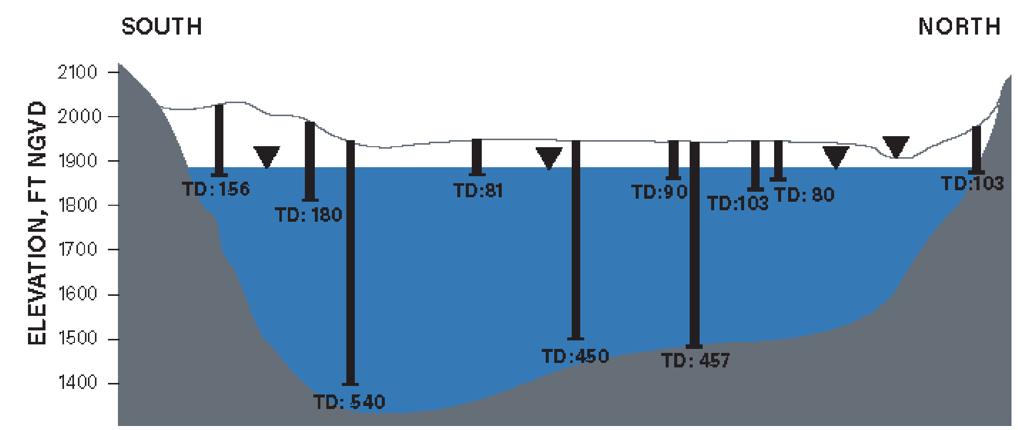

Figure 2. South-to-north cross section of aquifer showing thickness along eastern City limits. Courtesy of CH2M HILL, 1998

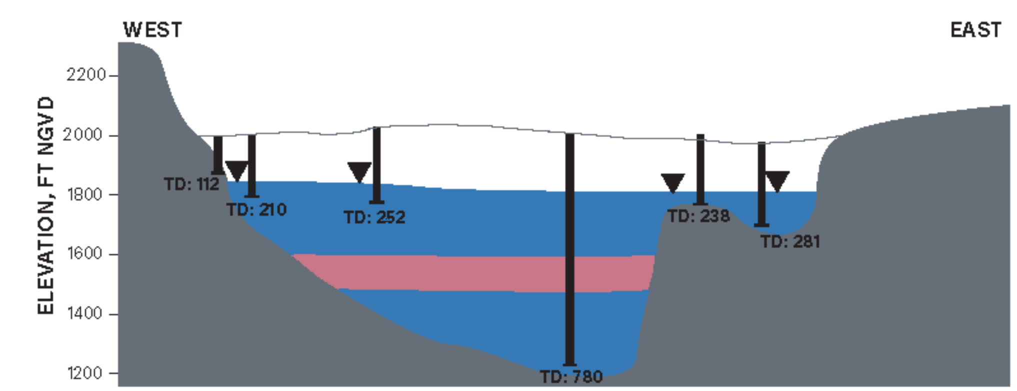

Figure 3. West-to-east cross section of the SVRP Aquifer in Hillyard Trough, near northern City limits, showing the aquifer's bifurcation into upper and lower units. Courtesy of CH2M HILL, 1998

HISTORY OF THE CITY'S WATER SYSTEM

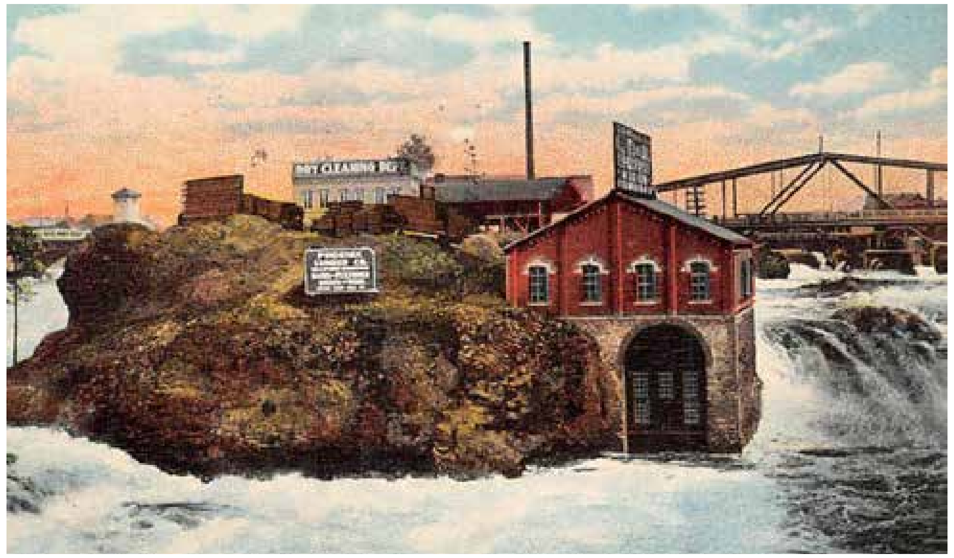

Figure 4. The 1888 location of Spokane's Water Works.

Late 1800s

Spokane's water service began in 1883/1884, with the installation of wooden water mains and the City's subsequent acquisition of a small water system that withdrew water from the river on Havermale Island in downtown Spokane. This system serviced a small community that existed on the south side of the river on the upstream side of the falls. Water was conveyed through roughly one mile of distribution main, and was pumped from the river by two water-driven 40-horsepower pumps.

In 1888 the withdrawal point was moved to the middle island (Canada Island) with the addition of two new pumps to supply more water to a growing City. Leaders saw the necessity of seeking a water source not in danger of surface contamination and after exhaustive examination, the City decided to acquire and move the water works 5 miles upstream.

In 1894, a timber crib dam was built at the modern-day Upriver Dam site for hydropower generation purposes, which formed a pool that extended up to the newly relocated river water intake. Water quality became problematic again over the years, which led the City to turn to groundwater and discontinue the use of river water soon after the dawn of the 20th century.

Early Groundwater Development

Groundwater was not known to be present beneath the City during its earliest years. One of the first written descriptions of an underground source of water was made by the Spokane Falls Review newspaper in 1883, approximately 11 years before the first "official" discovery of groundwater.

> *They soon found it a serious menace and tried to plug it up, but it boiled forth in a torrent. Water was pumped out of the spring at the rate of 20,000 gallons a minute without lowering it a particle. The water is ice cold and as clear as crystal.*
>
> —The Spokane Falls Review, May 19, 1893

The location of this observation is unknown. In 1894, during construction of the initial timber crib dam and hydroelectric generation facility at Upriver Dam, a City contractor encountered groundwater while digging out an excavation for the new facilities. Eleven years later, in 1905, the aquifer was rediscovered by a City contractor who was excavating for a new pump station at the dam. The contractor was unable to dewater the excavation, which caught the attention of City officials who were aware of the water quality issues with the river source water supply. City officials decided it was time to turn to a groundwater supply, and in 1907 excavation work began on the construction of two large-diameter shallow caisson wells to provide this new water supply source.

Figure 5. Well No. 1

These two caisson wells—Well 1 and Well 2 at the Well Electric Well Station—were open at their tops and contained multiple suction pumps. Well 1 alone had a rated capacity of 56 million gallons per day (mgd), which was more than sufficient to meet all water demand needs in the City and allowed the City to permanently discontinue the use of river water as a drinking water and municipal supply source.

Over the years, three more wells were excavated at this location, which became known as the Well Electric Well Station. Currently, Well 1 is offline and preserved as an educational/historical display for the public to visit. Wells 2 and 3 have been abandoned, though Wells 4 and 5 remain operational to this day and are an important water supply source for the northern portion of the City.

Spokane Water Chronicles

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"SPOKANE WATER SUPPLY TOO PURE."

START AT 1 P. M.

The New Water Works Will Send Water Into the City Today.

IS A POWERFUL PLANT

We Can Have Pure Spring Water Any Time—History of the Waterworks.

THE HEADRACE.

CHECK THE AWFUL WASTE

So Give Spokane Plenty of Water for Years to Come.

From Spokane Daily Chronicle
April 28, 1908

The people of Spokane will be able to travel across the new Washington street bridge by May, and will be drinking the underground water on or before the middle of the same month. City Engineer Ralston stated this morning that a week or 10 days will finish the work on the Washington street bridge, and all that is necessary in the development of the underground flow is to install a portion of the machinery, after which the water will be pumped into the river for several days before being turned into the mains.

* * *

New Upriver Dam Planned as Means of Aiding Unemployed Men

SPOKANE WATER IS FROM WELLS

The source of Spokane's sparkling, cool and pure water supply is from five wells that tap a great underground river flowing from east to west the entire length of the Spokane valley. These wells vary from 40 feet to 51 feet in depth and from 28 feet to 45 feet in diameter.

A little over half a century ago, Spokane citizens paid 25 cents a barrel for their water supply, which was obtained from a spring hauled to local homes. Later wells were dug in various sections of the little village. Pioneers will best recall the downtown well, of which the Chronicle of September 30, 1886, published the following article: "The old well at the corner of Main and Howard that has supplied the neighborhood with water for so long a time and which was one of the land marks of the city, is being filled up." Three years previous to that, Spokane's first city water service, pumped from the river, was established.

The growth of this city and its water system since then has been surprising. Yet, even more surprising has been the growth of the Chronicle, which in those days was a small four-page weekly newspaper with less than 200 subscribers. Through faithful service to this community the Chronicle has expanded its facilities for publishing the news, until today it is known as one of the nation's foremost dailies, and the preferred evening newspaper in 40,000 homes.

SPOKANE'S WATER SUPPLY DRAWN FROM DEEP WELLS

Purified by Running Through Gravel of Valley—Source Unknown.

SPOKANE WATER SUPPLY TOO PURE

"Spokane's water supply is too pure."

This was the statement today of Dr. Ralph Hendricks, commissioner of public affairs, in explaining the strong taste of chlorine in city water.

"All cities that use surface water—and most of them do—are forced to purify with chlorine," Dr. Hendricks said. "Impure water containing organic matter absorbs chlorine so it is not tasted. Water such as comes from Spokane's well, containing no organic matter, gives a much stronger taste of chlorine because it is not absorbed.

"So far as taste is concerned, people would be better satisfied if we turned the Spokane river into the wells, where organic impurities would absorb the chlorine."

Figure 6. News articles reporting on early development of the growing Spokane water system.

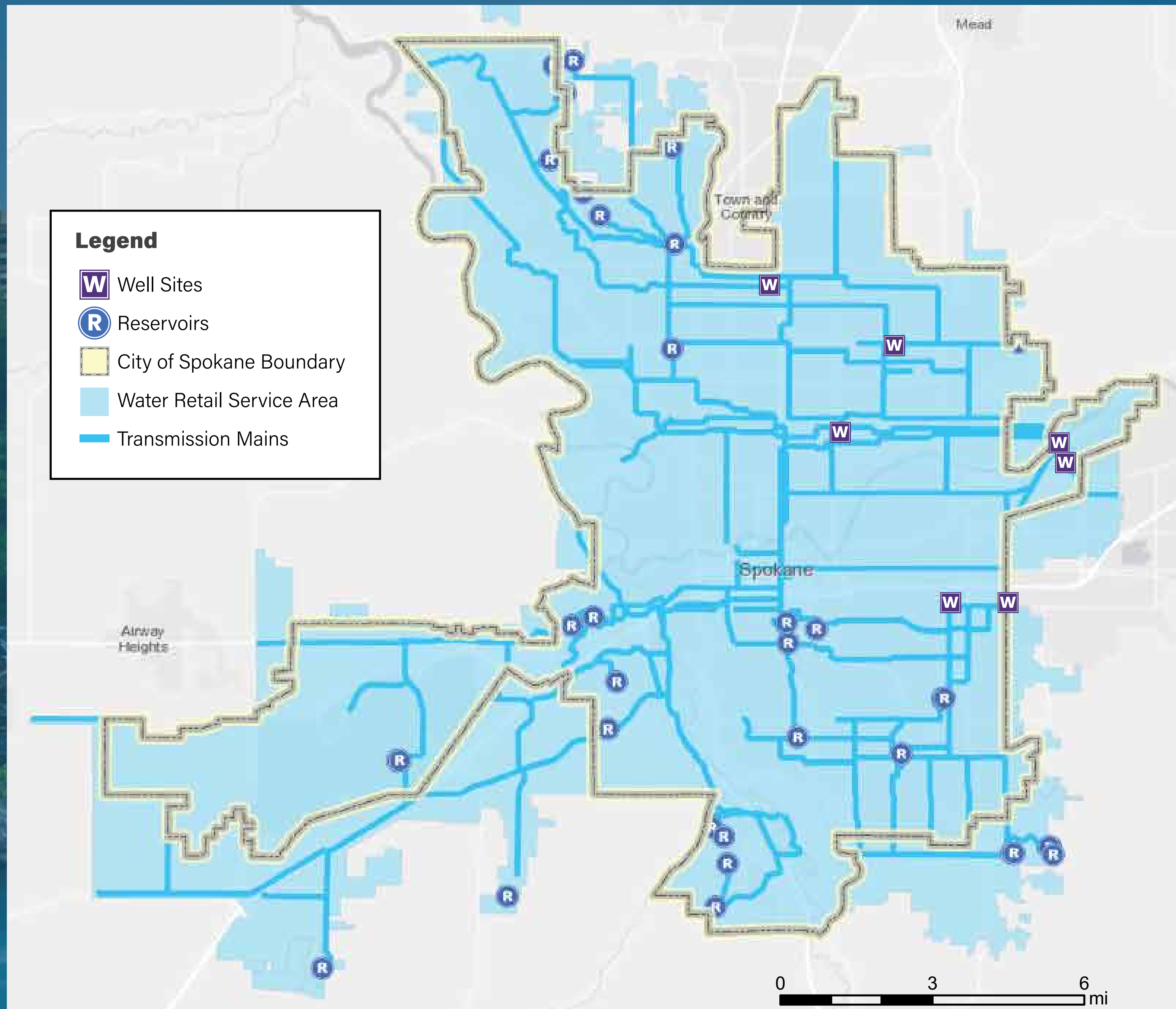
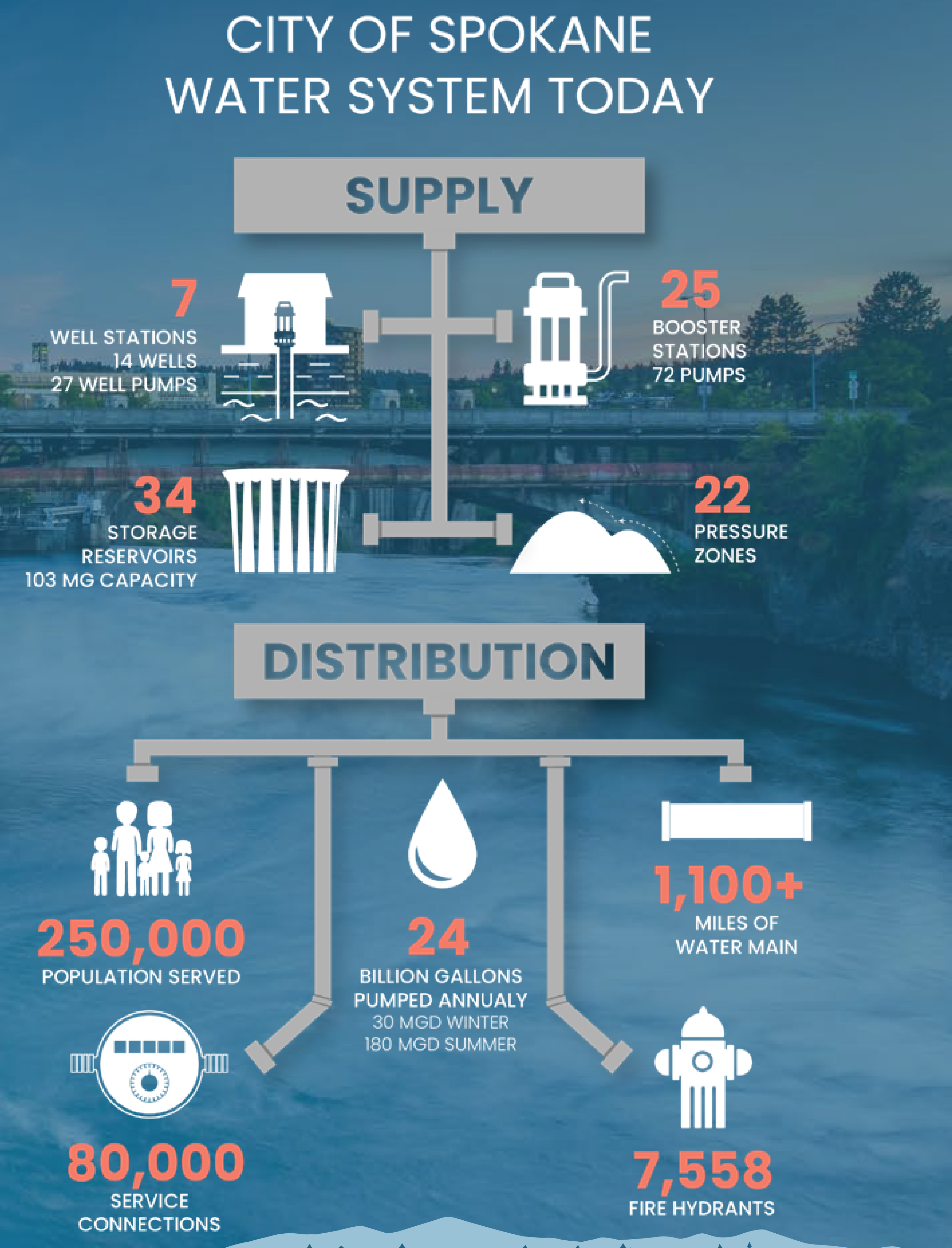


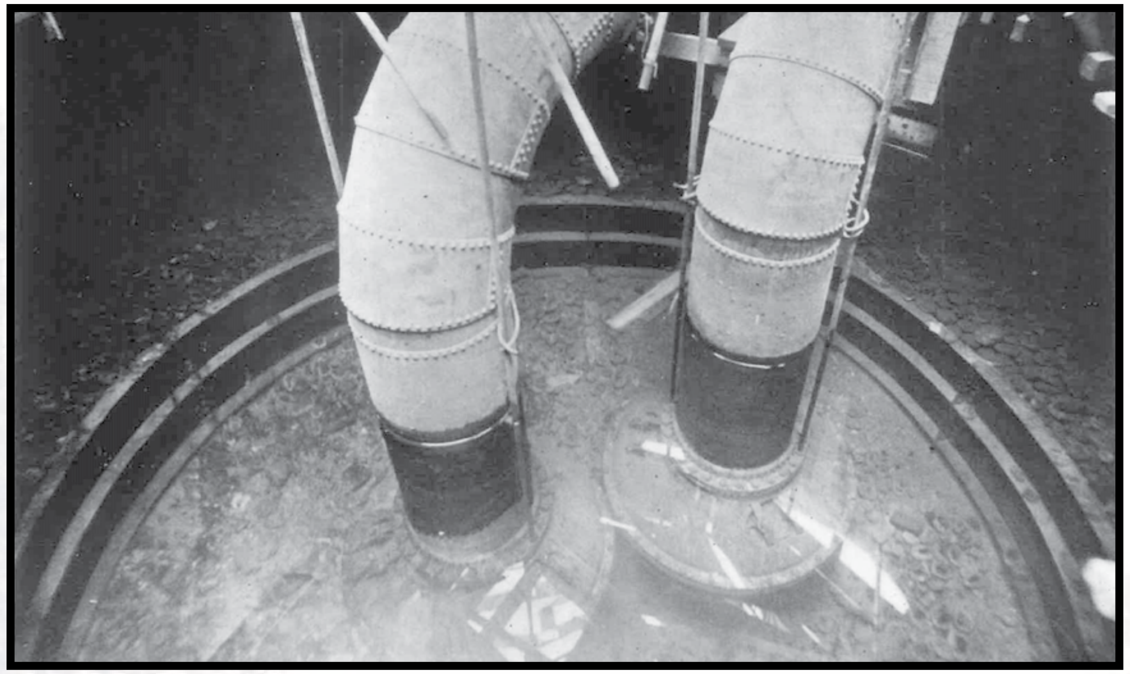
Figure 7. City of Spokane water system.



As Spokane grew, new well pumping stations, booster pump stations, reservoirs, transmission mains, and distribution mains were constructed to keep pace with the population's demand for water. In 1967, at the request of land developers, the Water Department began water service to customers outside the city limits. Today, the City of Spokane continues to use the Spokane Valley-Rathdrum Prairie Aquifer as its sole source of potable water. The water system has 7 well stations with 14 wells and 27 well pumps, 25 booster pump stations with 72 booster pumps, 22 pressure zones with 34 reservoirs, and more than 1,100 miles of water pipes. Spokane's rugged terain and substantial elevation changes necessitated the division of its distribution system into 22 pressure zones, each consisting of its own pumps, reservoirs and distribution mains.

CITY OF SPOKANE WATER SYSTEM TIMELINE

Original water pump inside the Upriver Facility, 1900.



Construction of well No. 2, 1911.

Construction of Ray Street Well Station, 1936.

1880 · 1890 · 1900 · 1910 · 1920 · 1930 · 1940

1883

The City purchased a private water system that was serving the downtown area. The original system comprised a water-driven pump installed in the Echo Flour Mill on Havermale Island to serve Spokane River water to a few customers in the new city. Some of the cast iron water mains constructed for this system continue to be used today.

1888

The pumping plant was relocated and a second pump was added to serve the expanding city.

1896

Upriver pumping facility began operation. The Upriver facility was located approximately five miles upstream of the City and constructed to address a growing population and deteriorating water quality in the Spokane River near the City. Pumps delivering water from the new facility to the City's customers were mechanically powered by water routed from a reservoir, created by a timber crib dam upstream of the facility. Groundwater encountered during construction was a nuisance and was overlooked as a potential supply source at the time.

1905

Continued population growth and pollution in the Spokane River drove a search for an alternative source of high-quality potable water. Groundwater discovered during construction of the Upriver facility was evaluated and considered as a potential new supply source for development.

1907

The first well was constructed at the Upriver facility (aka Well Electric Well Station) to withdraw water from the newly discovered groundwater source, ending the City's use of the Spokane River as a municipal source of supply. The groundwater source was later named the Spokane Valley–Rathdrum Prairie (SVRP) aquifer.

1910-1925

Additional groundwater wells completed in the SVRP aquifer were constructed at the Upriver facility/Well Electric Well Station. This well station consists of two 48-foot diameter caisson wells with four pumps (two vertical line shaft turbines and two centrifugal) ranging in size between 900- and 1,000-horsepower.

1920

Caisson production wells at the City's Hoffman Well Station were constructed as water supply sources for the Great Northern Railway before transferring ownership to the City.

