Yakima River Basin Integrated Water Resource Management Plan

Technical Memorandum: Programmatic Framework for Aquifer Storage and Recovery in the Ahtanum Valley

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Prepared by

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U.S. Department of the Interior
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Executive Summary

This technical memorandum presents a framework to implement the Ahtanum Aquifer Storage and Recovery (ASR) program, including the following:

- Permitting and start of groundwater recharge operations in 2014
- Installation of recovery wells in approximately 2016 and 2025 for recovery operations

The hydrogeological setting in the Ahtanum Valley is well suited to ASR. The system supports high-yield wells (e.g., 3,000 gallons per minute [gpm]) for recharge and recovery. The aquifer can contain water recharged to it for several years. Some seepage of recharge water during storage to stream flow is predicted.

The City of Yakima (city) currently has groundwater recharge capacity in two wells, but limited means of recovering the recharged water. The city plans to construct new wells in 2016 and 2025 with both recharge and recovery capacity to be permitted through an ASR program.

Benefits

Benefits from an ASR program are estimated under the following scenarios:

Scenario 1(2014): Recharge through existing wells, and no recovery for municipal use

Scenario 2(2016): Recharge through existing wells and one new well. Recovery of 3,000 acre-feet through the new well every third year during drought years for municipal use

Scenario 3(2025): Recharge through existing and two new wells. Recovery of 6,000 acre-feet through the two new wells every third year during drought years for municipal use

Municipal Supply: Permitting and installation of new wells under an ASR program will provide the city with 100 percent redundant water supply to continue the water supply if the diversion at the Naches Drinking Water Treatment Plant were interrupted for any reason. Additionally, the city could rely 100 percent on groundwater during drought years, and make surface water that might otherwise be diverted by the city available for other uses (e.g., 6,000 acre feet).

Streamflow and Total Water Supply Available (TWSA): In a drought year, ASR operations may increase streamflow immediately upstream of the Parker Gage during May-October by an average of 20 cfs during May-October, and a peak of 40 cfs. Streamflow augmentation could be further increased by pumping stored groundwater to the river. This would allow an equivalent volume of water to be retained in Yakima Project storage, increase Total Water Supply Available (TWSA), and reduce high streamflows below the reservoirs that adversely affect aquatic habitat.

Rural Water Supply: Constant year-round increased seepage to the river as a result of ASR operations could mitigate more than 4,000 rural domestic groundwater supplies that may impact on the Yakima River main stem, assuming a consumptive use for a rural domestic residence of 0.137 acre-feet per year. More detailed analysis is needed to estimate the volume of seepage that might occur to the lower reaches of tributaries to the Yakima River in the Ahtanum-Moxee Subbasin (e.g., Ahtanum Creek).

Groundwater Storage: Groundwater storage is increased under all scenarios. The residual increased groundwater storage resulting from groundwater recharge activities may be recovered for other uses, as allowed under an ASR permit. Recovery could be for direct use, or it could be discharged to the Yakima River to augment streamflows during critical periods and delivered for diversion at downstream points and beneficial use.