1936

The timber crib dam upstream of the Upriver facility was replaced with a taller concrete dam. Water in the reservoir behind the new dam was diverted to a new hydroelectric powerhouse, which powered electric motors that drove pumps installed in the groundwater wells.

1937

Ray Street Well Station constructed. This well station houses two 24-foot-diameter caisson wells and three 900-horsepower pumps, with two pumps in one well and a single pump in the second well.

1938

Hoffman Well Station acquired by the City from Great Northern Railway. This well station houses two 16-foot diameter caisson wells. Under full operating conditions, each well is equipped with a 600-horsepower vertical line shaft turbine pump. One of the wells has been out of service since 1993. The City is currently exploring potential repair options that would bring the well back online.

Echo Flour Mill and Original Spokane Water Works.

Southern Facade of Upriver Pump Station

Well Electric Pumping Station Construction, 1924.

Upriver Dam Spillway, 1940.

Hoffman Well Station, 1957.

Nevada Well Station, year unknown.

Lincoln Heights Reservoirs, 2005.

Construction of Havana Well, 2018.

1950 1960 1970 1980 1990 2000 2010 2020

1949

Parkwater Well Station constructed. This well station houses eight pumps in four 18-foot diameter wells. The pumps are vertical line shaft turbines ranging in size between 600- and 1,000- horsepower.

1950

Grace Well Station constructed. This well station houses one 18-foot diameter caisson well with two 900-horsepower pumps.

1956

Nevada Well Station constructed. This well station houses a single caisson well equipped with two 400-horsepower submersible pumps and two 800-horsepower vertical line shaft turbine pumps.

1959

Central Well Station constructed. This well station has two 7-foot diameter caisson wells with two 450-horsepower submersible pumps in each well.

1967

The City's Water Department began serving water to customers outside city limits.

1981-1984

Major improvements at the Upriver facility increased the hydroelectric generating capacity of the three existing generators from 1.3 to 2.0 megawatts each and added a second powerhouse with two additional 5.58 megawatt generators. The hydroelectric power generation allows the City's Water Department to sell power during times of low electrical demand from the City's water pumps. Revenue from power sales offset the cost of pumping water to help keep customers' water rates low and affordable.

1995

The Water Department replaced the City's last uncovered reservoir with two covered concrete tank reservoirs, protecting the water system from potential contaminants.

2018

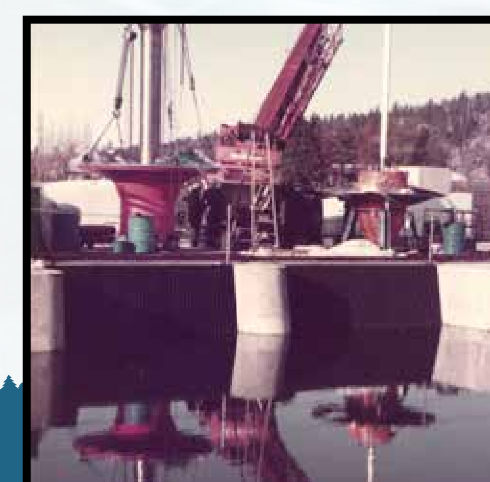
Havana Wellfield wells drilled and constructed. The wellfield consists of six 24-inch diameter vertical wells completed in the SVRP aquifer. Each well is capable of producing 3,750 gallons per minute. Final design and construction of the well station is currently in progress (as of fall 2019).

2019

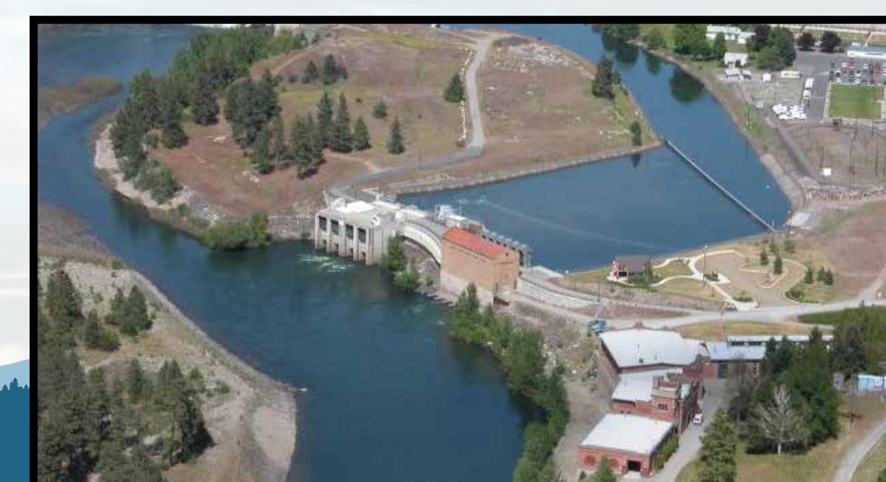
The City continues to use the SVRP aquifer as its sole source of potable water. Once the Havana Wellfield Station is complete, the City's water system will have eight well stations with 20 wells and 33 well pumps, 25 booster pump stations with 72 booster pumps, 22 pressure zones with 34 reservoirs, and more than 1,000 miles of water pipes.

Grace Well Station, 1957.

Central Well Station construction, 1959.



Power House Two construction, 1984.



Ariel view of Upriver Hydroelectric Facility and Pump House.

WHAT IS THE CHARACTER OF CURRENT WATER NEEDS IN THE CITY'S SERVICE AREA?

Overview

The existing and future retail service area is approximately 80 square miles in size with a diverse range of users. The service area consists of a core business district, scattered commercial activity, industrial zones, public lands, extensive medical facilities, pockets of multi-family housing and the largest land area is used for single family residences.

The four major use categories are as follows: Single Family Residential, Multi-Family Residential, Commercial/Industrial and Governmental. The Single Family sector represents the largest portion of annual consumption (37%) and the vast majority of accounts (88%). Annual water use for the City of Spokane Water Service Area is represented in Figure 8.

Outdoor water use is a significant portion of annual water use in the City and surrounding communities. The City's data shows that daily and monthly water consumption increase by a factor of 4 during the summer compared with the winter months. Nearly half this outdoor water use occurs in residential areas for indoor needs and outdoor irrigation uses (primarily lawns).

System Audit

The City Water Department conducted an extensive water system audit in 2014 using methods published by the American Water Works Association (AWWA). The audit identified the need for improved standardization of records, more active record keeping, and operational changes, focusing on these particular aspects of the water system:

- Production and customer meter testing and calibration
- Billing data anomaly analyses
- A more proactive comprehensive leak detection program

Findings and Path Forward

The audit identified a large amount of real and apparent losses in the distribution system over 150 gallons per connection per day. The audit identified the need for an action plan for addressing key issues through technology improvements to the system itself - such as advanced leak detection, pressure monitoring, customer meter assessments, and data management improvements.

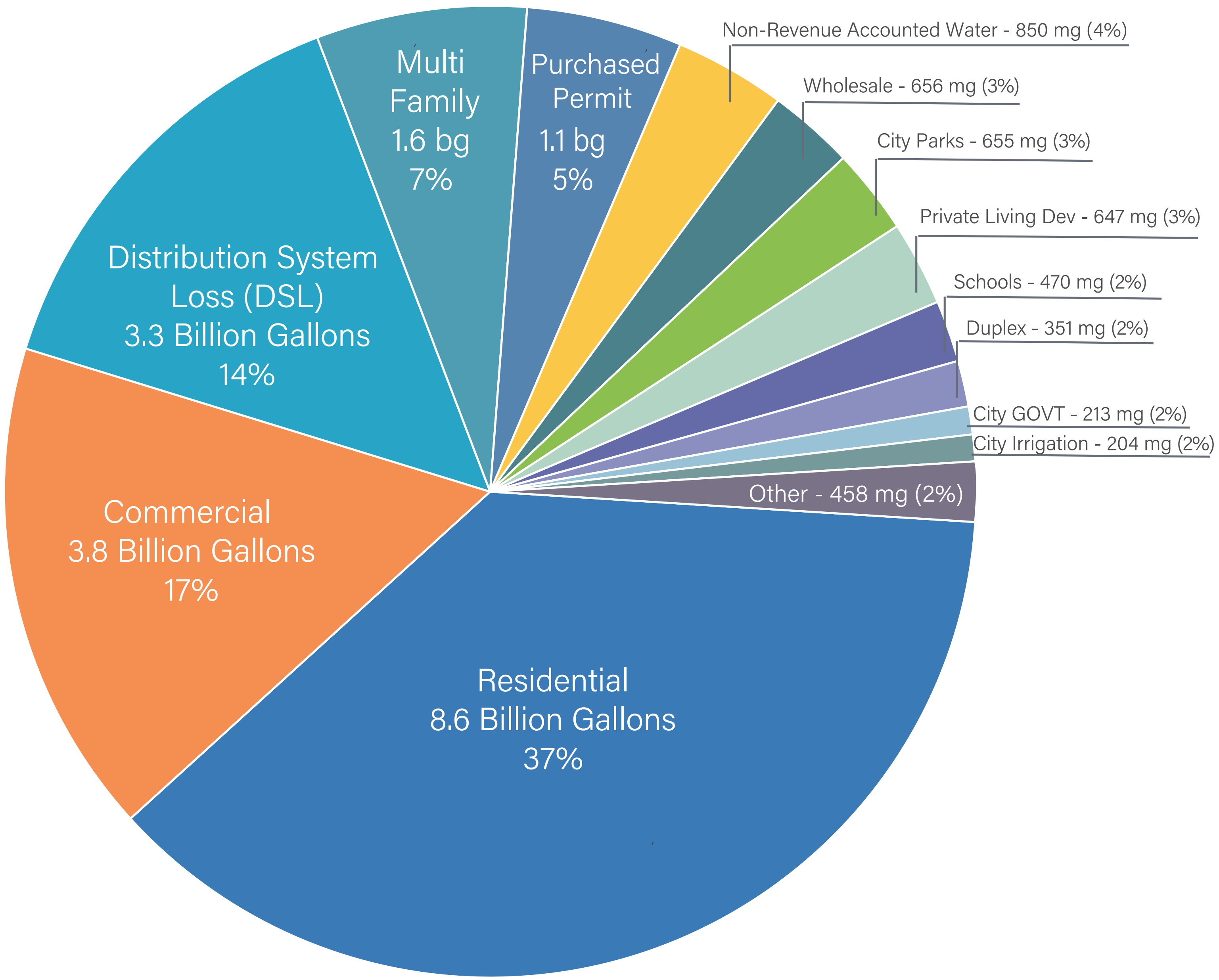


Figure 8. 2019 City water annual use ("Purchased Permit" is estimated).

AVERAGE PERCENT OF WATER PRODUCED BY CITY WELL STATIONS

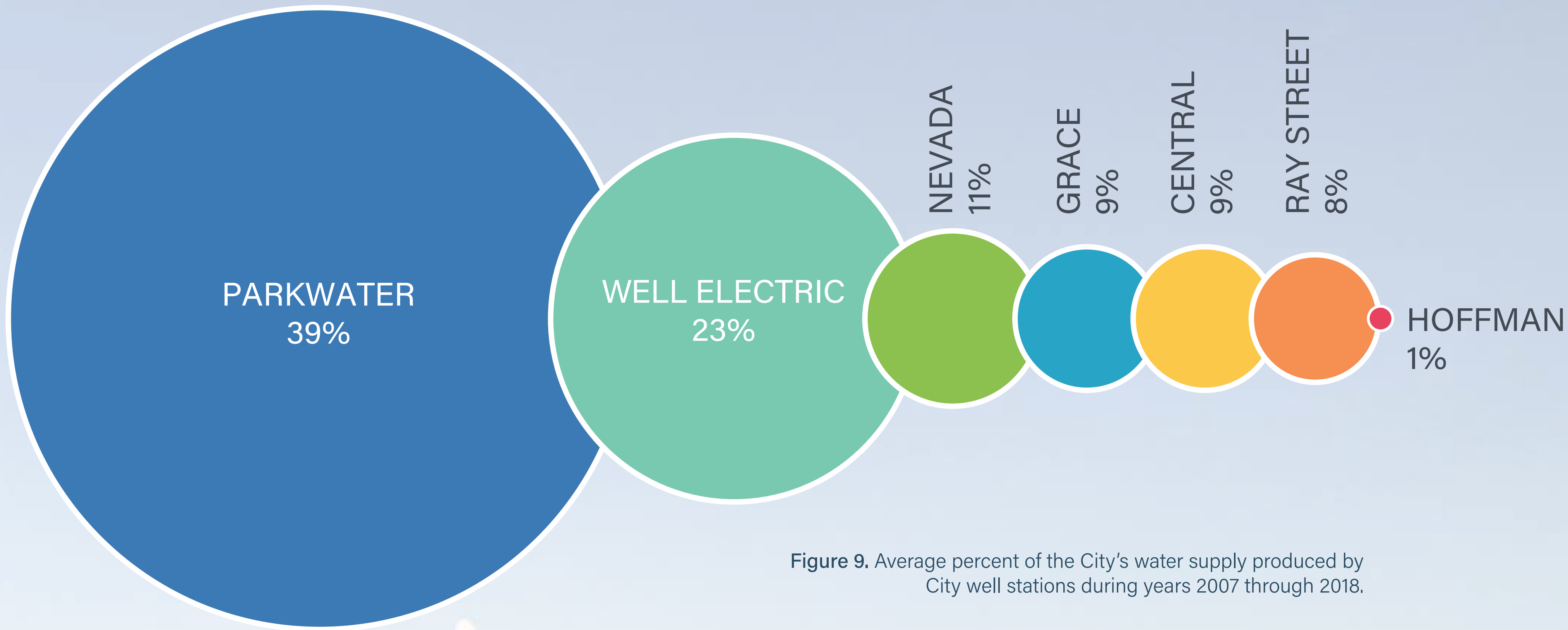
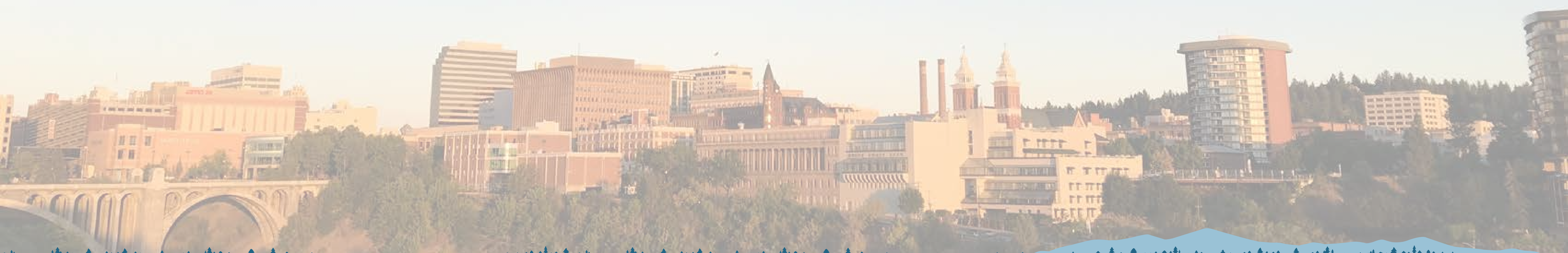


Figure 9. Average percent of the City's water supply produced by City well stations during years 2007 through 2018.



WHAT ARE THE FACTORS DRIVING THE NEED FOR STUDY AND ACTION?

Sole-Source Aquifer

The SVRP Aquifer is the sole source of water supply not just for the City of Spokane, but also for most communities in and around the Spokane/Coeur d'Alene metropolitan region. In 1978, the US Environmental Protection Agency designated the SVRP as a sole-source aquifer. This designation increased public awareness for this high-quality resource and supported development of protective management strategies. Currently, protection efforts are cooperatively managed by local and regional stakeholders and state agencies in both Washington and Idaho.

Protecting Drinking Water Quality

The SVRP Aquifer is unconfined and highly transmissive, and therefore highly susceptible to contamination from surface spills or leaky pipes. The City's water supply planning and management program includes recognition that a regional petroleum pipeline (Figure 10) now lies near the City's two largest well stations— Well Electric and Parkwater—which together provide more than half of the City's groundwater pumping capacity.

Figure 10. Approximate location of pipeline (shown in yellow).

In addition to this future potential source of contamination, the Spokane River can create water quality issues at Well Electric when high river flows temporarily flood the caissons, creating the risk of bacterial contamination. Although the petroleum pipeline has never caused a shutdown of either pumping station to date, high river flows (15,000 cubic feet per second and higher) have historically caused Well Electric to be shut down for periods as long as two or even three months as a precautionary measure.

Climate Change

The hydrology of the watershed has a controlling effect on water levels in the Spokane River and the SVRP Aquifer, which in turn influences the depth to water in the existing caisson wells under pumping and non-pumping conditions alike. During drought years, reduced river flows and lower groundwater levels in the SVRP Aquifer cause pumping water levels to approach critical minimum operational levels, threatening the reliability of the well station production capacity. Structural and/or mechanical improvements to the well stations and/or adjustments to well station operations are necessary to improve reliability under current conditions, as well as under potential future conditions that could be characterized by longer duration and/or lower summertime groundwater levels arising from changing climate conditions.

Aging Infrastructure

The American Water Works Association's State of the Water Industry reports for years 2014–2018 list renewal and replacement of aging water and wastewater infrastructure as the most important issue faced by the US water industry. The ages of the subject well stations range between 83 (Ray Street) and 100 (Hoffman) years old. Though still operable and in fair condition overall, these well stations are verging on the end of their useful life.

Figure 11. Looking down caisson Well 2 at the Hoffman Well Station. Courtesy of GSI Water Solutions, Inc.

In 1993, the City removed the vertical turbine pump from one of the Hoffman Well Station's caisson wells due to concerns regarding the structural integrity of the brick caisson wall, leaving only one well (one pump) online at this well station (Figure 11). The current production capacity of the well station is approximately 7.86 million gallons per day (mgd), which is only half of the full capacity that was achieved when both caissons were online.

Well Performance

Overall, the well stations and pumps are in good condition, showing no signs of diminished performance. Well performance and reliability improvements for the existing caisson wells at Well Electric, however, are needed to provide additional pumping reliability during the summer months. During this period, groundwater elevations decline to their seasonal low levels, causing the two centrifugal pumps to be turned off and resulting in a loss of production because of insufficient intake submergence.

Interties to Provide Emergency Supplies to Neighboring Communities

As the region's largest water provider, the City played an important role in providing water at certain times to nearby communities through intertie agreements. City leaders feel they have an ethical responsibility to take care of neighbors during a public health emergency/crisis, such as the loss of supply in those outlying areas. For example, Spokane recently began providing water to the City of Airway Heights through an intertie after contamination caused municipal wells in the area to be shut down. The City of Spokane provides this service so that its neighbors in metropolitan Spokane have an available backup water supply source during unexpected events affecting their own water sources.

Accommodating Near- and Long-Term Growth

Growth planning is a significant driving cause behind the need to increase the capacity, resiliency, and reliability of the City's municipal water supply system (Figure 12). The City conducts its water supply planning work with the recognition that the region's population continues to grow along with its economy and therefore its commercial water needs.

The City's water distribution model and the Well Evaluation Study that is the subject of this booklet are based on the future level of demand that is estimated to occur in the year 2040. These plans evaluate 2040 conditions under the average daily demand (ADD) and the demand on the highest-demand day of the year (known as the maximum daily demand, or MDD).

Conservation: Increasing Water System Reliability and Enhancing Resource Stewardship

The City also plays an important role in resource stewardship through its efforts to conserve and protect water resources in the aquifer and the Spokane River (Figure 13). The City and its neighbors have long used educational programs to promote community awareness and attention to the aquifer and the river, and water conservation programs (including the City's new menu of water efficiency rebates) are being initiated to further increase protection of local water resources and water supplies.

Because water use goes up in the summer when flows in the Spokane River's watersheds are at annual lows, the City and neighboring purveyors are working together to design and implement programs that encourage water conservation and lead to less groundwater pumping, which in turn can allow more groundwater to naturally enter the river.

Increasing Resiliancy, Reliability, and Public Health Protection

The City is acting on multiple fronts to increase near-term and long-range resiliency and reliability in the water supply and delivery system while also maintaining an eye on future growth-driven demands and demand management (including conservation), cost stewardship on behalf of its customers, and the need to protect the aquifer and the Spokane River. **The City's assessment of its water system identified the need to conduct this Well Evaluation Study, and also led to the decision to build the new Havana Street wellfield.** The new wellfield (just south of I-90) will increase pumping efficiency in the water distribution system, move a portion of the City's groundwater pumping capacity away from the river and the regional oil pipeline, add a modern facility (traditional vertical wells, rather than shallow caisson wells) to the City's portfolio of water supply sources, and increase water service reliability—benefits that were recognized and appreciated by state regulators during permitting of the new wellfield.

> *We applaud your work to improve the operations of the City of Spokane Water Department and increase public health protection. Your proactive approach is a hallmark of successful, sustainable water systems."*
>
> Letter from Dorothy Tibbetts, Washington Department of Health, Regional Manager, Office of Drinking Water, to Dan Kegley, Director, City of Spokane Water Department; November 21, 2014

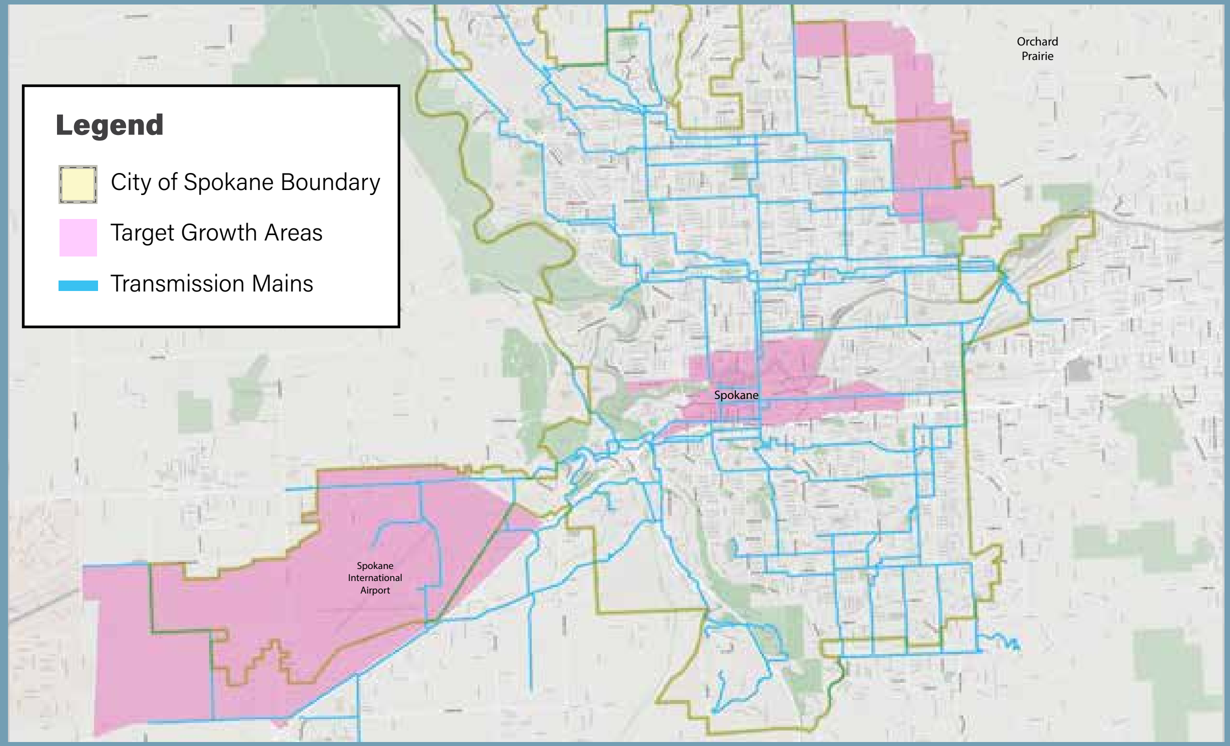


Figure 12. Targeted Growth Areas

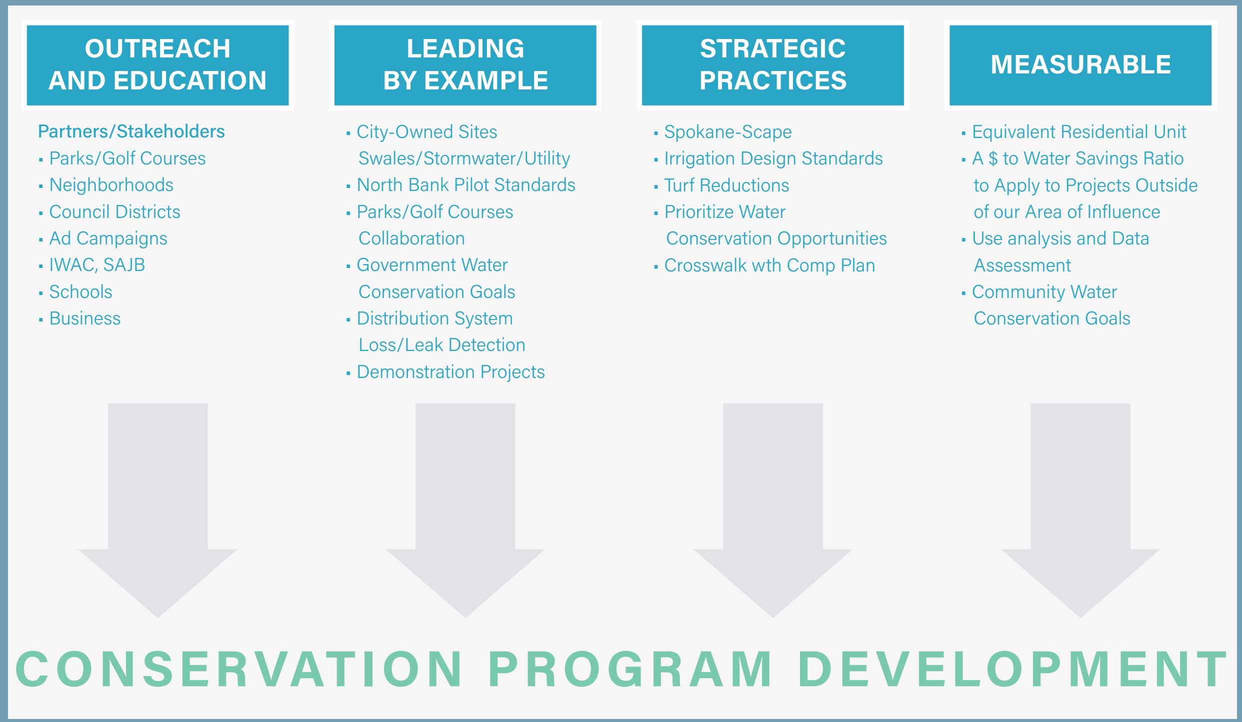


Figure 13. City of Spokane conservation program planning efforts.

WHAT TYPES OF IMPROVEMENTS ARE NEEDED TO INCREASE WATER SUPPLY RESILIENCY?

The City's hydraulic model of its water transmission system was used to identify limitations in the system and the locations and design characteristics of transmission system upgrades that might be needed if the pumping capacity at Hoffman, Ray Street, and Well Electric is expanded to meet future levels of demand. Three operational scenarios were run through the hydraulic model during this study:

- **Scenario 1 (emergency scenario):** Parkwater is offline due to potential impacts from a Phillips Pipeline failure or other source contamination. Under this scenario, the expanded Well Electric and Ray Street well facilities are being maximized in addition to the new Havana wellfield and the existing sources.
- **Scenario 2 (operational scenario):** Well Electric and Parkwater are offline. This scenario evaluates whether the City's new Havana wellfield and its expanded facilities at Ray Street and Hoffman can provide sufficient supply to the system.
- **Scenario 3 (operational scenario):** The City's entire system is served solely by Well Electric and Parkwater, and all other well stations are offline. This scenario describes a protocol that the City could use in the future during seasonally low system demand and/or during periods of high-water stage in the Spokane River to maximize power generation at the Upriver Hydroelectric Dam facility.

Hydraulic analyses were conducted with the model to evaluate system limitations and improvement needs that would arise under a defined set of design criteria relating to system pressure, flow velocity, and head losses in the system. This was evaluated in the following three transmission corridors:

- **North Hill Transmission Corridor (Figure 14):** Combination of (primarily) new and parallel transmission from the Well Electric well facility and integrating the Hoffman well facility to connect to the existing transmission system near the Five Mile and Indian Hills reservoirs.
- **Intermediate Transmission Corridor (Figure 15):** Includes two options for a direct transmission main from the new Havana wellfield and existing Ray Street well facility to the High Pressure Zone. The proposed transmission mains in the model were configured to increase transmission capacity to the High Pressure Zone by extending a proposed transmission corridor from the Ray Street well facility.
- **Low Transmission Corridor (Figure 16):** Expanded transmission from the Well Electric and Parkwater well station facilities through the Low Pressure Zone to provide direct supply to the west and southwest portions of the City's service area.

The City's primary challenge with its water supply system is the location of its groundwater supply sources relative to service area locations, and in particular growth areas. The City's highest-capacity well stations are located on the eastern side of the City, with its lower-capacity well stations located in the north-central portion of the City. Much of the City lies outside of the location where the aquifer is present, which means the transmission system has to push water uphill and over long distances to service the South Hill area, the western portion of the City (including newly developing areas just west of Highway 195), and the northern and northwestern fringes of the City's service area—all of which are far from most of the City's source wells. In other words, much of the City's water is produced along the eastern City limits and has to be pushed radially outwards over long distances from the east side of the City. Although the City's water rights permits allow it to consider developing additional well stations in the future at sites near Audubon Park and Corbin Park, this would not fundamentally change the fact that much of the water supply will be obtained from well stations on the eastern side of the City.

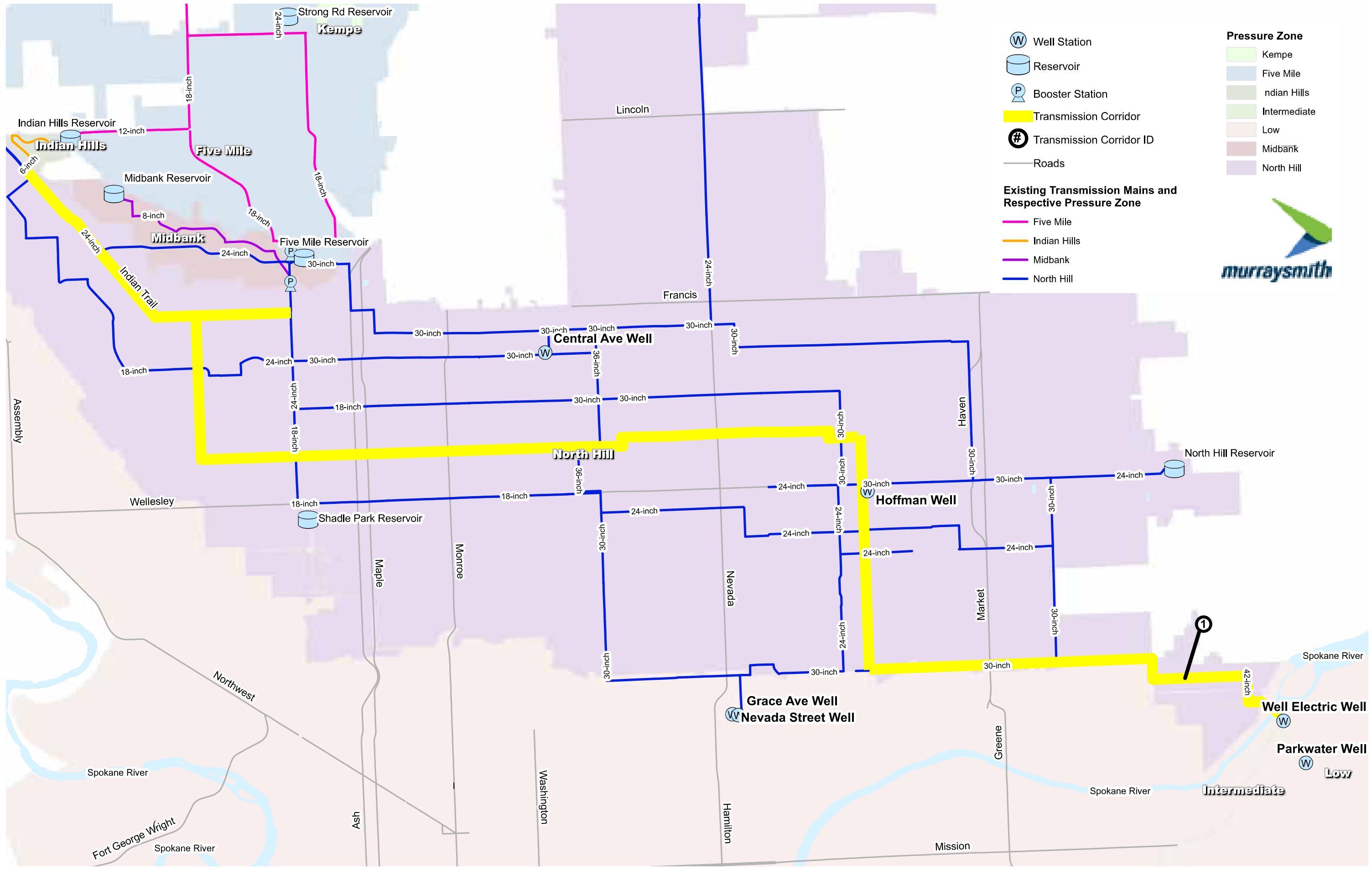


Figure 14. North Hill pressure zone transmission corridor (in yellow). Figure courtesy of Murraysmith, Inc.

The hydraulic analysis revealed the following particular limitations and needs for the transmission system:

- Additional transmission capacity is required in all defined transmission corridors to convey flow from the expanded sources under the 2040 MDD. Transmission capacity limitations particularly constrain growth in system source capacity at the Well Electric and Ray Street facilities.
- For Scenario 1, taking down the largest water source (Parkwater) still allows the City to adequately serve the projected 2040 MDD in the Low and Intermediate pressure zones, but only as long as capacity is expanded at Well Electric (via a new wellfield), Ray Street (via improvements to the existing facilities), Hoffman (by returning Well 2 to service), and the Havana wellfield (bringing this new facility online). Two new transmission corridors also would need to be constructed.
- For Scenario 2, taking Well Electric and Parkwater offline results in deficient supply to meet the projected 2040 MDD in two of the three pressure zones (Low and North Hill), though the demands in the North Hill pressure zone could be met by installing new vertical wells at Well Electric and bringing Caisson Well 2 back online at Hoffman.
- For Scenario 3, the Well Electric and Parkwater facilities by themselves cannot provide sufficient supply to meet the projected 2040 MDD for any of the three pressure zones. If the City installs a sufficient number of new conventional vertical wells at the Well Electric facility, then Well Electric and Parkwater together can supply the projected 2040 ADD.

Figure 15. Intermediate transmission corridor (in yellow). Figure courtesy of Murraysmith, Inc.

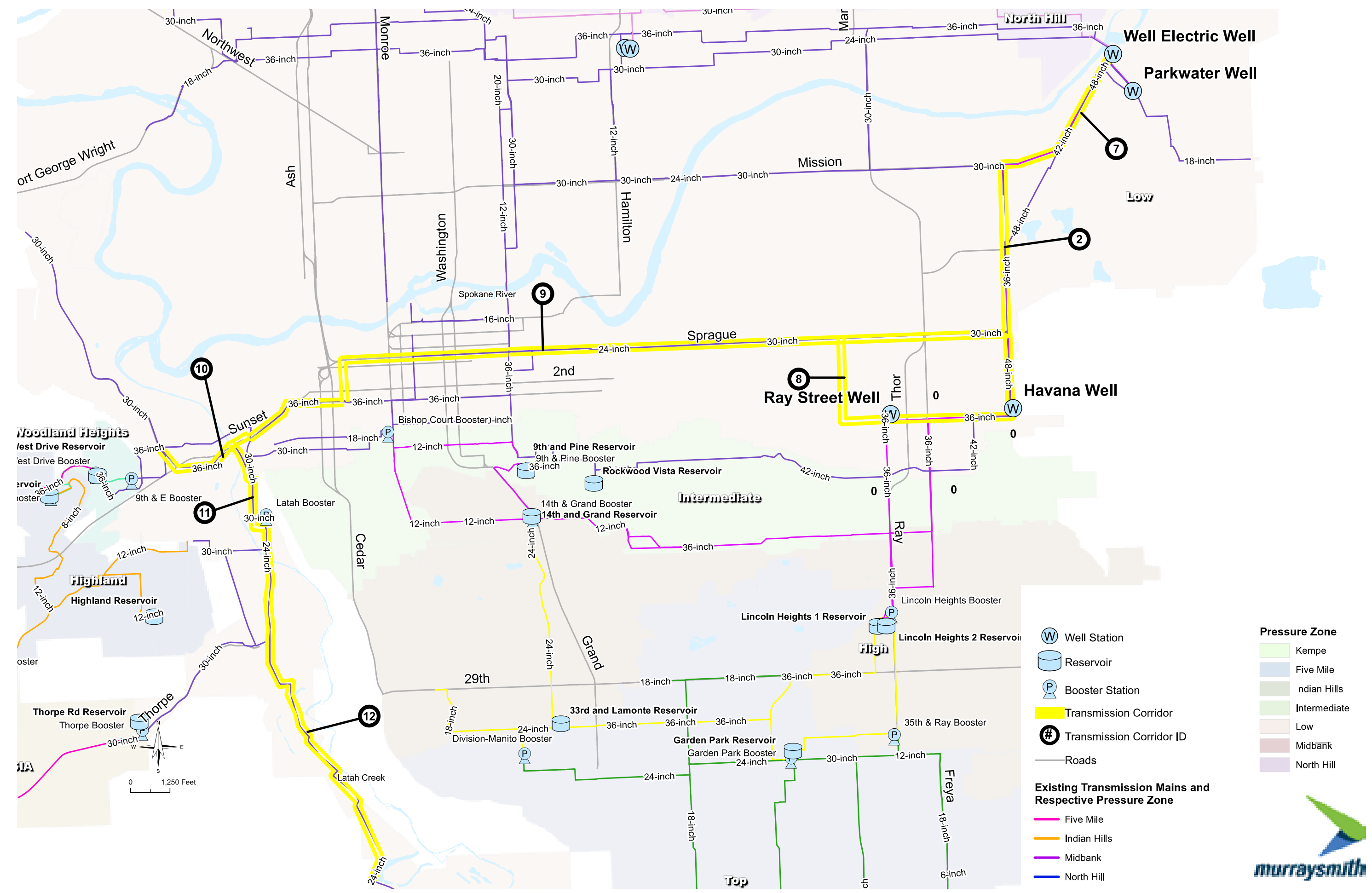


Figure 16. Low transmission corridor (in yellow). Figure courtesy of Murraysmith, Inc.

HOW WERE THE EVALUATIONS OF SOURCE IMPROVEMENT NEEDS CONDUCTED?

Purpose

The purpose of the Well Evaluation Study is to identify the most cost-effective ways to maintain or increase the supply resiliency of each of these three well stations, whether by modifying existing facilities and/or constructing additional groundwater pumping infrastructure at one or more of these three well stations.

Scoping Design

The project team developed an overall project approach based on City-identified goals and priorities, and a data compilation and completeness evaluation. The data evaluation consisted of compiling a list of data needs; visiting each well station; conducting a review of the extent to which the available data are complete and provide sufficient information for the purposes of the study; and preparing a technical memorandum that inventories the data and identifies data gaps/needs. The data gaps/needs assessment focused on items that were deemed by the project team as being likely to have a significant effect on either (1) the assessments to be conducted under subsequent study tasks or (2) any rehabilitation work that might occur following completion of the site visits and well assessments.

HOFFMAN

GOAL: Return the reliable production capacity back to its past production rates and provide greater operational/production redundancy from this well station.

RAY STREET

GOAL: Improve performance and reliability through structural and/or operational changes that will limit or reduce the impact that lower seasonal water levels in the SVRP Aquifer have on production capacity.

WELL ELECTRIC

GOALS: (1) Improve performance and reliability through structural and/or operational changes that will limit or reduce the impact that lower seasonal water levels in the SVRP Aquifer have on production capacity, and (2) avoid creating nearby direct hydraulic connection with surface water from the Spokane River so as to increase the well station's current seasonal reliability by allowing year-round groundwater production from this property.

DEFINING PROJECT OBJECTIVES AND SCOPE

Identify and Understand Problem
- Meet with City
- Discuss and understand goals and priorities
- Identify deliverables

Define Objectives and Scope
- Hoffman
- Ray Street
- Well Electric
- Develop schedule to complete

Search and Review Information
- Obtain and review data
- Completeness review
- Identify data gaps

Develop Approach
- Design and conduct field investigations
- Analyze data
- Evaluate repair alternatives
- Estimate site production capacity
- Conduct workshop

ASSESS EXISTING FACILITIES
IDENTIFY CURRENT OPERATIONS AND OPPORTUNITIES FOR IMPROVEMENT

Conduct Data Review
- Gather
- Organize
- Assess
- Identify data gaps

Address Data Gaps
- Well videos
- Pumping tests
- Exploratory drilling
- Water quality

Assess Repair Alternatives
- Identify list
- Conduct assessment
- Develop cost estimates
- Identify preferred alternative

Develop Concept Plan for Preferred Alternative
- Design criteria/ objectives
- Design features
- Permitting requirements
- Uncertainties
- Additional work needed

CONCEPT PLANS FOR NEW GROUNDWATER PUMPING FACILITIES AT RAY STREET AND WELL ELECTRIC

Conduct Data Review
- Gather
- Organize
- Assess
- Identify data gaps

Wellfield Siting
- Water rights review
- Setback requirements
- Developable area

Wellfield Design
- Exploratory drilling
- Well design
- Production capacity modeling
- Cost Estimates

Develop Concept Plan
- Well field layout
- Design features
- Permitting requirements
- Uncertainties
- Additional work needed

Well Station Construction

The Hoffman Well Station houses two open caisson production wells (Well 1 and Well 2; Figure 18) that pump groundwater from the SVRP aquifer and supply water to the North Hill Pressure Zone of the City's water supply system. The caisson production wells were constructed circa 1920 as water supply sources for the Great Northern Railway before ownership was transferred to the City.

- Well 1 was drilled (dug) to a depth of approximately 215 feet below ground surface while Well 2 was drilled (dug) to a depth of approximately 228 feet below ground surface.
- Each well is composed of an upper brick-lined, bell-shaped caisson and a lower perforated steel casing column:
  - » The diameter of the brick caisson wall is between approximately 6 and 16 feet in diameter in Well 1 and between 6 and 10 feet in diameter in Well 2. Both wells obtain water through perforated steel casing installed below the depth of the brick caisson walls.

The current maximum instantaneous pumping rate of the Hoffman Well Station is approximately 5,460 gallons per minute. The total production capacity is based on the total nameplate capacity of the existing vertical turbine pump of Well 1, given that the pumping system for Well 2 was removed in 1993. During low water years, however, the capacity of Well 1 appears to be limited by correspondingly deep groundwater levels, which ultimately reduces the potential production capacity of the well. The maximum instantaneous pumping rate of the Hoffman Well Station with both pumps in operation is approximately 10,920 gallons per minute.

Field Investigation

An inspection of the well station (Figure 17) was conducted to (1) characterize current conditions of the brick caisson wells and steel casings, (2) verify caisson well depth and construction information, (3) establish a common reference datum, and (4) evaluate facility modifications that would be needed to access existing wells for repair/alteration.

The investigation consisted of both above- and below-water video surveys inside the caisson wells. A survey of the condition of the caisson wall and perforated steel casing below the water table could not be completed in Well 1 because it is equipped with a pumping system that obstructed access.

A 3D laser mapping survey of Well 2 was conducted to gather information about the plumbness and alignment of the well to help inform development of potential repair alternatives.

Figure 17. Photos of well condition assessment surveys being conducted at Hoffman Well Station Well 2

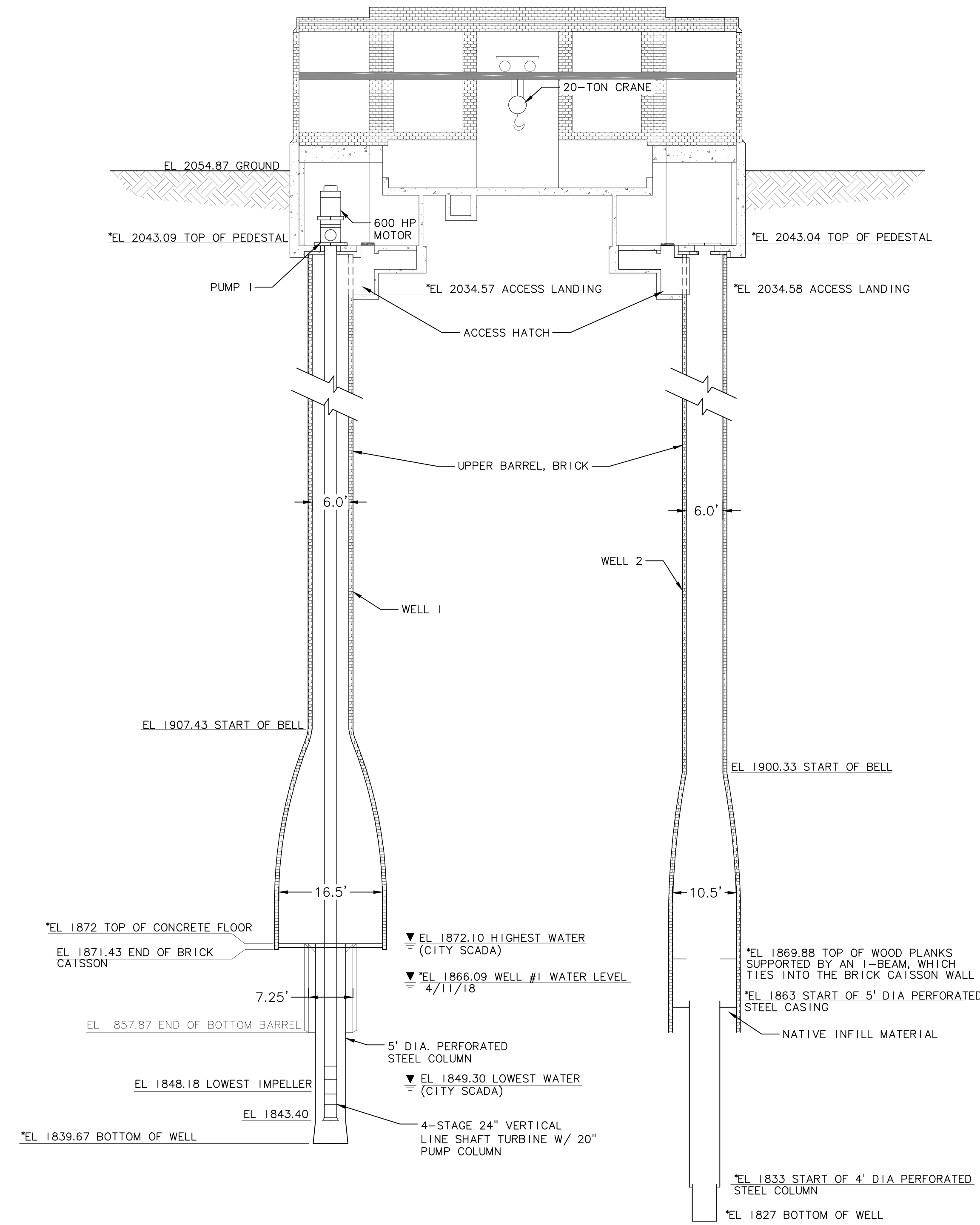


Figure 18. Well construction schematic for Hoffman Well Station Well 1 (left) and Well 2 (right). Courtesy of City of Spokane and Murraysmith, Inc.

Summary of Findings

Results from the well assessment investigation indicate that the well station is in fair to good condition overall. Visual surveys of Well 2 revealed some cracks (up to 1 inch wide) in the brick caisson wall and some minor encrustation of the well casing and perforations. In the currently operational caisson Well 1, the inspection survey shows that although some bricks are missing the caisson wall is generally in good condition.

The hydrology of the watershed has a controlling effect on water levels in the Spokane River and the SVRP Aquifer, which in turn influences the depth to water in the existing caisson wells at Hoffman under pumping and non-pumping conditions alike. During periods of below-normal runoff in the watershed and below-normal flows in the Spokane River, ambient groundwater levels beneath the Hoffman Well Station at times may be low enough to cause water levels in the currently operating caisson (Well 1) to drop to the critical-low threshold levels that need to be maintained for proper pump operations and water delivery.

Well station operations continuously monitored during a period from 2015 through 2017 (Figure 19) exhibit the following general operational characteristics:

- Total monthly production is typically highest during July and lowest during March.
- Pumping water levels are deepest during the high demand summer months when the well station is in full operation and groundwater levels in the aquifer are at seasonal lows.

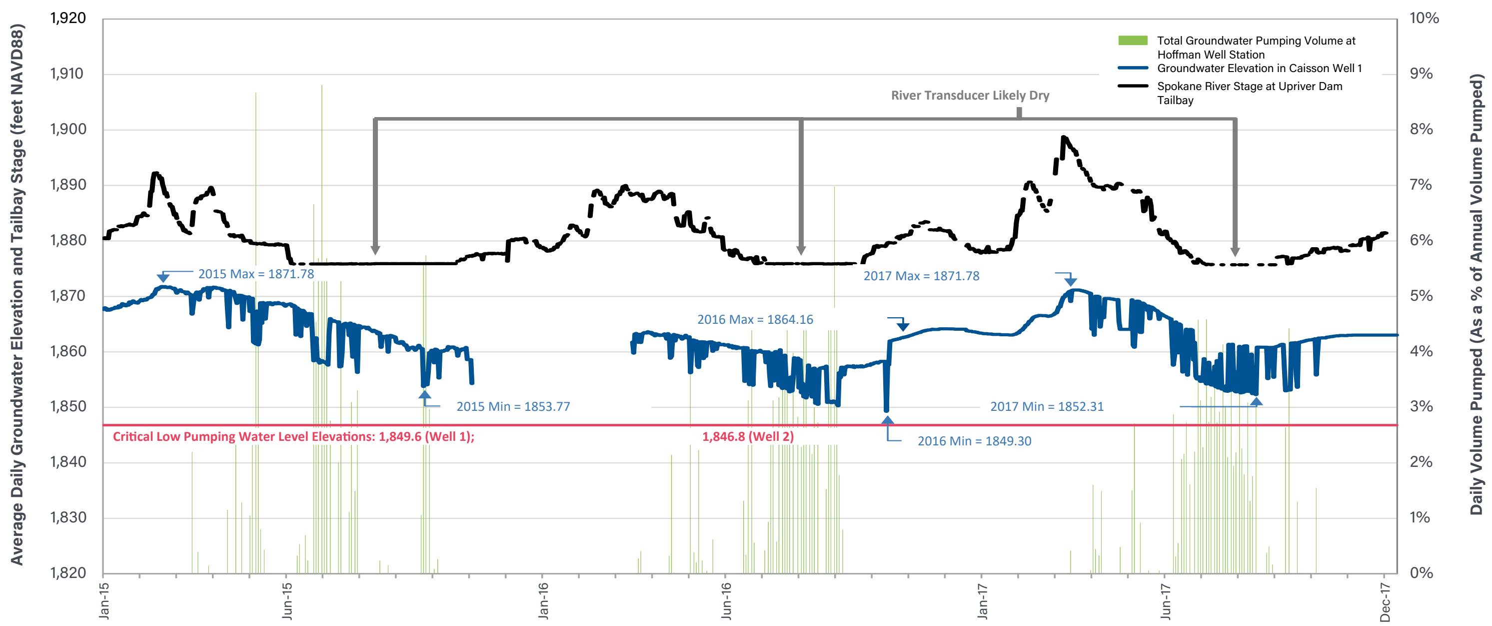


Figure 19. Annual pumping volumes monitored during a period from 2007 through 2018 ranged between approximately 37 and 480 million gallons (MG). During this time, this well station supplied between 0.2 and 2.0 percent of the City's total water system demand. Courtesy of GSI Water Solutions, Inc.

Observations from the 3D laser scanning survey are summarized below and shown on Figure 20:

- A cross-section at the base of the brick caisson wall shows the position of the 5-foot diameter perforated casing to be off-center relative to the 10.5-foot diameter caisson wall. The image shows the brick caisson wall to be out of round near its base.
- A cross-section of the upper brick caisson wall near the access landing immediately below the pedestal floor shows that the caisson is approximately 6 feet in diameter.
- An overlay of the two cross-sections described in the bullets above shows the top of the perforated well casing to intersect the upper brick caisson wall (see Figure 20). The overlapping area limits the potential repair options for this well.

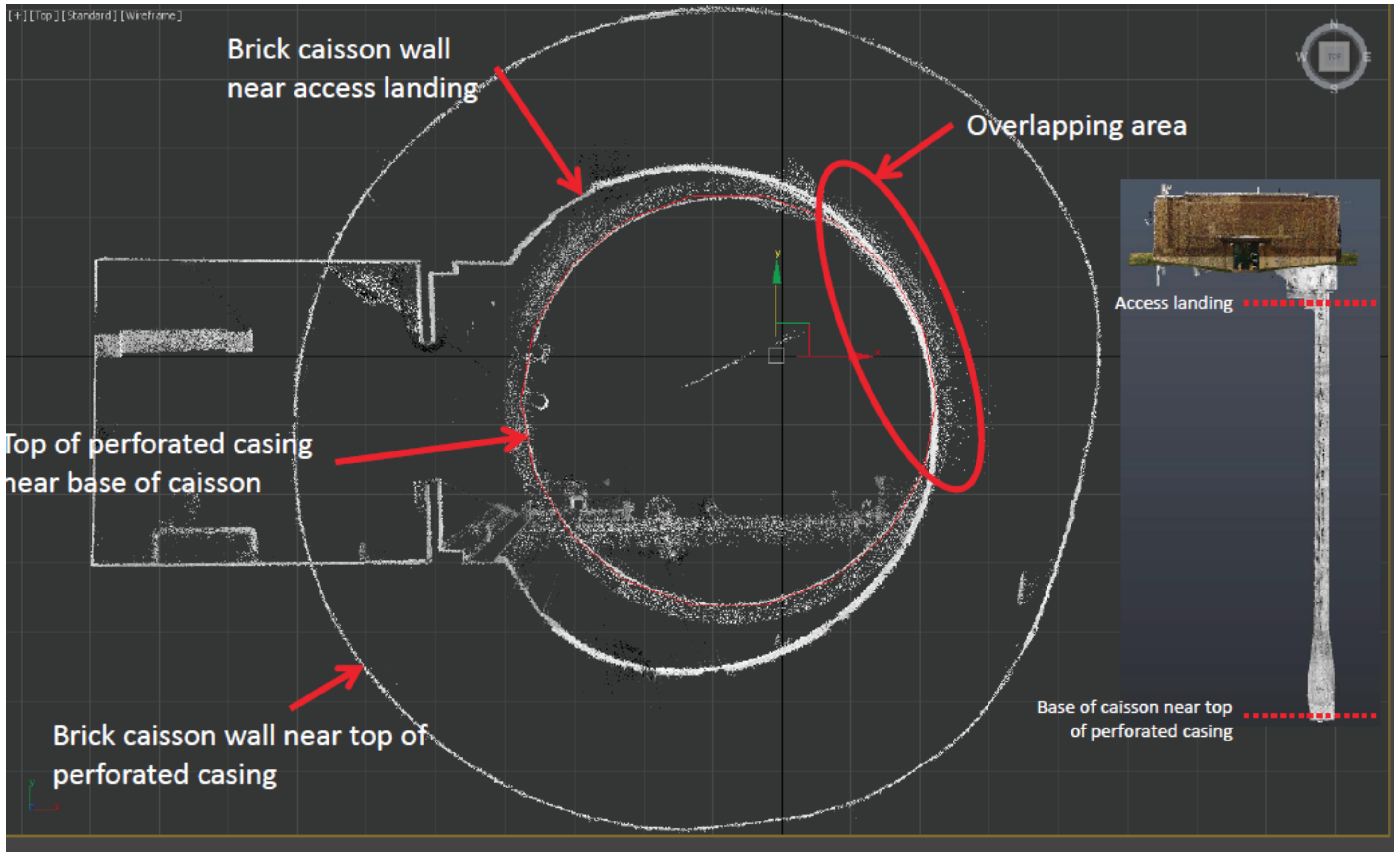


Figure 20. Cross-sections from 3D laser mapping of the inside of Hoffman Well Station Well 2. Courtesy of Bauer Forensics, LLC. and GSI Water Solutions, Inc.

WHAT IMPROVEMENTS WERE CONSIDERED?

Alternatives Considered

Observations from the well inspection surveys indicate that some minor settlement has taken place in Well 2, particularly in the middle and lower portions of the brick caisson. Minor evidence of past water seepage was also noted, though isolated to a single location. These existing conditions support the need to patch and/or repair the brick caisson before it is brought back into service, or institute a monitoring program for further evaluation.

Two repair alternatives were identified to reinforce the brick caisson wall in Well 2 and bring the well station back to its maximum pumping capacity. Both alternatives involve some degree of brick reinforcement, either by pneumatically-applied concrete or mortar (i.e., shotcrete or gunite) or by extending the steel well casing to the access landing and filling the annular space with grout:

- **Alternative 1:** Line the existing brick caisson wall by repairing and strengthening the inside surface of the brick face with a two-layer system containing a carbon fiber reinforced grid with high tensile strength that is combined with a high performance sprayable mortar to create a structural layer.
- **Alternative 2:** Install a 3-foot diameter, solid steel casing liner inside Well 2 and fill the annular space between the liner and existing caisson wall with a grout seal material.

The two repair alternatives were identified by considering constructability, cost, and the overall performance goal of returning the reliable production capacity of the Hoffman Well Station back to its past production rates. Alternatives to drill and deepen the caisson wells are not recommended and were not further considered for fear of exacerbating existing settlement/deformation conditions that may arise during drilling and driving casing.

A third alternative is to design and implement a real-time, automated crack-monitoring program. The other two repair alternative options however, may need to be reconsidered and implemented if results of the crack-monitoring program indicate signs of continued caisson settlement:

- **Alternative 3:** Design and implement an automated crack monitoring program using displacement transducers to monitor crack movement over time.

WHAT IS THE POTENTIAL INCREASE IN CAPACITY IF NEW WELLS ARE CONSTRUCTED?

In addition to modifying the existing facilities at the Hoffman Well Station, the analysis of potential future changes at this property also considered the option of installing a new wellfield that would consist of one or more vertical wells located in the vicinity of the existing caisson wells. A wellfield would provide a new groundwater supply source that could provide greater operational/ production redundancy and/or support longer periods of sustained pumping while minimizing (if not eliminating) the restricting influence of seasonal-low water levels on pumping operations (which is a severe limiting factor for the existing caisson wells).

Wellfield Layout and Estimated Capacity

Using the City's groundwater flow model, pumping simulations were conducted for multiple scenarios involving various operating alternatives for the two existing caissons and for new vertical wells at the Hoffman Well Station property. Results from groundwater modeling analyses indicate that a new 10-well wellfield of vertical wells could support a groundwater production capacity of at least 45,000 gpm (64.8 mgd) on a long-term basis if the caisson wells are not operating. This yield however, is possible only if the City is able to develop the site in a manner that complies with the state's sanitary setback requirements for municipal supply wells.

Limitations and Uncertainties

The use of deeper water production facilities (i.e., vertical wells) at the Hoffman site is likely viable, given the substantial depth to bedrock and aquifer thickness that are thought to be present in this area based on regional geologic studies. Operation of a vertical wellfield however, likely would adversely affect the existing caisson wells to a degree that pumping from one or both caissons would need to be reduced or even curtailed during any period when deeper vertical wells are pumping.

The lithology, depth, and thickness of the SVRP aquifer are not well known in the Hoffman Well Station area because no wells or other boreholes have penetrated deeper than the shallow caisson wells located on the Hoffman property. An exploratory drilling program would need to be designed and completed to explore soil conditions below the site for the purpose of verifying that soil conditions are suitable for wellfield development.

Hoffman Well Station, photograph by Charles Libby 1957.

HOFFMAN: WHAT IMPROVEMENTS HAS THE CITY SELECTED FOR FUTURE IMPLEMENTATION?

Concept Plan Summary

The selected alternative for repairing Well 2 consists of installing and sealing a new casing liner inside the existing brick-lined caisson (Figure 21), reinstalling the pump that was previously operating in Well 2 with a new motor and column, and replacing the electrical system for this pump to match the system that is currently in use for Well 1.

Based on results from the 3D laser mapping survey (Figure 20), the preferred repair alternative is to install a 3-foot diameter, solid steel casing liner inside the brick caisson and fill the annular space with a grout seal material. The new casing liner extension would telescope inside the existing 5-foot diameter steel casing and extend 180 feet to the pump pedestal. The bottom portion of the 3-foot casing liner that extends into the existing casing would be equipped with stainless steel formation packers sized to fit the inner diameter of the existing 5-foot casing. The formation packers and steel plate would prevent seal material from entering the well. The new steel casing liner would extend approximately 180 feet to the pump pedestal. The annular space between the existing caisson brick wall and newly installed steel liner would be filled with bentonite to form a lower seal envelope that covers the steel plate and casing transition, and then filled to the pedestal base with neat cement grout in lifts.

The 3-foot diameter casing liner is projected to provide enough clearance to compensate for any differences in caisson plumbness and alignment and ensure that the new casing liner and seal are adequately positioned and installed within the caisson. The minimum annular space between the new 3-foot diameter casing liner and existing brick caisson wall is estimated to be 12 inches, and is large enough to meet the minimum four inches of annular space required for placement and installation of well seal material.

Structural support of the new steel casing liner and annular grout material will be primarily from the gravel formation at the base of the brick caisson where the 5-foot diameter perforated steel casing protrudes.

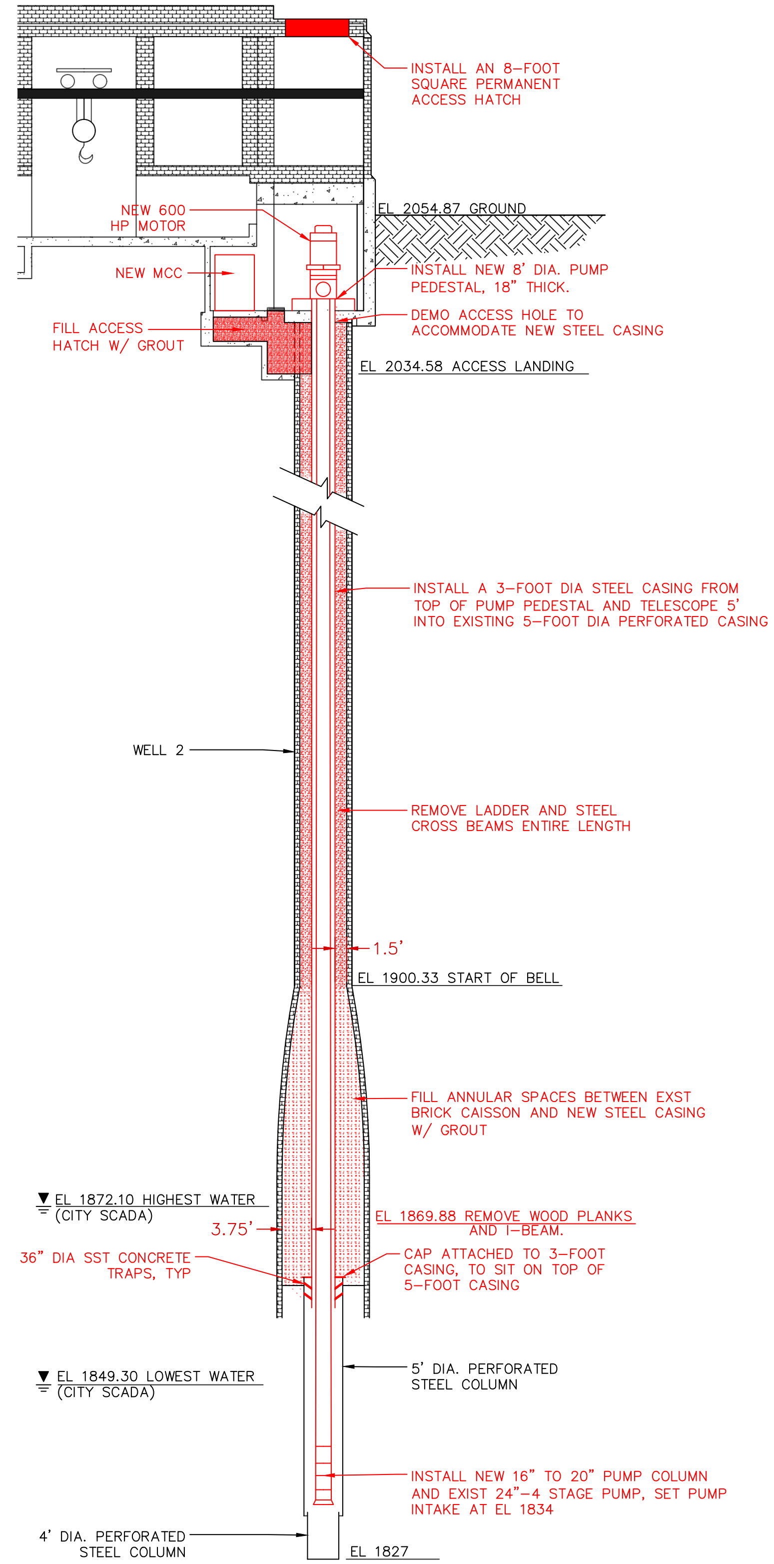


Figure 21. Profile of Hoffman Well Station Well 2 showing the preferred well repair concept. Courtesy of Murraysmith, Inc.

The final design of the steel casing liner and annular grout material will need to consider provisions to minimize loading of the existing perforated steel casing, such as:

- Placing a structural concrete fill at the bottom of the existing caisson to provide a base foundation on which the annular grout material above will bear and transfer load via end bearing to the gravel formation surrounding the existing steel casing.
- Limiting the load placed on the existing perforated steel casing by the new 3-foot diameter steel casing liner using a steel shroud or equivalent welded to the end of the steel casing liner that fits over the existing 5-foot diameter perforated steel casing and rests on the surrounding formation.
- Use of compressible rigid material and/or bond breakers to limit the structural connection (loading) between the new steel casing liner and annular grout material to minimize potential settlement and limit the loading on the existing perforated steel casing.

The existing well station building will need to be modified temporarily to allow access for materials and tooling to install and seal the casing liner. Access will require cutting an 8-foot by 8-foot square opening in the roof above the Well 2 caisson to allow crane access to suspend the casing liner string during installation and sealing. A permanent roof hatch will be installed over the opening after the work is completed for future access to the wellhead. Other well station modifications or improvements will include:

- Removal of currently installed accessories from the caisson well (e.g., ladder, steel cross beams, wood planks, and drop tubes/ piping).
- Installation of new pump column piping and a new pump motor
- Installation of a new electrical system, including power and controls to operate the pump

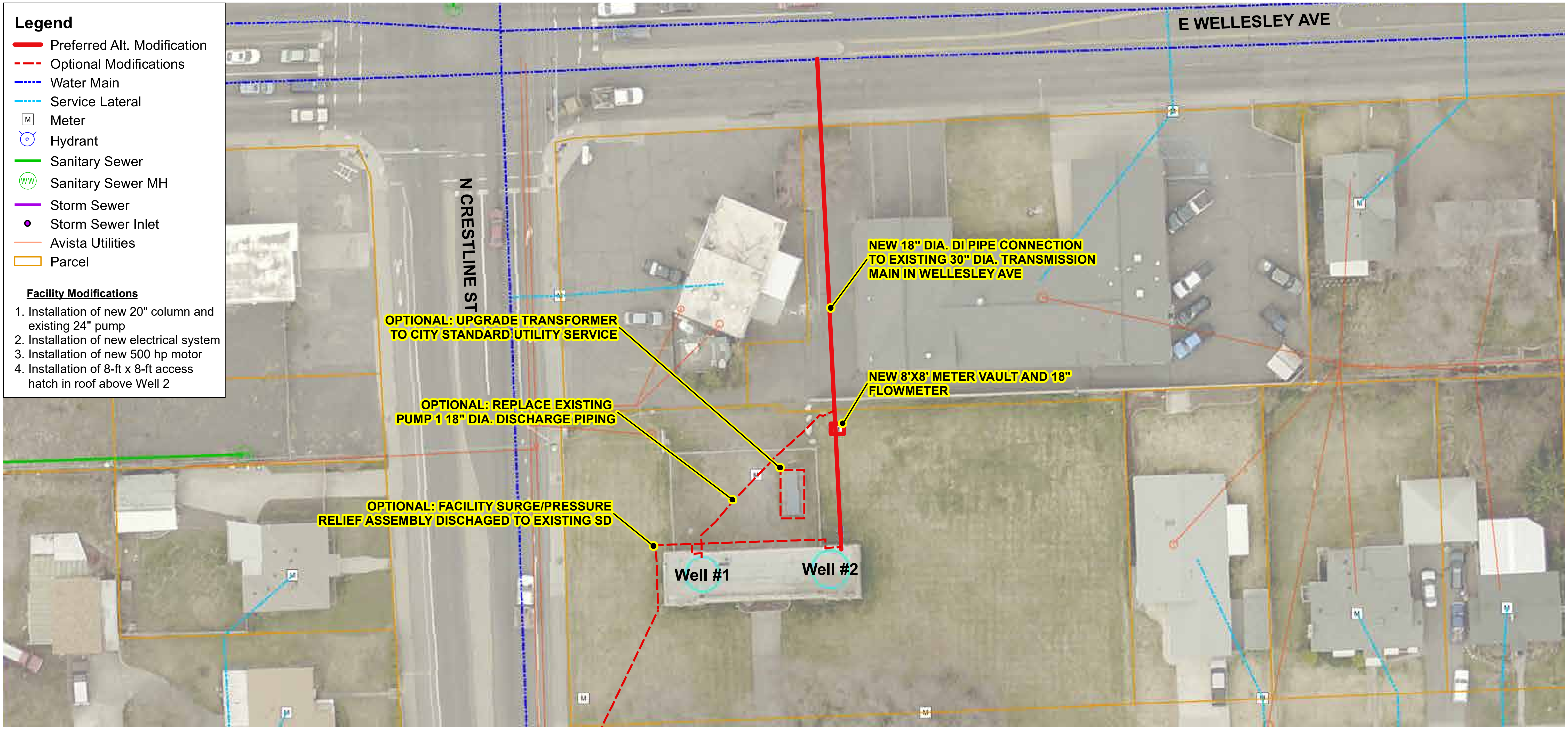


Figure 22. Site plan for the selected repair alternative at the Hoffman Well Station. Courtesy of Murrysmith, Inc.

Well Station Construction and Capacity

The Ray Street Well Station houses two caisson production wells (Well 1 and Well 2) that pump groundwater from the SVRP aquifer and supply water to the Intermediate Pressure Zone of the City's water supply system. The caissons were constructed circa 1940 as water supply sources for the City:

- Each caisson well was drilled (excavated) to a depth of approximately 80 feet.
- Each well is composed of an upper reinforced concrete caisson and lower perforated sheet-pile casing.
- Each caisson is 24 feet in diameter and extends to a depth of approximately 42 feet.
- The steel casing is 21 feet in diameter and is constructed of 52 sheet piles forming a circular extension from the base of the concrete caisson to a depth of roughly 80 feet.
- Every fourth sheet pile is perforated with 1-inch by 6-inch slots cut on 12-inch vertical centers. The perforations serve as the intake portion of the caisson wells, allowing water to enter from the saturated aquifer.

Figure 23. Exploratory drilling and monitoring well construction at the Ray Street Well Station. Courtesy of Landau Associates, Inc.

Well 1 is equipped with two 900 horsepower vertical line-shaft turbine pumps (Pumps 1 and 2). Well 2 is equipped with one 500 horsepower pump (Pump 3). Based on the total nameplate capacities of the existing pumps, the combined maximum instantaneous pumping rate of the two caisson production wells is approximately 18,700 gallons per minute.

Field Investigation

An inspection of the well station was conducted to (1) characterize current conditions of caisson wells above the water level, (2) verify caisson well depth and construction information, (3) establish a common reference datum, and (4) evaluate facility modifications that would be needed to access existing wells for future repair/alteration work. Visual inspections of the concrete caissons and perforated steel casings below the water table were conducted to further characterize the current conditions of the caisson wells below the water level and verify depths of the pump bowls/intakes (Figure 24).

Figure 24. Underwater photo of existing conditions at Ray Street Well 1.

An exploratory drilling investigation was conducted to characterize geologic and hydrogeologic conditions in the SVRP aquifer beneath the Ray Street Well Station property (Figure 23). Because of the relatively shallow depth of groundwater, monitoring wells and production wells are typically less than 100 feet deep, and the depth to bedrock and the saturated thickness in this area and throughout much of the SVRP aquifer are not well defined. The goal of the investigation was to evaluate the depth of unconsolidated soils above bedrock, and whether the aquifer at these greater depths has the capacity to support production wells screened deeper than the existing caisson wells.

Summary of Findings

The overall condition of the well appears to be good. The visible portions of the concrete caisson walls, platform bases, perforated steel sheet-pile casings, and sheet pile bracing rings appear intact. The casing and bracing rings appear somewhat corroded and encrusted with inorganic deposits, though appear to be in good condition overall. Some casing perforations exhibit minor encrustation, but are largely unobstructed and appear to be in good condition (Figure 24).

Two general hydrogeologic units with the following characteristics were identified during the drilling investigation:

- **High Transmissive Unit (0 to 100 feet bgs):** Primarily composed of gravel and coarse sand with an average saturated hydraulic conductivity of 5,780 feet per day.
- **Low Transmissive Unit (below 100 feet bgs):** Primarily composed of fine sand and silt with an average saturated hydraulic conductivity of 9 feet per day.

Groundwater was encountered at a depth of 32 feet. A monitoring well was constructed inside the exploratory boring for water quality sampling and continuous water level monitoring.

Groundwater level data available from monitoring nearby resource protection wells located upgradient of the Ray Street facility (Figure 25) indicate that groundwater elevations in this area are:

- Typically highest from late February or late March through May when river flows, river stages, and aquifer recharge are high and pumping demands are below their summer-season peak rates.
- Decline steadily through the late spring and early summer, reaching seasonal low levels that are fairly steady through August and much of September.
- Typically lowest during the late summer months of August and September when pumping demands are high and aquifer recharge is low.

Trends in the stage of the Spokane River appear to have a significant controlling effect on groundwater elevation trends in the caisson wells at Ray Street (Figure 26). During low river stage periods, the capacity of the well station appears to be limited by correspondingly deep groundwater levels, which ultimately reduces available drawdown and the potential production capacity of the well station (Figure 27) and could limit the pumping operations of one or both caissons wells during future periods of seasonal low water levels.

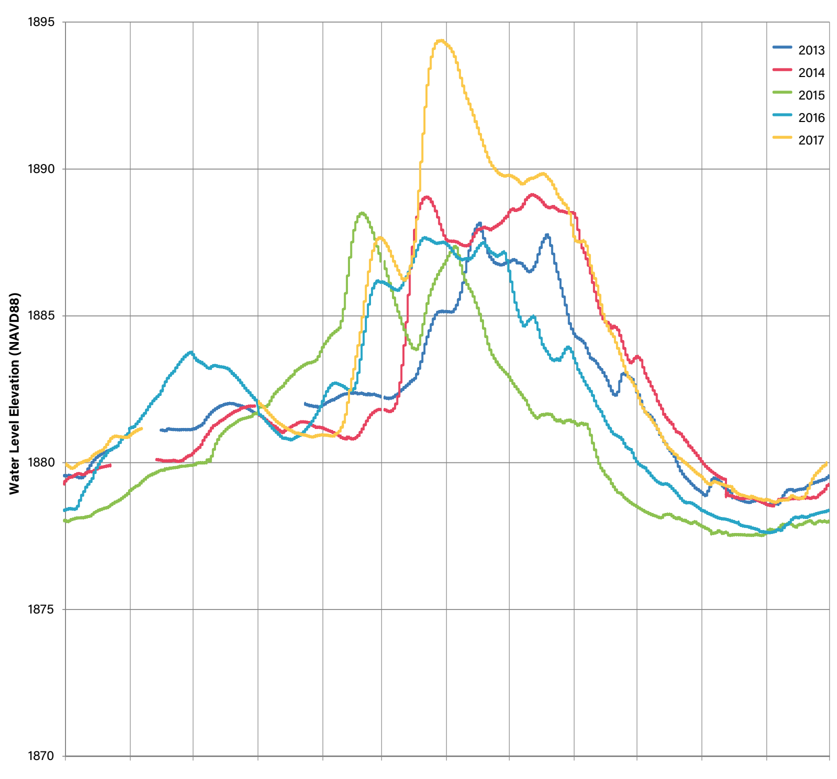


Figure 25. Groundwater elevations from nearby resource protection wells for years 2013 through 2017. Courtesy of GSI Water Solutions, Inc.

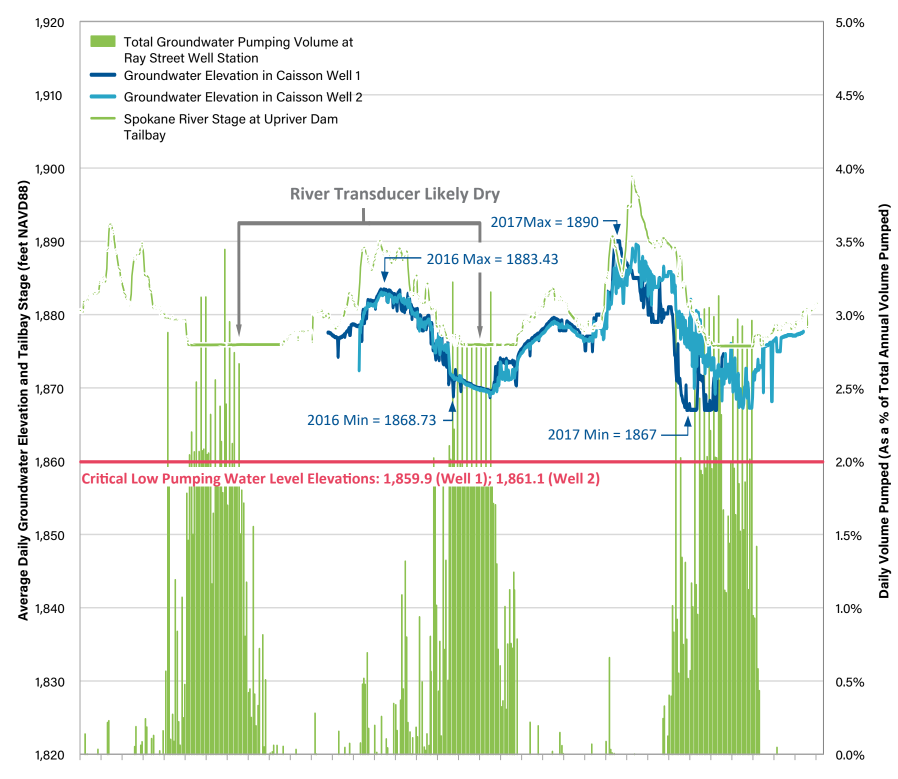


Figure 26. Groundwater elevation in Ray Street Well Station Wells 1 and 2, Spokane River stage, and total groundwater pumping volumes. Courtesy of GSI Water Solutions, Inc.

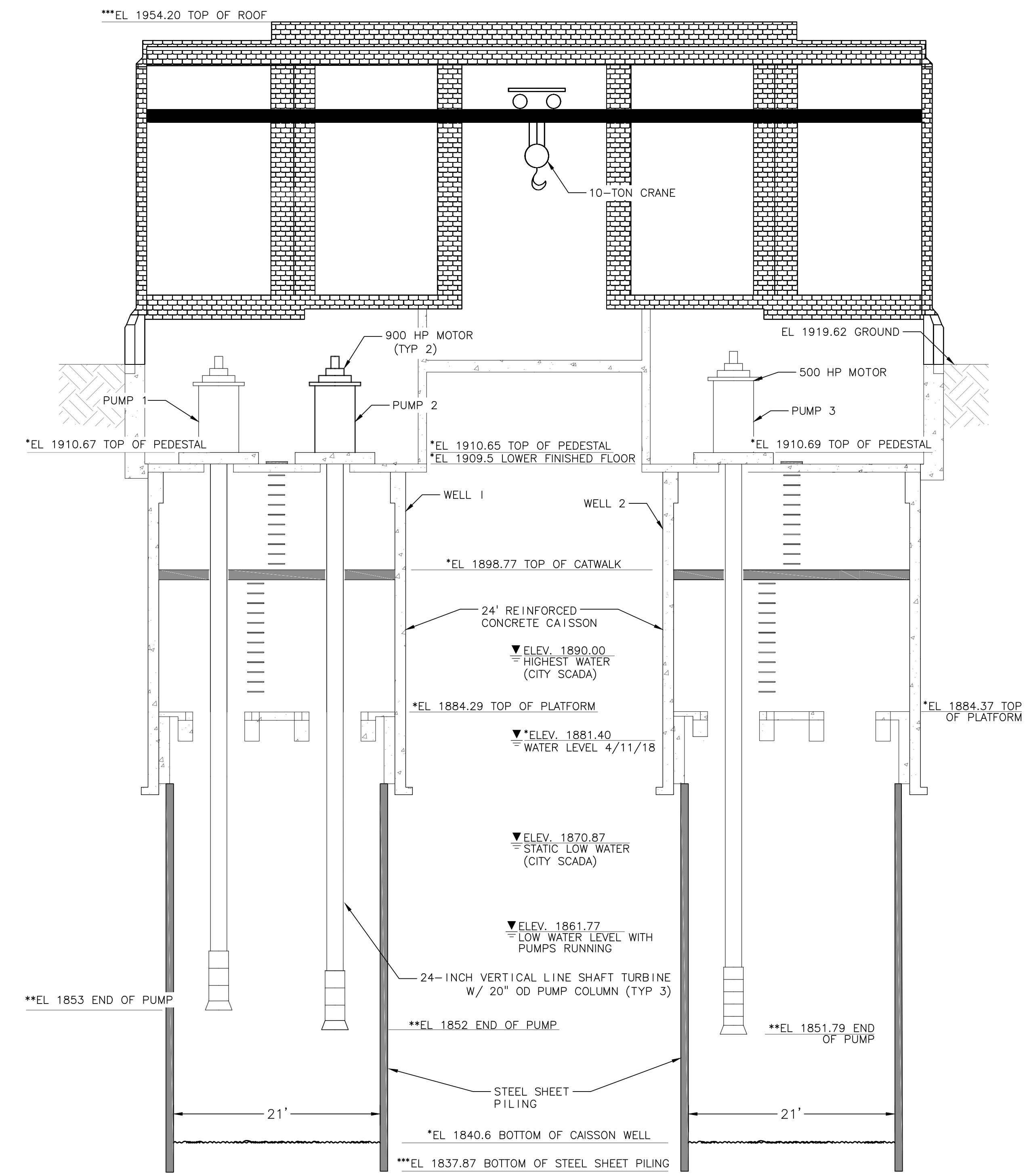


Figure 27 - Profile of Ray Street Well Station Well 1 (left) and 2 (right). Courtesy of Murraysmith, Inc.

WHAT IMPROVEMENTS WERE CONSIDERED?

Alternatives Considered

The pumping capacity of the Ray Street facility during periods of low groundwater levels is constrained by insufficient available drawdown and well inefficiencies that limit the City's ability to simultaneously operate Pumps 1 and 2 in Well 1. Furthermore, calculations of remaining available drawdown indicate that the well station capacity is vulnerable to further declines in seasonal low water levels in its current configuration. The alternatives considered were developed to address these operational limitations and improve the reliability of the facility.

Three upgrade/modification alternatives to improve the efficiency and capacity of the two Ray Street caisson wells were identified and evaluated for this study:

- **Alternative 1:** Modifying existing pumping systems, adding a fourth pump, and redistributing pumping between caisson wells.
- **Alternative 2:** Installing deeper perforated sheet pile casings, adding a fourth pump, and redistributing pumping between the caisson wells.
- **Alternative 3:** Advancing pump chambers below the base of the existing caisson, adding a fourth pump, and redistributing pumping between the caisson wells.

The three repair alternatives listed above were initially identified by considering the overall performance goals of improving system reliability and potentially increasing the overall capacity of the Ray Street Well Station. Each alternative was further evaluated relative to effectiveness, constructability, regulatory considerations, and cost.

Two additional alternatives were identified early in the evaluation, but eliminated from further consideration due to various logistical issues, constructability limitations, superstructure demolition and reconstruction requirements and costs, cost-benefit uncertainties, and worker safety concerns:

- **Perforate Existing Caissons:** This alternative would consist of installing additional perforations in the sidewalls of the existing sheet pile caissons to add lateral open area for the purposes of improving the pumping efficiency and performance of the caisson wells.
- **Drill and Install Lateral Well Screens:** This alternative would include extending horizontal screens (laterals) through the caisson walls into the formation in a radial pattern to increase lateral open area, similar to a radial collector well.

WHAT IS THE POTENTIAL INCREASE IN CAPACITY IF NEW WELLS ARE CONSTRUCTED?

In addition to modifying the existing facilities, the analysis of potential future changes at this property also considered the option of installing a new wellfield that would consist of one or more vertical wells located in the vicinity of the existing caisson wells. The purpose of a new vertical wellfield would be to provide a new groundwater supply source that could meet one or more of the following objectives: (1) regain any lost production capacity from the existing caissons that might occur under periods of particularly low regional water levels in the aquifer, (2) provide greater operational/production redundancy to complement production from the existing caisson wells, and/or (3) increase the amount of groundwater development capacity that is sustainable to pump on a long-term basis from this property.

Wellfield Layout and Estimated Capacity

The refined understanding of the general hydrogeologic units identified during the drilling investigation was subsequently utilized to design new production well prototypes, refine aquifer characteristics in the SVRP numerical groundwater model, and to evaluate the potential capacity of the Ray Street Well Station. Using the City's groundwater flow model, simulations were conducted for multiple scenarios involving various operating alternatives for the two existing caisson wells and for new vertical wellfield wells at the Ray Street Well Station property. Results from groundwater modeling analyses indicate that the site can support a network of deeper vertical wells that would support longer periods of sustained pumping while reducing the restricting influence of seasonal-low water levels on pumping operations.

A new vertical wellfield that maximizes production across two developable areas on the Ray Street property (Figure 28) could operate best as a seasonal replacement water supply source during periods of low ambient water levels in the aquifer, in lieu of pumping the existing caissons. Groundwater modeling analyses indicate that a new wellfield consisting of an estimated 19 wells could support a groundwater production capacity of at least 66,500 gallons per minute (96 million gallons per day) on a long-term basis if the caisson wells are not operating. If the caissons are operating at a capacity of 23,050 gpm, modeling results indicate that a vertical wellfield consisting of five wells with a capacity of 17,500 gallons per minute (25.2 million gallons per day) is feasible.

Limitations and Uncertainties

A maximum groundwater production capacity of potentially as much as 66,500 gallons per minute should be sustainable on a long-term basis, although this yield may be somewhat less if future water levels in the aquifer decline to, or below, the historically observed lowest groundwater elevation. The actual achievable groundwater production capacity also will depend on the number and spacing of vertical wells, which will be affected by other design considerations (for example, the number and size of well houses).

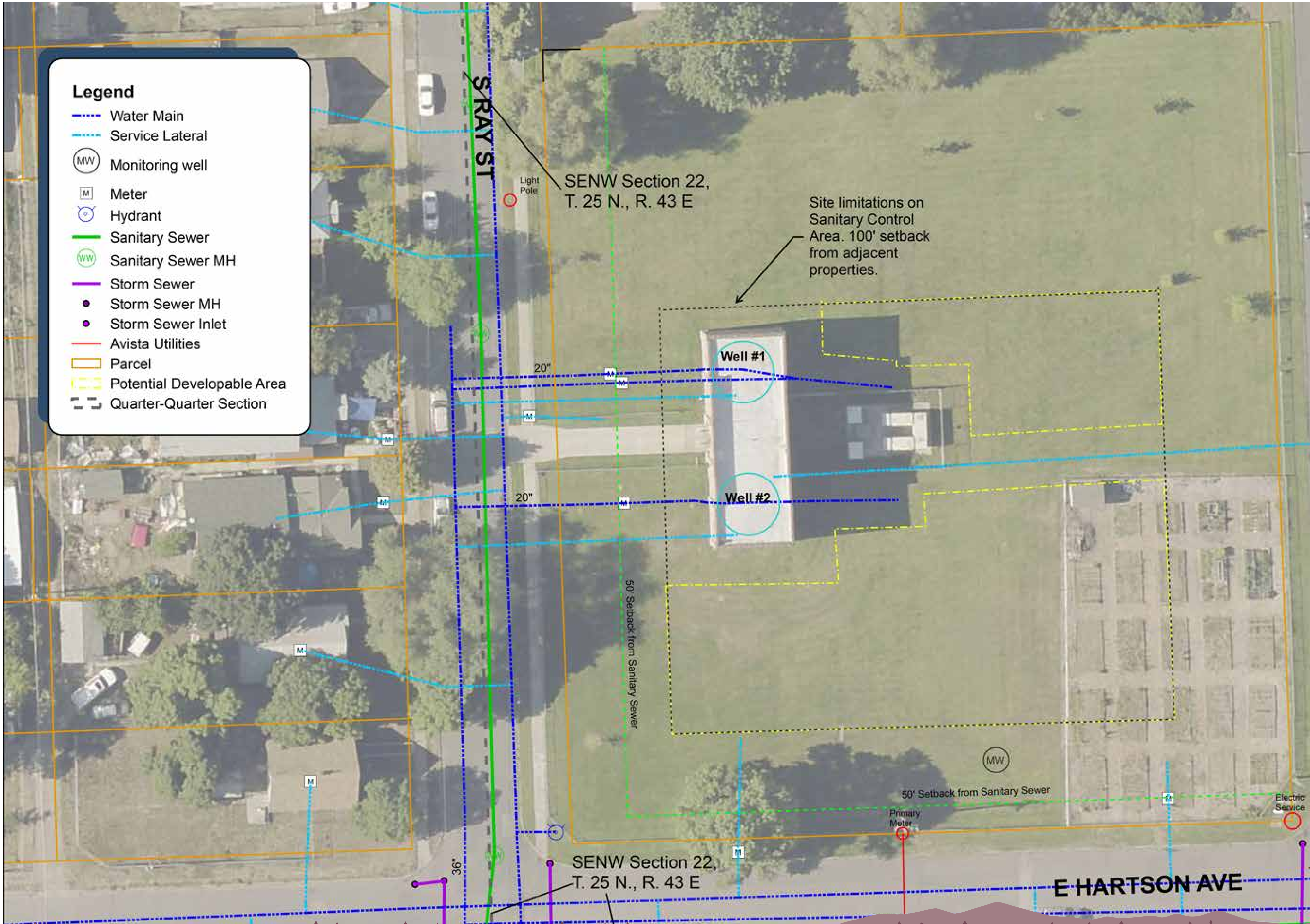


Figure 28. Site map of the Ray Street Well Station facility and facility piping. Areas outlined in yellow illustrate the potential developable area for wellfield wells. Courtesy of Murraysmith, Inc.

RAY STREET: WHAT IMPROVEMENTS HAS THE CITY SELECTED FOR FUTURE IMPLEMENTATION?

Concept Plan Summary

The selected alternative consists of two parts: (1) modifying the pumping systems in both caisson wells and (2) installing a new wellfield in the southeastern portion of the Ray Street Well Station property.

Under this concept, the improvements to the existing caissons would increase their maximum achievable production rate by an estimated 6,850 gallons per minute (which is equivalent to 9.9 million gallons per day), while the new wellfield would provide an additional 17,500 gallons per minute (25 million gallons per day) of estimated pumping capacity. Together, these improvements would increase the nominal operating capacity of the Ray Street Well Station site by 150 percent, from its current 16,200 gallons per minute (23.3 million gallons per day) to an estimated 40,500 gallons per minute (58 million gallons per day)

Caisson Well Modifications

The selected alternative for the existing caisson wells redistributes the pumping capacity between each caisson, lowers the intakes of the three existing pumps, and adds a fourth pump to increase facility production capacity (Figure 29). These modifications would (1) increase the amount of available drawdown compared with present conditions, (2) optimize the hydraulic efficiency of pumping operations, and (3) utilize existing infrastructure to the maximum extent possible and avoid unnecessary capital expenditures. Incidental repairs are expected to be limited to repairing small amounts of exposed reinforcing steel and spalling concrete that were identified during visual structural inspection.

Pumping system modifications would consist of (1) lowering the intakes of each pump, (2) moving current Pump 2 (an existing 7,200 gallon per minute pump with 900 horsepower motor) from Well 1 to a space that has already been reserved for a new pump in Well 2, and (3) adding a new pump in Well 2 (a new 4,350 gallon per minute pump and 500 horsepower motor, including downhole appurtenances consisting of a chlorine injection tube). These modifications will increase the total capacity of the facility by redistributing pumping so as to enable installation of an additional pump and create more efficiency when operating two pumps in each caisson.
Other well station modifications or improvements will include:

- Construction of a pump pedestal and hole through the floor for the new pump assembly.
- Construction of new 20-inch diameter discharge piping and appurtenances, including a surge anticipator/pressure relief valve assembly for routing water from the pump to the 36-inch water main located west of the facility in Ray Street.
- Installation of a new electrical system, including power and controls to operate the new pump.

New Wellfield

The new 5-well wellfield was designed by optimizing the design (e.g., screen diameter and slot size) and layout (e.g., regulatory setbacks and spacing between wells) of the wellfield wells. The recommended well design consists of 125-foot deep production wells with 24-inch diameter, wire-wrapped, stainless-steel well screens (Figure 30). Each well screen would be 25 feet in length, have a 0.175-inch slot size, and have a design capacity of 4,000 gpm. Downhole appurtenances in each well would include a chlorine injection tube, level sensor tube, video inspection tube, raw water sampling pump, and pump column.

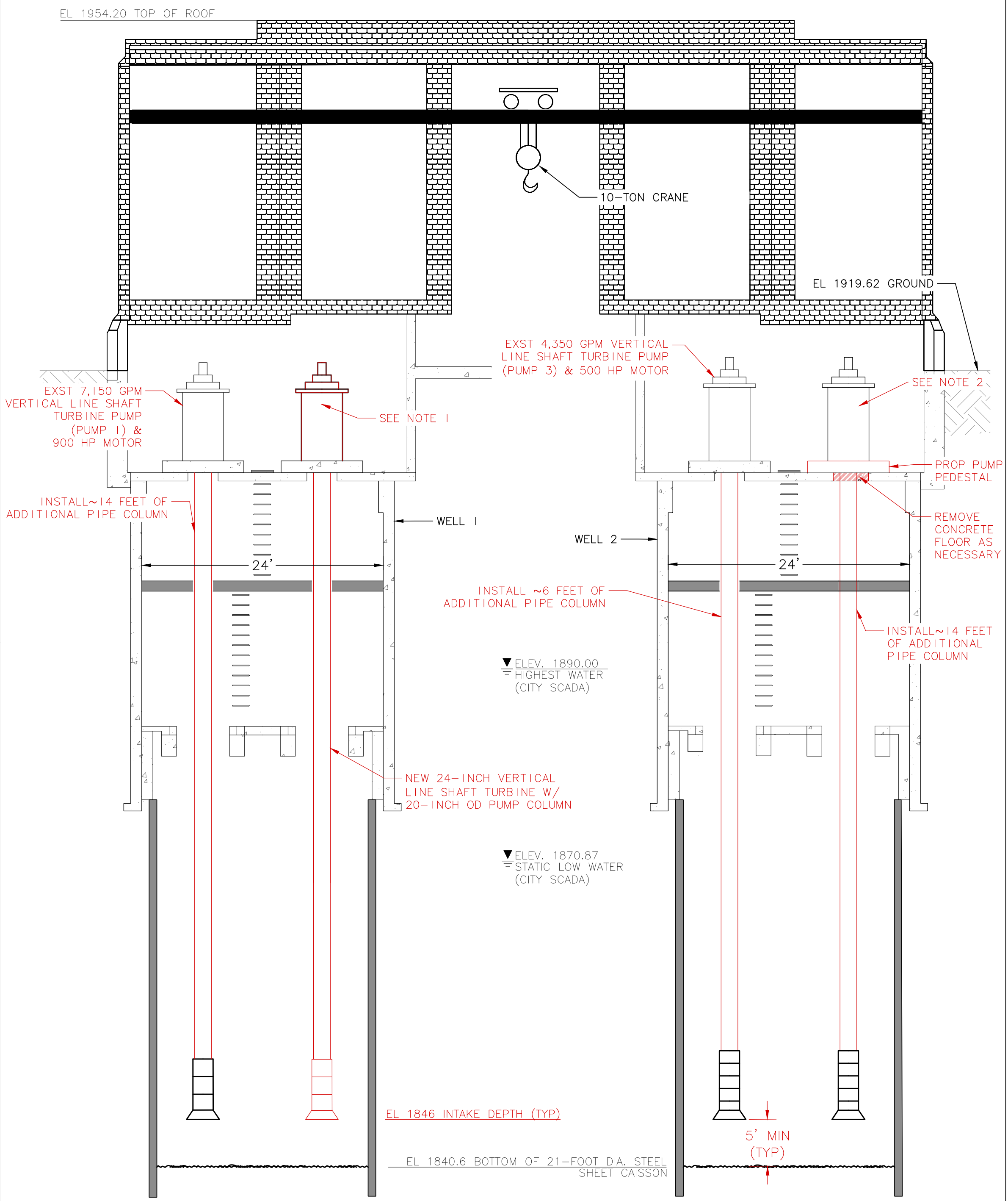


Figure 29. Profile of the Ray Street Well Station illustrating the preferred station upgrade/modification alternative. Courtesy of Murraysmith, Inc.

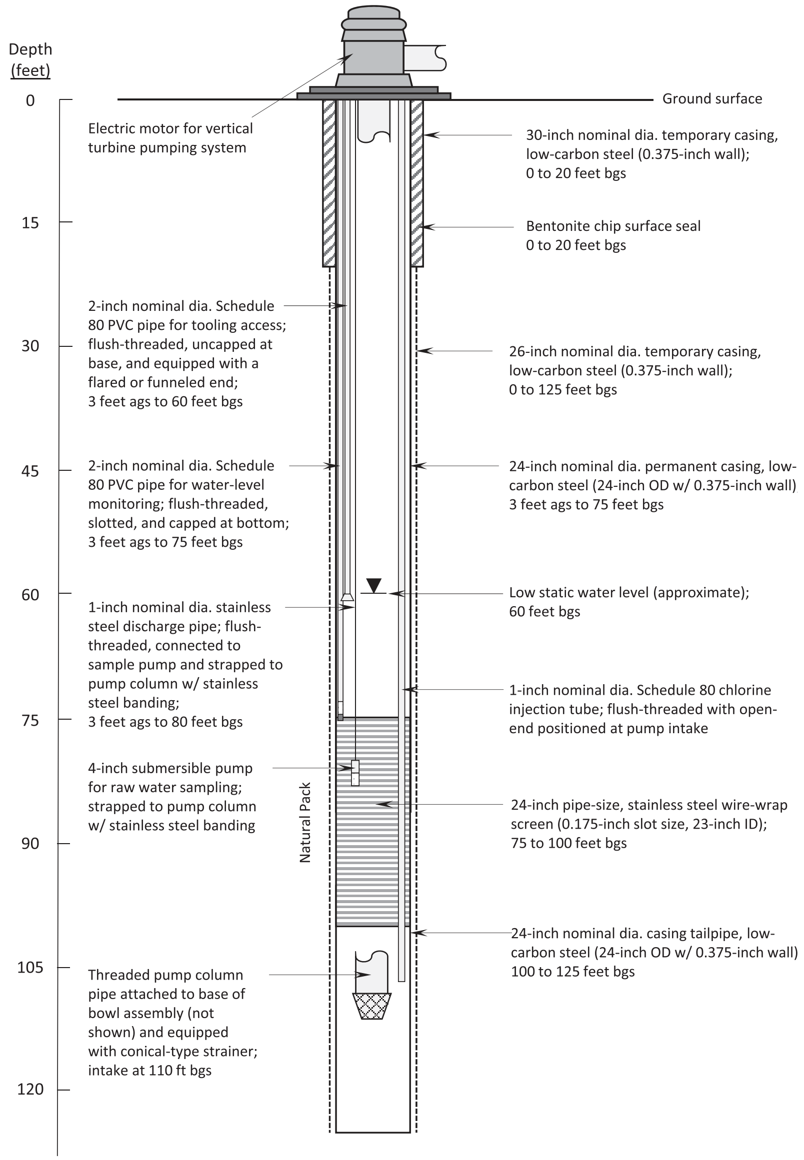


Figure 30. Conceptual well design for Ray Street wellfield production well with downhole appurtenances.

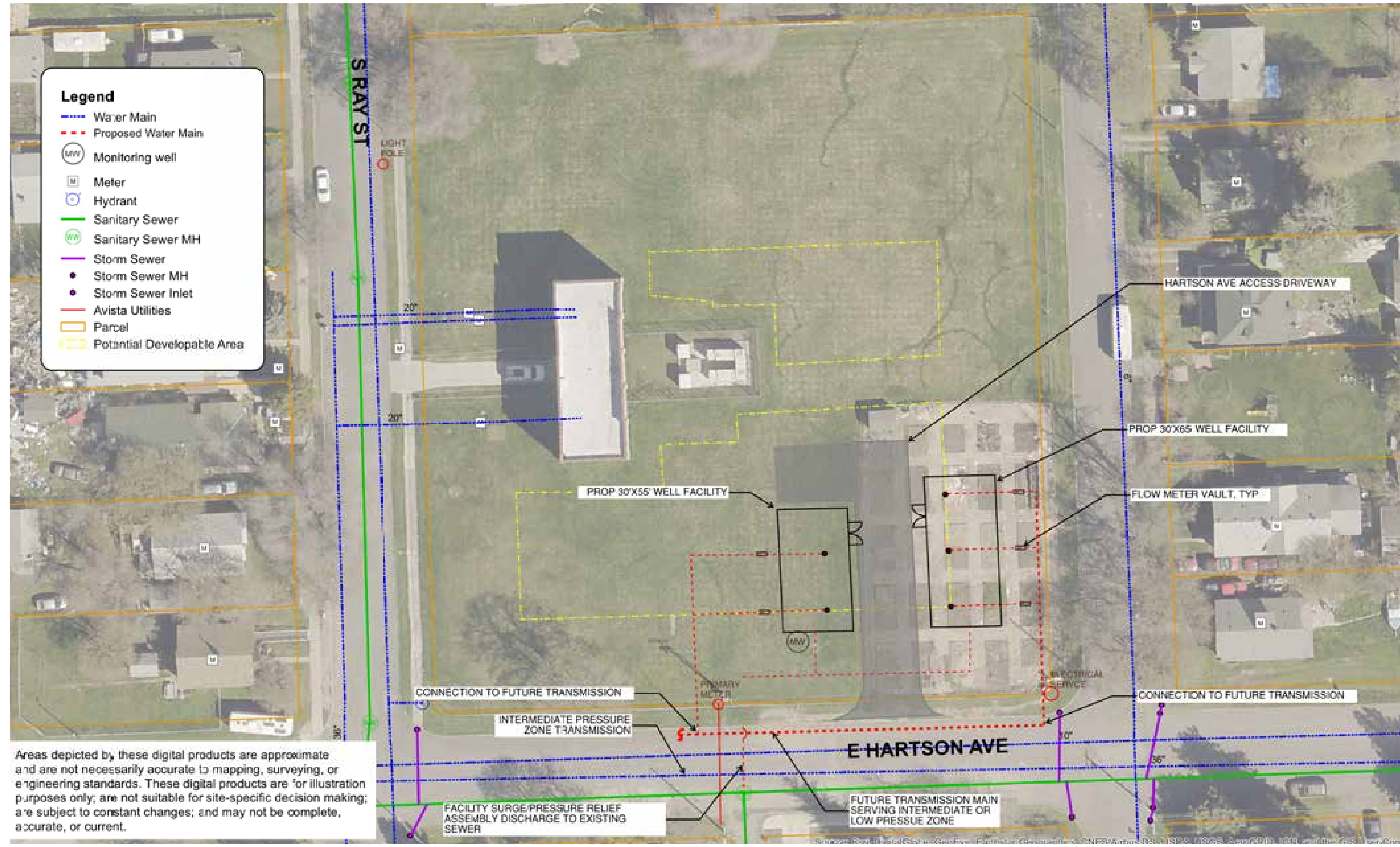


Figure 31. Conceptual site plan showing the locations of wellfield production wells, facility buildings and site piping. Courtesy of Murraysmith, Inc.

Results from groundwater modeling analyses indicate that when simultaneously operating these five wells at 3,500 gallons per minute each, the amount of water level drawdown in each well is likely to be less than (and perhaps only half as much as) the 16 feet of drawdown that is available in each well under the historical low summer static water level for the aquifer beneath the Ray Street property – even when accounting for the added influence of drawdown interference from pumping of the modified caisson wells.

Two buildings situated on either side of an access driveway extending north from East Hartson Avenue in the southeastern portion of the property would be constructed for the wellfield wells (Figure 31).

The building on the west side of the access driveway would house two wells, while the building on the east side of the access driveway would house three wells. Inside a given building, the wells would be spaced 25 to 30 feet apart. Discharge piping from each well pump will include an individual flow meter and connect into a common header onsite before connection into a new transmission main that would be installed in East Hartson Avenue. Since the new wellfield is anticipated to supply both the Low and Intermediate pressure zones, two new transmission mains would be required. The new wellfield would contain five traditional vertical production wells that would provide supplemental water supply and would be able to operate simultaneously with pumping from the two caisson wells.

WELL ELECTRIC: WHAT IS ITS CONDITION?

Well Station Construction and Capacity

The Well Electric Well Station houses two caisson production wells (Well 4 and Well 5) that pump groundwater from the SVRP aquifer and supply water to the Low, Intermediate, and North Hill Pressure Zones of the City's water supply system. The two caisson production wells were constructed circa 1921 (Well 4) and 1925 (Well 5) as water supply sources for the City (Figure 32):

- Both caisson wells were originally drilled (dug) to depths ranging between an estimated 40 and 45 feet below ground surface. Each are bell-shaped and constructed of reinforced concrete.
- The concrete caisson of Well 5 houses two perforated steel casing columns with estimated diameters of 28 to 36 inches. Each casing extends approximately 10 feet below the base of the caisson and serves as a pump chamber for vertical turbine Pumps 1 and 3.

Based on the total nameplate capacity of the existing pumps, the combined maximum instantaneous pumping capacity of the two caisson wells is rated at approximately 39,300 gallons per minute (56.6 million gallons per day). Testing by the City in 2016 indicates that the current reliable operational capacity of the two caisson production wells together is 36,500 gallons per minute (52.6 million gallons per day).

During low river stage periods in dry years (such as 2015), the capacity of the well station appears to be limited by lower-than-normal groundwater levels (Figure 33), which reduces the amount of available drawdown and affects the ability to operate the centrifugal pumps. During this period, the City voluntarily stops pumping from this well station whenever the flow at Post Falls Dam rises above 15,000 cubic feet per second to minimize the potential for surface water to enter the caissons. Accordingly, each year, groundwater production capacity is adversely affected by spring-season peak water levels, summer-season low water levels, and the configuration of the pumps and caisson wells.

Field Investigation

An inspection of the well station was conducted to (1) verify existing data, (2) observe and document the current facility condition, and (3) evaluate facility modifications that would be needed to access existing wells for future repair/alteration work. A step-rate pumping test was conducted at Well 5 to evaluate well performance and the hydraulic parameters of the aquifer system at the existing well station. Visual inspections and video surveys inside the caissons to characterize existing conditions and to verify caisson well depths, construction information, or pump intake depth settings could not be conducted during this investigation due to caisson access constraints (i.e., high groundwater levels and sealed pump pedestal flooring).

An exploratory drilling investigation program was conducted to characterize geologic and hydrogeologic conditions in deeper portions of the SVRP Aquifer beneath the Well Electric Well Station. Because of the relatively shallow depth of groundwater, monitoring wells and production wells are typically drilled to depths of less than 100 feet below ground surface. As a result, the depth to bedrock and the saturated thickness in this area and throughout much of the SVRP Aquifer are not well defined. The goals of the exploratory drilling investigation on the Well Electric well station property were to evaluate the thickness of the unconsolidated soils above bedrock, and assess whether deeper portions of the aquifer are influenced by the river and have the capacity to support production wells screened deeper than the existing caisson wells.

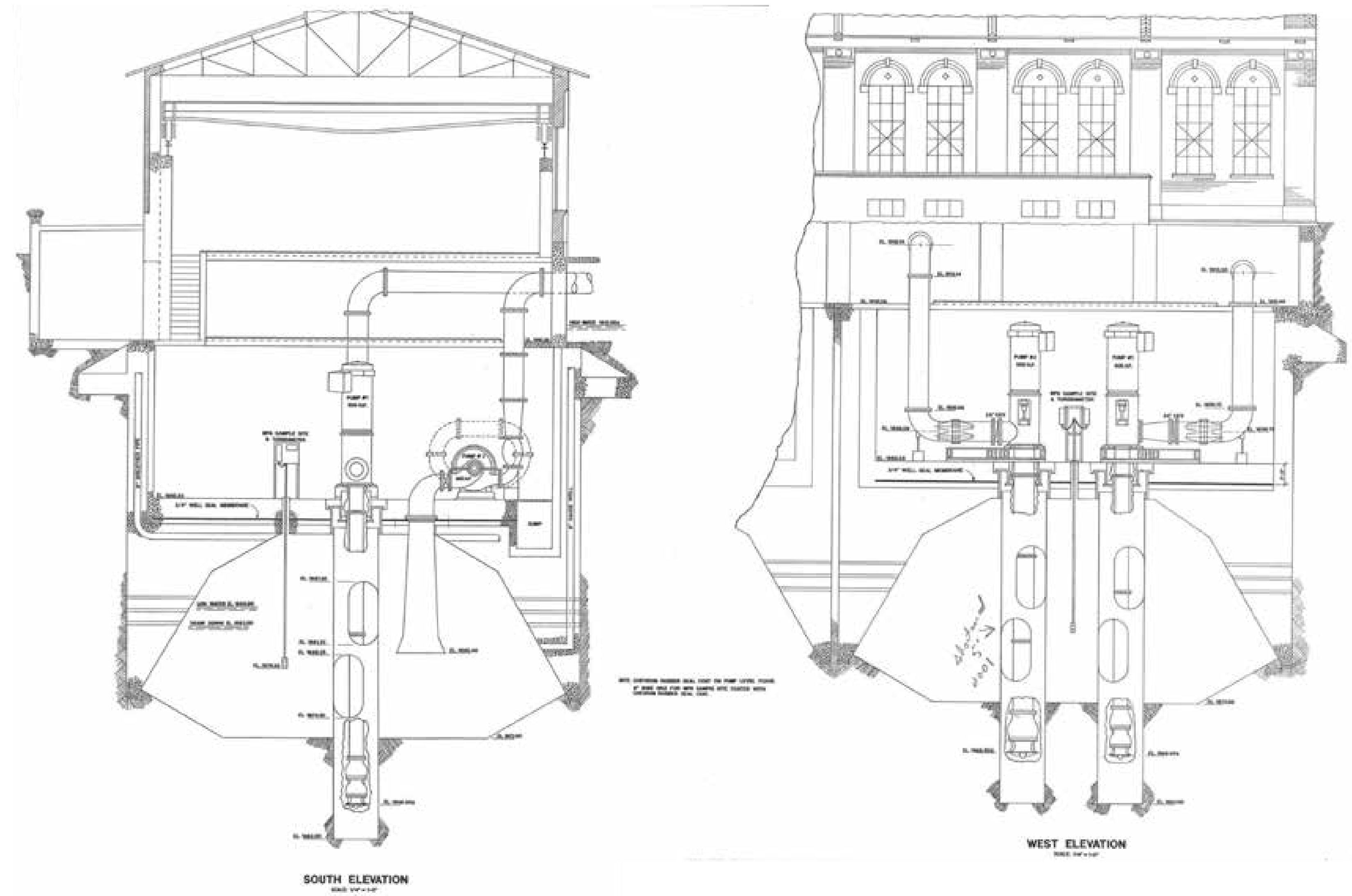


Figure 32. Caisson well construction diagram of Well 5. Courtesy of City of Spokane and Murraysmith, Inc.

Summary of Findings

Groundwater level data available from the Well Electric Well Station (Figure 33) and from a resource protection monitoring well (Figure 34) located upgradient of Well Electric indicate that groundwater elevations in this area are:

- Typically highest from late February or late March through May when river flows, river stages, and aquifer recharge are high and pumping demands are below their summer-season peak rates.
- Decline steadily through the late spring and early summer, reaching seasonal low levels that are fairly steady through August and much of September. Because of lower snowpack volumes and decreased spring runoff in 2015 and 2016, the spring-season declines in groundwater levels began much earlier during those two years than during the other three years for which data are presented (2013, 2014, and 2017).
- Typically lowest during the late summer months of August and September when pumping demands are high and aquifer recharge is low.

The hydrology of the watershed has a controlling effect on water levels in the Spokane River and the SVRP aquifer, which in turn influences the depth to water in the existing caisson wells at the Well Electric Well Station under pumping and non-pumping conditions alike. Historical data analyses and groundwater modeling evaluations together indicate that during periods of below-normal runoff in the watershed and below-normal flows in the Spokane River, ambient groundwater levels beneath the Well Electric Well Station at times are low enough to cause water levels to approach the critical-low threshold levels that need to be maintained for proper operation of the two centrifugal pumps (Figure 33), thereby reducing the reliability and magnitude of groundwater production from the Well Electric Well Station.

The exploratory boring identified the presence of a thick sand-dominated unit in the SVRP aquifer. The top of the sand unit was encountered at a depth of 125 feet and continued to (and likely beyond) the total depth of the borehole (400 feet). Neither the base of this deep sand unit nor the top of the underlying basement bedrock comprising the base of the SVRP aquifer were encountered in this exploratory borehole. A monitoring well was installed in the deep sand unit in the exploratory borehole and instrumented with automated continuous-recording water level monitoring equipment (Figure 35).

The general hydrogeologic units with the following characteristics were identified:

- **Coarse-Grained Shallow Gravel Unit (0 to 125 feet bgs):** Primarily composed of coarse sands and gravels with a 50 percent passing grain size of 0.09 inches and an average saturated hydraulic conductivity of approximately 2,800 feet/day.
- **Finer-Grained Deep Sand Unit (below 125 feet bgs):** Primarily composed of sand with some silt with a 50-percent-passing grain size ranging between 0.04 and 0.07 inches, equating to an average saturated hydraulic conductivity of between approximately 500 and 800 feet/day.

**Groundwater was encountered at a depth of 36 feet.*

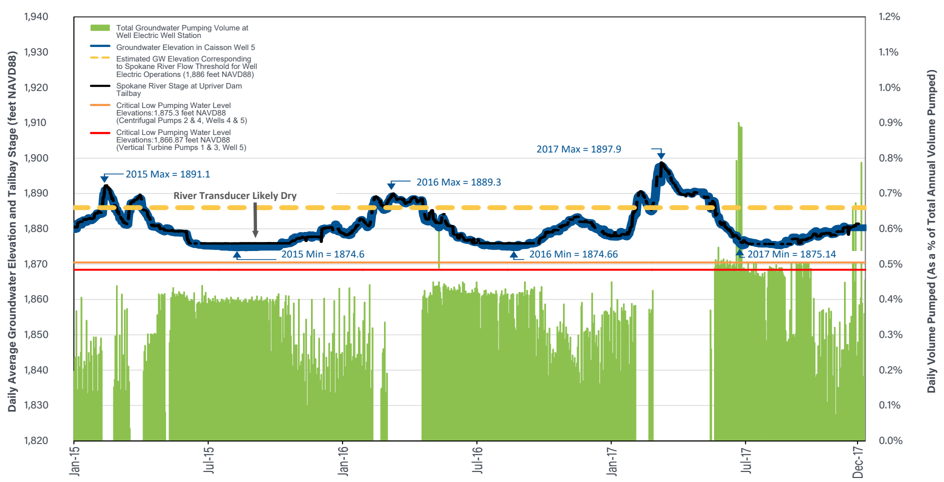


Figure 33. Groundwater elevation in Well Electric Well Station Well 5, Spokane River stage, and total groundwater pumping volumes. Courtesy of GSI Water Solutions, Inc.

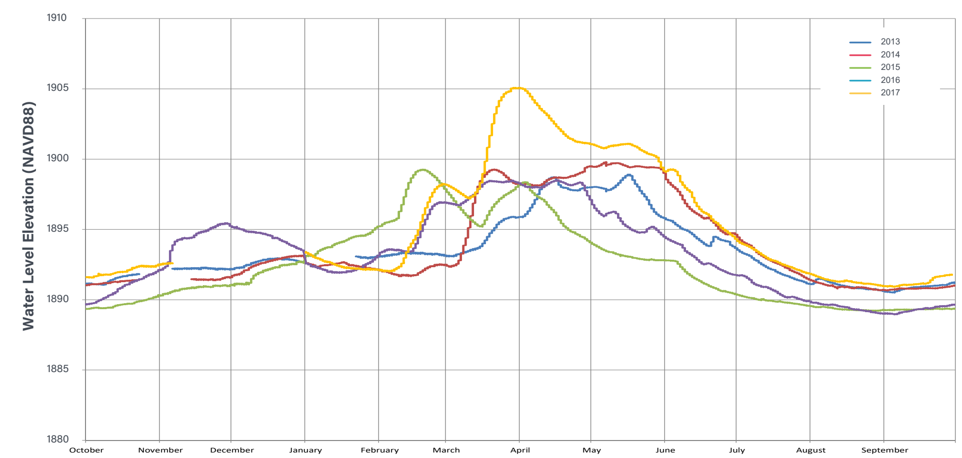


Figure 34. Groundwater elevation from resource protection monitoring well near Felts Field for years 2013 through 2017. Courtesy of GSI Water Solutions, Inc.

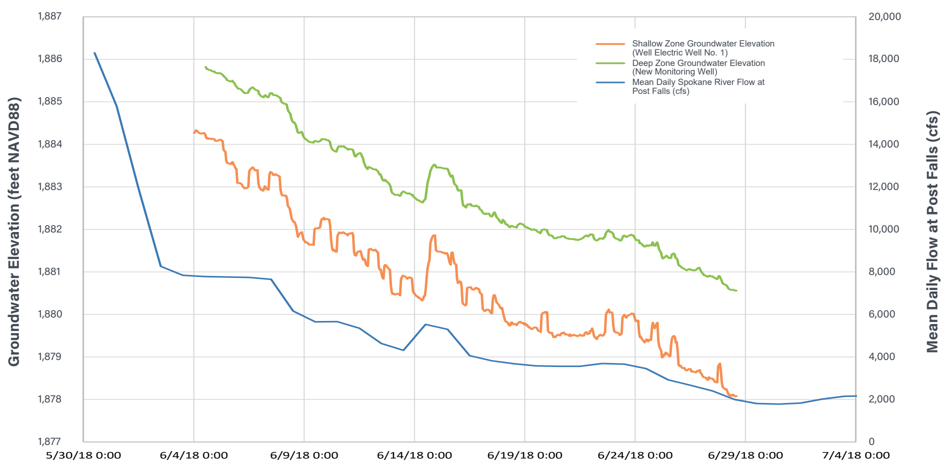


Figure 35. Monitoring at the newly constructed, deep monitoring well and at a nearby, shallow observation well (Well 1) during summer 2018 illustrate that (1) groundwater levels in both units fluctuate in response to changes in Spokane River stage and (2) an upward hydraulic gradient exists from the deep sand unit to the shallow gravel unit in this general area. Courtesy of GSI Water Solutions, Inc.

WELL ELECTRIC: WHAT IMPROVEMENTS WERE CONSIDERED?

Alternatives Considered

The reliable capacity of the Well Electric Well Station has been affected seasonally in two ways: (1) seasonally low Spokane River stages adversely impact available drawdown at the caisson wells during dry water years, affecting the ability to operate the two centrifugal pumps and (2) the well station must be shut off during high Spokane River stage periods because of the potential hydraulic connection between the caisson wells and surface water from the river.

Two alternatives for modifying the existing Well Electric facilities were identified and evaluated for improving the performance and reliability of the two caisson wells during the peak demand season (late spring through fall), particularly during dry years (such as the summer of 2015) when ambient water levels in the aquifer decline below normal levels.

- **Alternative 1:** Deepen both of the existing caisson wells, install lateral open area in the caisson extensions, lower the two existing vertical turbine pumps in Well 5, and install one new vertical turbine pump in Well 4. This alternative would improve the operating efficiencies of the active pumps by redistributing pumping capacity between the two caisson wells and increasing the amount of submergence of the intakes for the vertical turbine pumps. This alternative would be a substantial construction project, entailing partial or complete removal and replacement/restoration of the building superstructure, plus complete removal of the reinforced concrete platforms capping the caissons to provide unrestricted access to the wells for placement of the caisson extensions.
- **Alternative 2:** Modify Well 4 by (1) advancing steel casing below the base of the existing concrete caisson to function as a pump chamber, and (2) adding a vertical turbine pump to the new pump chamber. This alternative would increase the reliable capacity of Well 4 by adding a vertical turbine pump that has more submergence/available drawdown than the centrifugal pump. The existing well station building may need to be modified temporarily to allow access for materials and tooling. Unlike Alternative 1 however, building removal and replacement/restoration would not be required under this alternative, nor would the caissons themselves be modified in any way.

These modifications would increase system reliability and operating efficiency and individually provide a modest (6 million gallon per day) increase in the operating capacity of the existing facilities at the Well Electric Well Station. Despite this however, neither of the two alternatives accomplishes one of the City's primary objectives: eliminating the need to cease pumping operations from both caisson wells during periods of high river stages, when hydraulic connection is possible between the caisson wells and the river. Accordingly, alternatives for addressing the issue of connection to the river are limited to concepts for developing a new water supply source consisting of vertical wells.

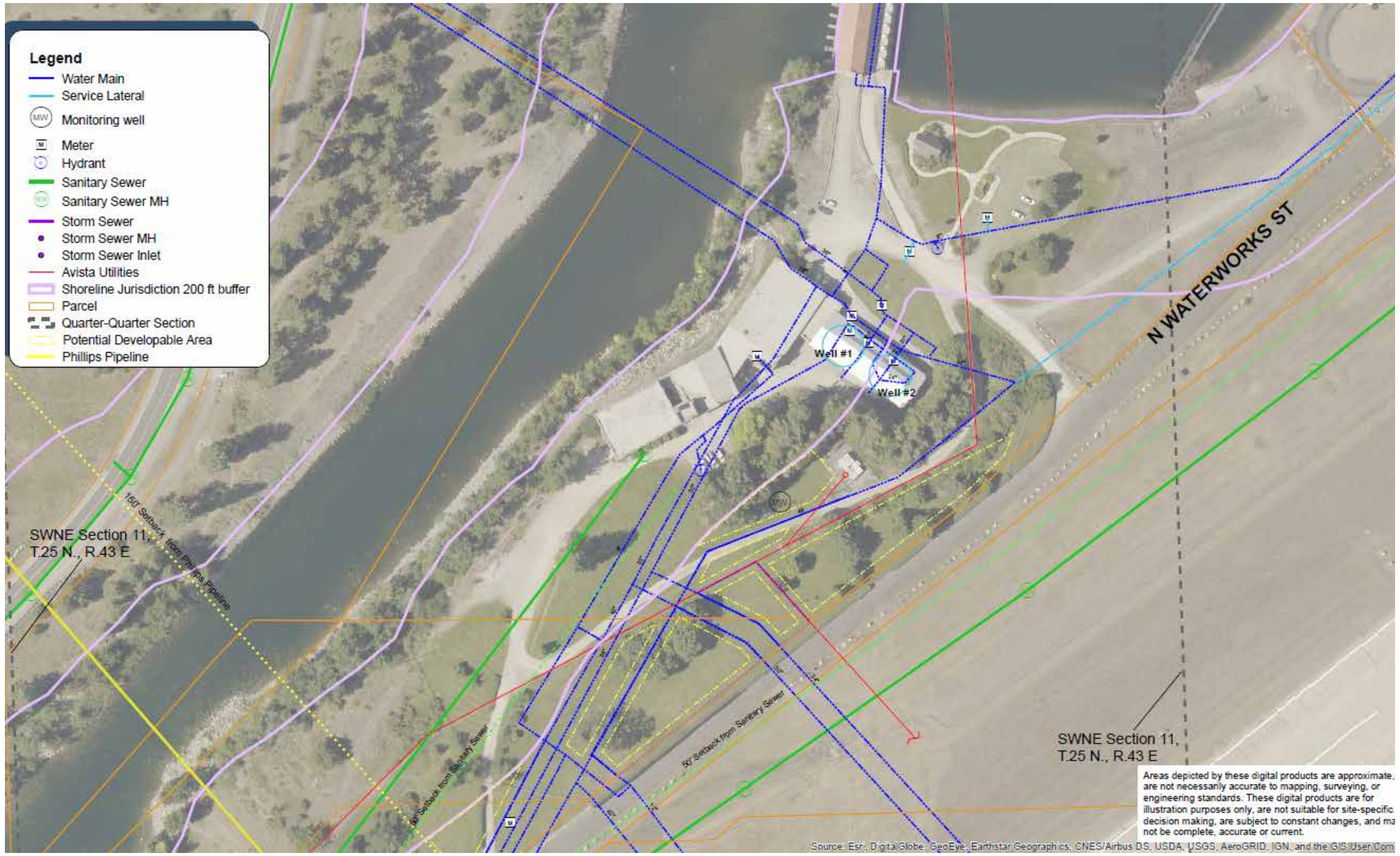


Figure 36. Site map of the Well Electric Well Station facility and facility piping. Areas outlined in yellow illustrate the potential developable area for wellfield wells. Courtesy of Murraysmith, Inc.

WELL ELECTRIC: WHAT IS THE POTENTIAL INCREASE IN CAPACITY IF NEW WELLS ARE CONSTRUCTED?

Wellfield Layout and Estimated Capacity

The refined understanding of the general hydrostratigraphic units within the SVRP aquifer at the location of the exploratory borehole was subsequently utilized (1) in developing a deep production well prototype design, (2) to refine aquifer characteristics in the City's existing groundwater model, and (3) to evaluate the potential capacity of the Well Electric Well Station. A new vertical wellfield on the Well Electric Well Station property (Figure 36) could operate as a spring-season replacement water supply source during periods when the existing caisson wells are shut down because of high groundwater levels induced by high flow/stage conditions in the Spokane River. Results from a 3D groundwater modeling analyses indicate that a new wellfield comprised of sixteen 400-foot deep wells screened in the deep sand unit of the SVRP aquifer could support a production capacity of at least 80,000 gallons per minute (115 million gallons per day) on a long-term basis (5,000 gallons per minute each well). If the existing caisson wells are operating at their target capacity of 40,900 gallons per minute (58.9 million gallons per day) under Alternative 2 for their modifications, the modeling results indicate that total groundwater production from the property could be as high as 120,900 gallons per minute (174 million gallons per day). A reduction in the production rates from the existing caissons however, likely will be necessary when river levels are high, and also may be necessary if groundwater levels drop to levels lower than historically observed.

How to Address River Influence?

The modeling analyses (Figure 37) indicate that (1) groundwater in the upper portion of these well screens would originate from areas east of the wellfield, rather than from the overlying surficial gravel unit and (2) the design depths of the well screens for each production well likely would allow groundwater to be pulled from a more radial direction and at great depths in the aquifer (see the red, green, and blue groundwater flowpaths, rather than from the uppermost model layer and the river (see the yellow flowpaths) as occurs with the existing caisson wells.

Limitations and Uncertainties

Because only one borehole/monitoring well has been drilled into the deep sand unit on this property, and because no other deep boreholes or wells are known to exist elsewhere in the eastern part of the City or nearby portions of the Spokane Valley, uncertainty exists regarding the depth, thickness, and continuity of the deep sand unit beneath and surrounding the Well Electric Well Station property. Additionally, because of the lack of deep boreholes regionally, no high-stress long-term groundwater pumping is known to have been conducted from the deep sand unit, which means the hydraulic properties and groundwater production potential of this hydrostratigraphic unit can only be estimated from the grain-size analyses that were conducted on the core samples collected from the exploratory borehole.

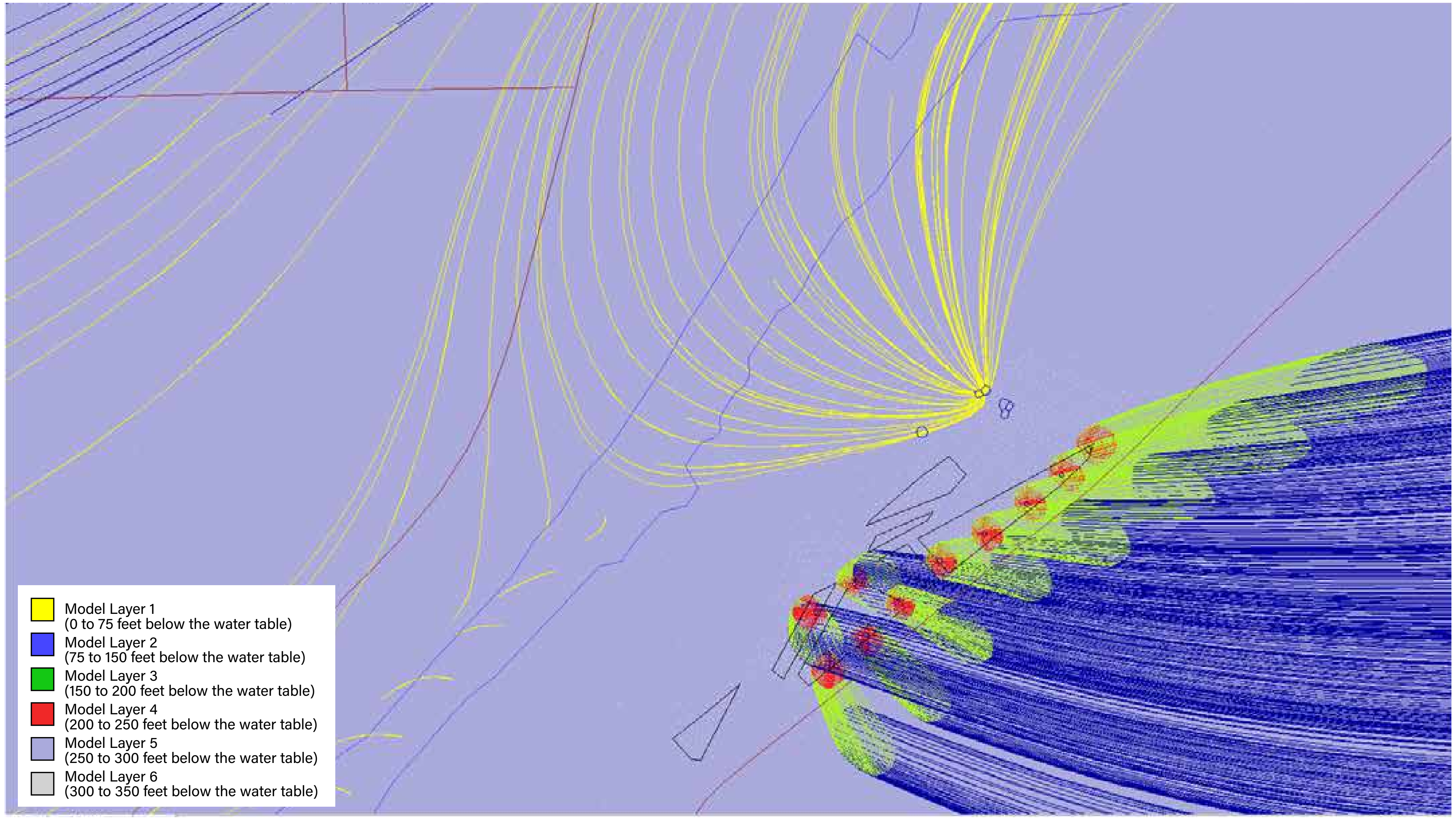


Figure 37. Results from groundwater modeling analyses show groundwater capture zones generated by pumping wellfield production wells completed in the deep sand unit at the site to migrate eastward and away from the Spokane River.

Concept Plan Summary

The City has identified its preferred alternative for the Well Electric Well Station property as consisting of constructing a new wellfield in multiple phases, with no modifications to the existing caisson wells. This is the only alternative that can both (1) reduce the influence of surface water during seasonally high flows in the Spokane River and (2) create resiliency to future lower summer-season groundwater levels that is not possible to achieve through modifications to the caisson wells.

As shown in Figure 36, the future wellfield would be developed in a grassy portion of the property along the west side of North Waterworks Street. The wellfield concept would be developed in phases:

- **Phase I –** The first phase would consist of installing four high-capacity production wells capable of producing a combined capacity of an estimated 20,000 gpm (5,000 gpm each well) to serve the North Hill pressure zone. Two of the four wells would be in reserve, with an available maximum supply capacity of 10,000 gpm (14 mgd).
- **Phase II –** The second phase would consist of installing an additional five production wells:
    - Three wells with an available maximum total supply of an estimated 15,000 gpm (22 mgd) to supply the Low pressure zone
    - Two wells with an available maximum supply of an estimated 10,000 gpm to supply the Intermediate pressure zone.
- **Future Phases –** Additional phases of wellfield development would occur after future upgrades to the transmission system are conducted to accommodate full-scale production from a new wellfield (at 80,000 gpm, or 115 mgd). The maximum total instantaneous withdrawal rate for the current facility is 39,300 gpm (56.6 mgd).

The recommended well design consists of 400-foot deep production wells with 24-inch diameter, wire-wrapped, stainless-steel well screens. Each well screen assembly would be approximately 200 feet in length, have variable slot sizes, and have a design capacity of 5,000 gpm (Figure 38). Downhole appurtenances in each well would include a chlorine injection tube, level sensor tube, video inspection tube, raw water sampling pump, and pump column (Figure 39).

Two separate buildings would be constructed for the first two phases (Figure 40). The first building would be dedicated to serve the North Hill pressure zone and would include four wells (two active and two in reserve). The second building would include five wells: two wells to serve the Intermediate pressure zone and three wells to serve the Low pressure zone. Buildings for the subsequent phases of development would be expansions of and/or separate from those constructed under the first two development phases.

Inside a given building, the wells would be spaced 25 to 30 feet apart. Results from the groundwater modeling analyses indicate that when simultaneously operating 16 wells at 5,000 gpm each, the amount of water level drawdown in each well could be on the order of 15 feet or less, assuming well efficiencies of 75 to 80 percent and a hydraulic conductivity on the order of 4,000 feet per day for the deep sand unit. This drawdown estimate is substantially less than the amount of available drawdown in each well (138 feet). Further field investigations are recommended to improve the understanding of the extent and hydraulic properties of the deep sand unit, which will influence (refine) the wellfield design and estimates of drawdown during pumping.

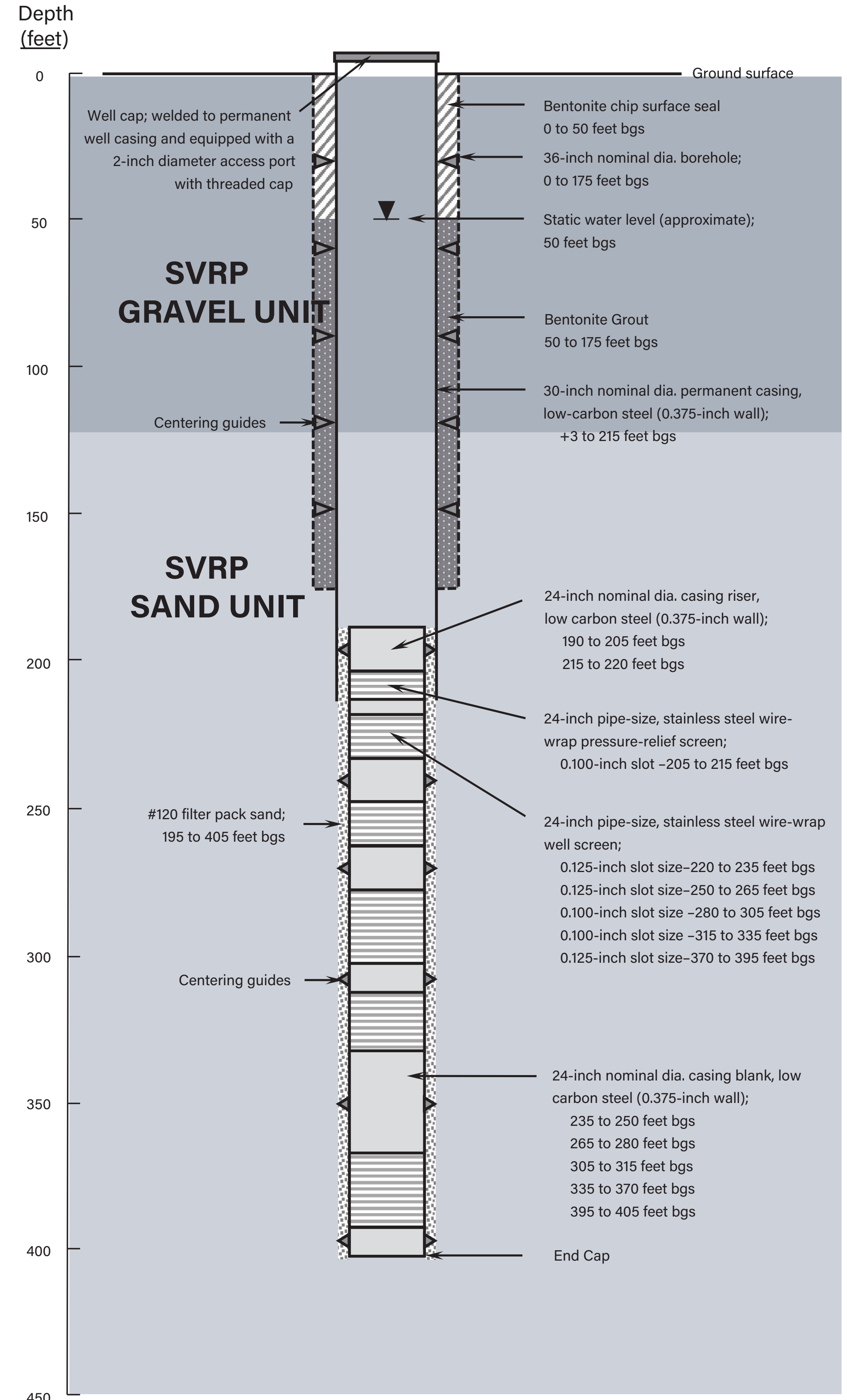


Figure 38. Conceptual well design for a single wellfield production well at the Well Electric Well Station. Courtesy of GSI Water Solutions, Inc.

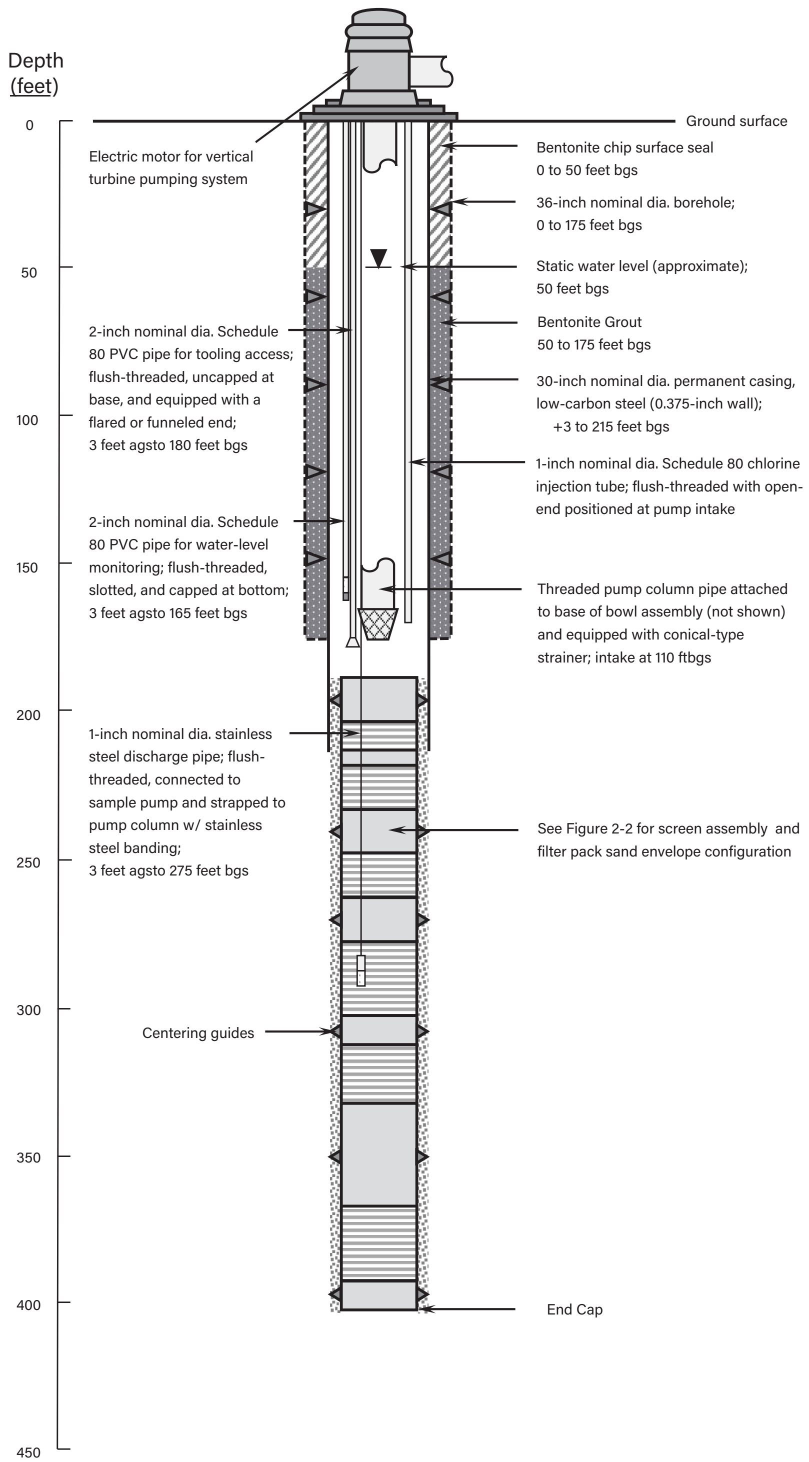


Figure 39. Conceptual well design for a single wellfield production well at the Well Electric Well Station with downhole appurtenances. Courtesy of GSI Water Solutions, Inc.

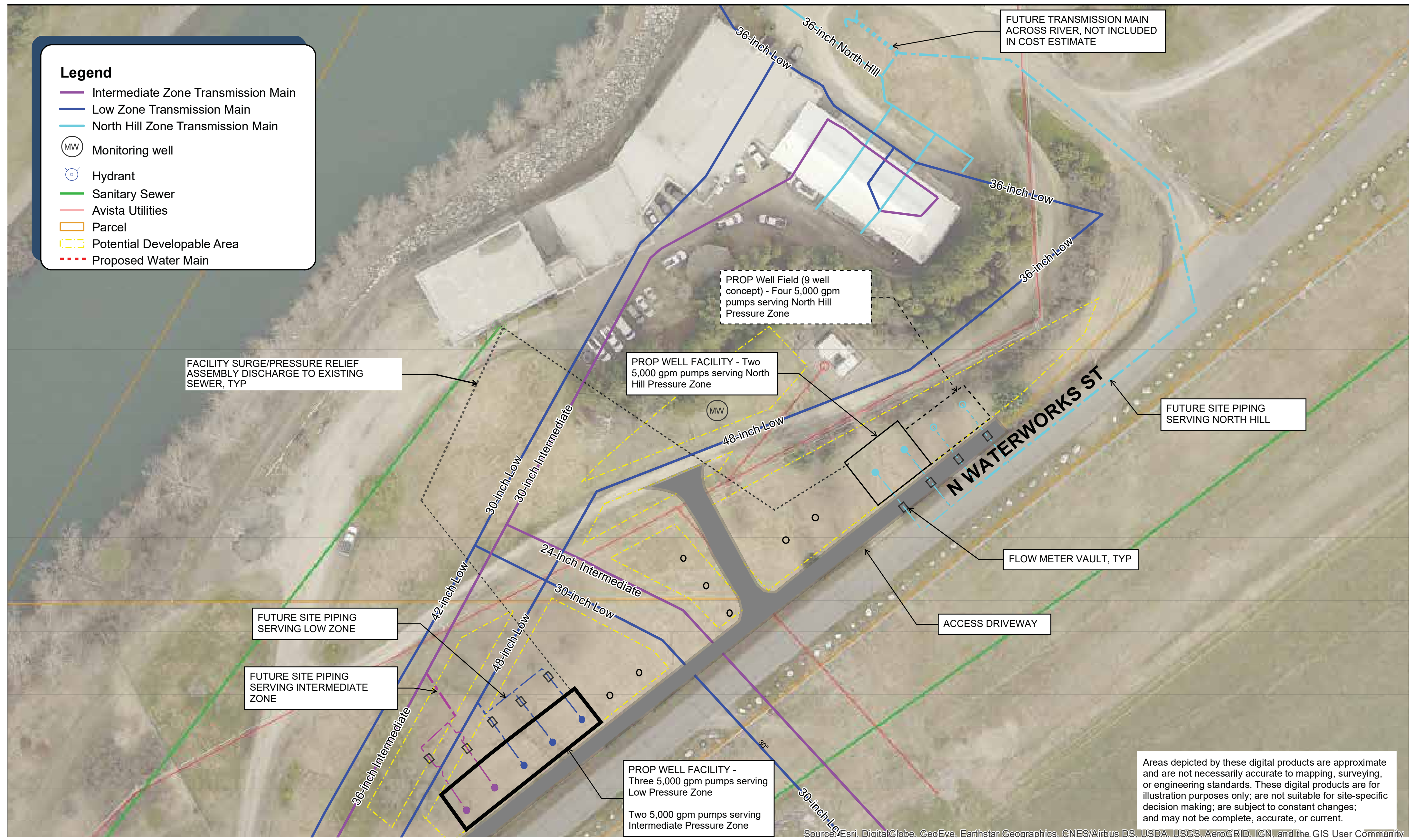
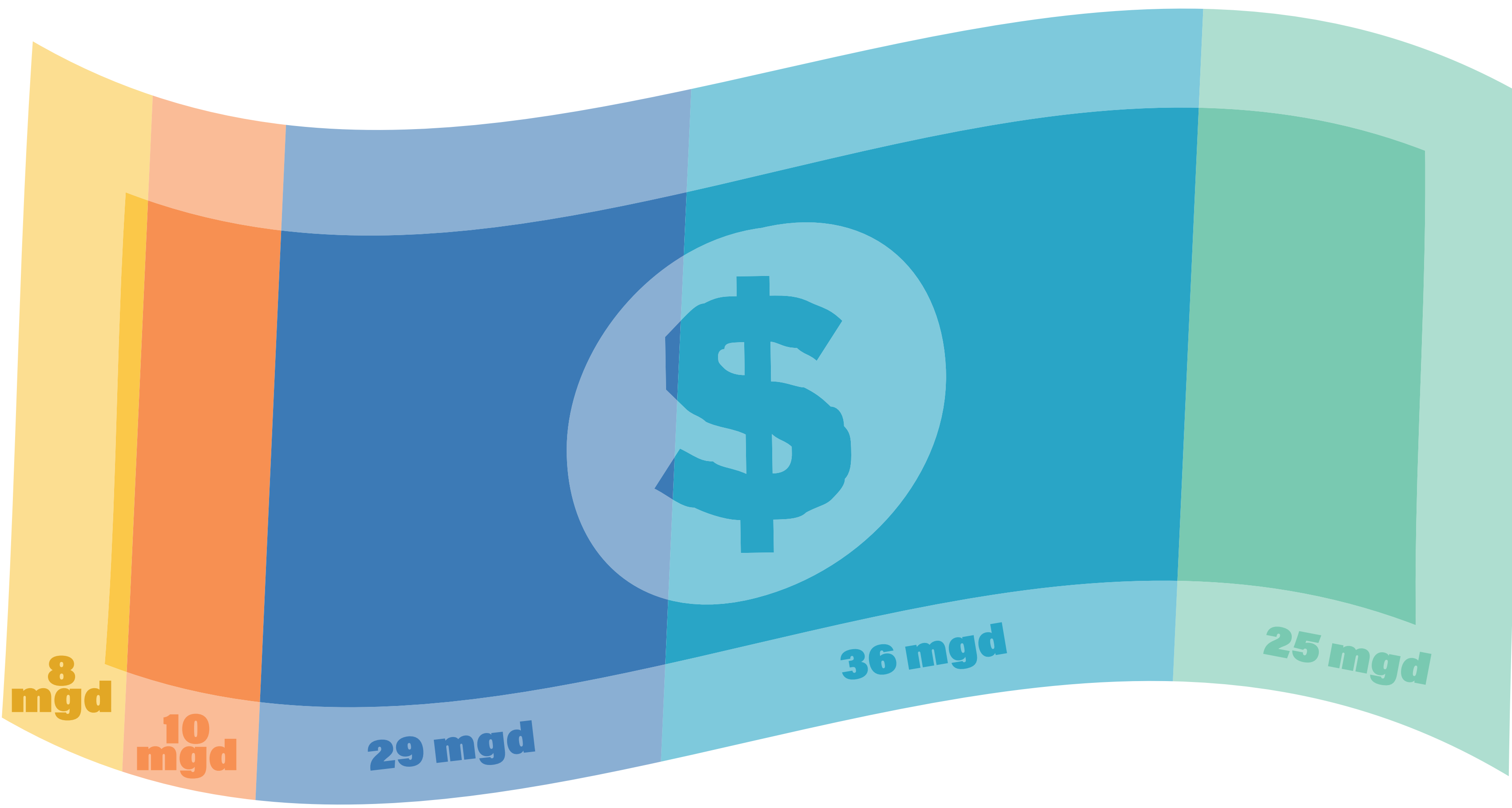


Figure 40. Conceptual site plan showing the locations of wellfield production wells, facility buildings and site piping. Courtesy of Murraysmith, Inc.

WHAT WILL THIS COST? WHAT IS THE TIMEFRAME FOR IMPLEMENTATION?

ADDED PRODUCTION CAPACITY BY WELL STATION CONCEPT OPTION AND PLANNING-LEVEL COST ESTIMATES FOR DEVELOPMENT



NEAR-TERM DEVELOPMENT PLANNING

WELL ELECTRIC WELL STATION
Phase I Wellfield
Concept: A 4-well wellfield including, wellfield facility building(s), piping, disinfection, electrical, HVAC and controls
Estimated additional production capacity: 28.8 mgd
Total estimated cost per mgd: $380,000 to $815,000

WELL ELECTRIC WELL STATION
Phase II Wellfield
Concept: A 5-well wellfield expansion, including wellfield facility building, piping, disinfection, electrical, HVAC and controls. Three of the five wells will supply the Low pressure zone and the remaining two will supply the Intermediate pressure zone.
Estimated additional production capacity: 36 mgd
Total estimated cost per mgd: $330,000 to $710,000

RAY STREET WELL STATION
Pumping System Modifications
Concept: Modifying existing pumping systems, adding a fourth pump, and redistributing pumping between caisson wells
Estimated additional production capacity: 9.9 mgd
Total estimated cost per mgd: $110,000 to $240,000

RAY STREET WELL STATION
New Supplemental Wellfield
Concept: A 5-well wellfield including, wellfield facility building(s), piping, disinfection, electrical, HVAC and controls
Estimated additional production capacity: 25 mgd
Total estimated cost per mgd: $315,000 to $680,000

HOFFMAN WELL STATION
Well 2 Repair
Concept: Install permanent casing liner with seal and install new pumping system and controls to serve the North Hill pressure zone. Two of the four wells would be held in reserve for future use.
Estimated additional production capacity: 7.86 mgd
Total estimated cost per mgd: $165,000 to $360,000

LONG-TERM DEVELOPMENT PLANNING

WELL ELECTRIC WELL STATION
Potential Future Wellfield Expansion
Concept: A 7-well wellfield expansion
Estimated additional production capacity: 50.2 mgd

RAY STREET WELL STATION
Potential Future Full-Scale Wellfield
Concept: A 19-well wellfield that would replace the existing caisson wells
Estimated additional production capacity: 96 mgd

HOFFMAN WELL STATION
Potential Future Full-Scale Wellfield
Concept: A 10-well wellfield that would replace the existing caisson wells
Estimated additional production capacity: 65 mgd

Note: Estimated costs are Class 5 estimates prepared in accordance with the guidelines of the American Association of Cost Engineering (AACE), and are in Year 2018 U.S. dollars.

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GSI Water Solutions, Inc. would like to take this opportunity to acknowledge City of Spokane staff and our consulting partners that provided field support, technical assistance, guidance, and support throughout this study. We would first like to extend our thanks to the **City of Spokane** for giving us and our teaming partners the opportunity to assist the City with this project, particularly the following staff members from the City's **Department of Integrated Capital Management** and **Water Department**: Marcia Davis, Jim Sakamoto, and Steve Burns. Other City staff that contributed greatly to the success of this project and that we would like to thank include Dan Kegley, Katherine Miller, Cadie Olsen, Beryl Fredrickson, Jeanne Finger, Doug Greenlund, Seth McIntosh, Isaac Swanson, Mark Papich, Evariste Mulindangwe, Bill Rickard, and Kristen Zimmer.

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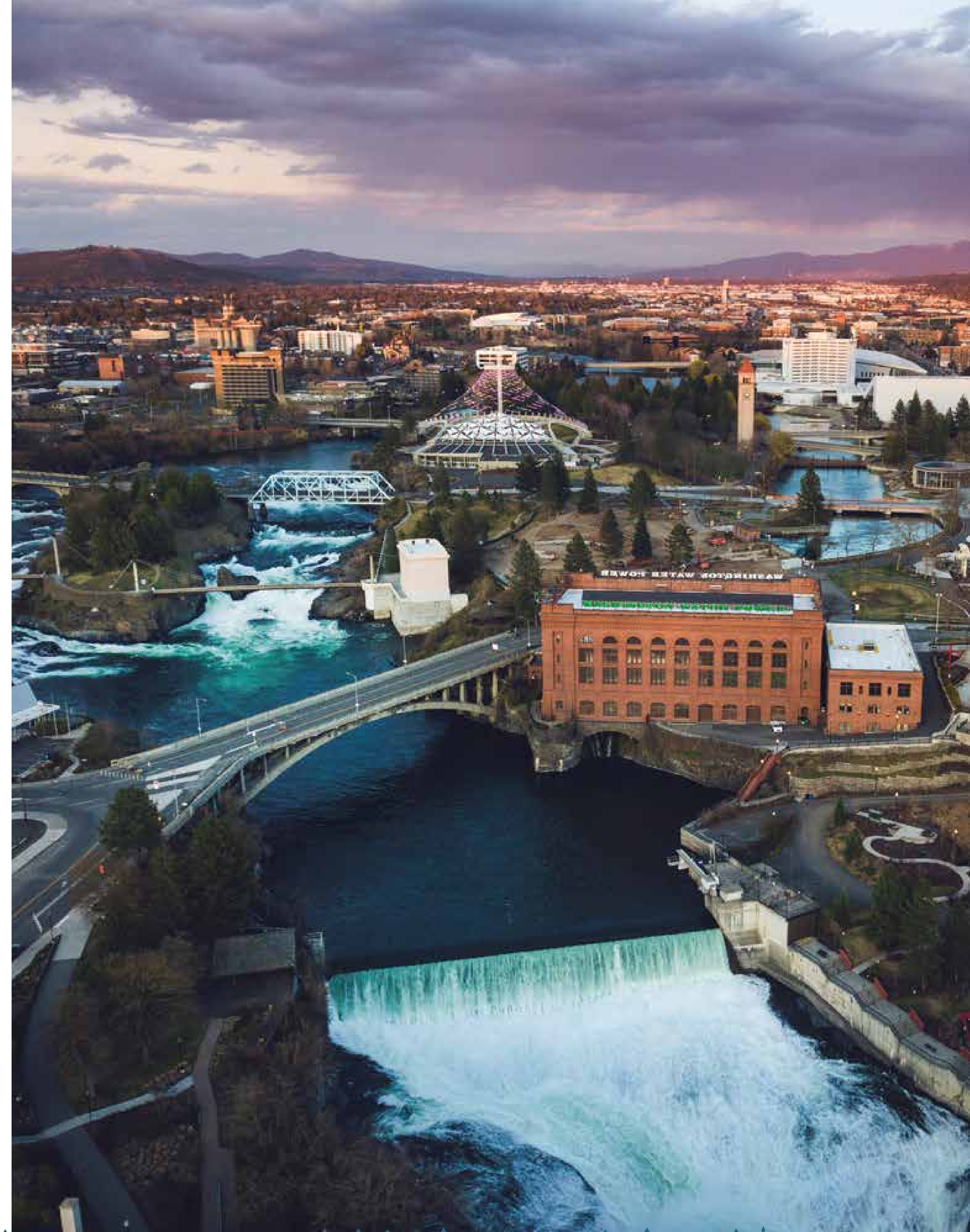
Lastly, we would like to thank the following GSI staff members that helped deliver this project on time and on budget: Project Director John Porcello, Project Manager Kenny Janssen, Senior Technical Reviewer Walt Burt, and supporting staff members Robyn Cook, Ryan Dougherty, Ailco Wolf, Nicole Palmer, Laura Parisi, Andra D'Auvergne, and Nancy Steensma.

Thank you wonderful team,

GSI Water Solutions, Inc.

Kenny Janssen, LG
Project Manager

John Porcello, LHG
Project Director



GSI Water Solutions, Inc.

CITY OF SPOKANE