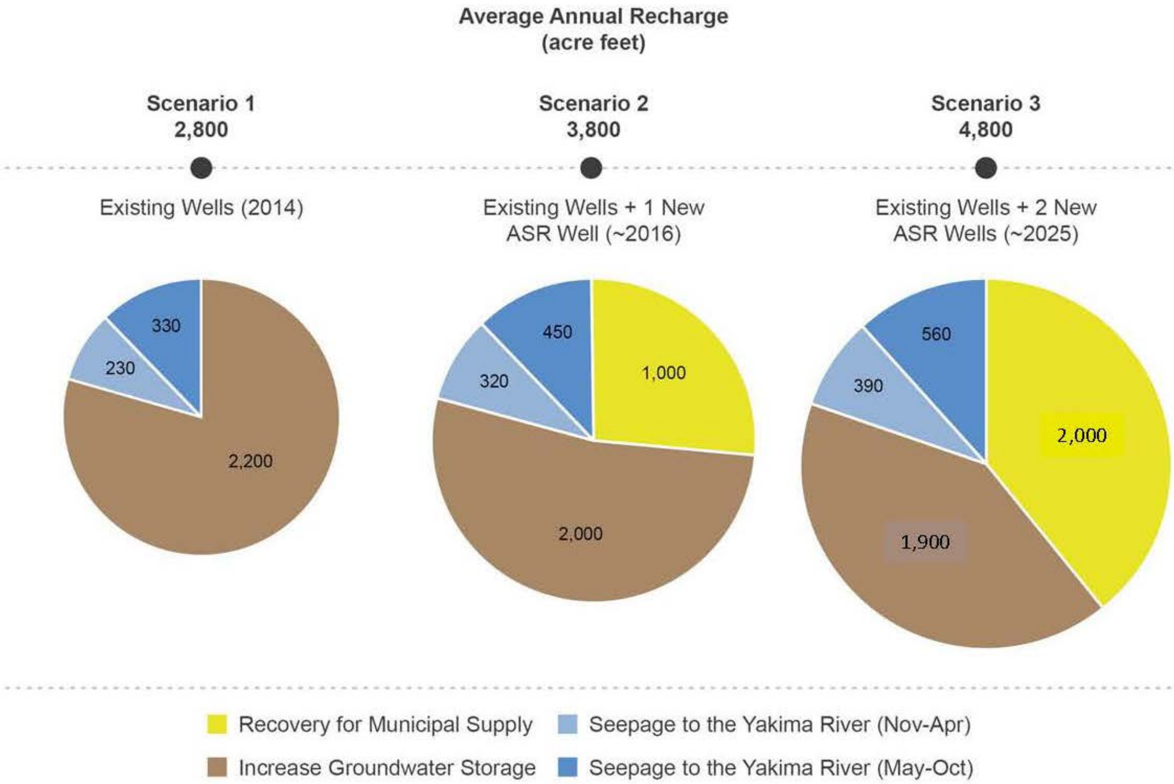

Figure 1. Average Annual Groundwater Balance Estimates for Three-year ASR Cycles (acre-feet)

Limitations and Full Optimization of ASR Capacity

Water balance estimates derived in this report are extrapolated from modeling data of Golder (2009) using assumed conceptual relationships. Although the presented results are considered representative, more detailed analysis may be conducted for ASR permitting purposes.

Implementation is subject to technical limitations that may arise, such as the pressure buildup at wellheads, which will be evaluated during planned recharge testing in 2014-2015.

Realizing the full range of potential benefits of the presented ASR program is also subject to emplacement of the following appropriate management components:

- Water rights
- Use of infrastructure agreements
- Allocation management for non-city uses of recharged water

The city has surface water rights to use in an ASR program to meet municipal water supply needs in drought years. A new winter surface water right for 3,000 acre feet per year from the Naches River could be issued to provide water for recharge for other than city uses, which are represented by seepage to surface water and increased groundwater storage (Figure 1). The new water right could have additive annual quantity, and instantaneous quantity non-additive to the city's existing surface water rights, and would make full use of the built out system.

Two new wells are needed to provide the city with recovery capacity. However, only approximately 40 percent of the recharge capacity of the built out system is necessary to recharge the volume of water needed to provide municipal supply in drought years. Therefore, 60 percent of the assumed recharge capacity of the built out system may be available for other applications. The following potential project proponents may partner with the city to make full use of the ASR system capacity:

- Government agencies, such as the U.S. Department of the Interior Bureau of Reclamation, Ecology, Yakima County, and adjacent water systems
- Non-profit/non-governmental organizations, such as the Washington Water Trust
- For-profit entities

Project proponents and the city may enter into an agreement to treat and recharge water in addition to municipal uses. Such an agreement may include the following elements:

- Schedule of operations
- Cost sharing of new well installation, treatment of water to be recharged, and pumping for recovery of recharged water
- Protocols, if the city is asked to temporarily rely on groundwater to meet full municipal demand during droughts to forego diversion of surface water

If water is recharged with the intent of applying credits to specific benefits, such as mitigation for rural water supply development, appropriate financial and water permitting accounting structures should be developed.

Schedule and Costs

Testing of the Gardner well is scheduled for May 2014. Operational recharge through two wells is scheduled for November 2014. Construction of new wells is scheduled for 2016 and 2025. A summary of costs is presented in Table 1.

Table 1. Summary of Estimated Costs (2014 dollars).

	Scenario 1	Scenario 2	Scenario 3
Anticipated year of implementation	**2014**	**2016**	**2025**
Average annual recharge (acre feet)	2,800	3,800	4,800
Recovery in a drought year (acre feet)	0	3,000	6,000
Cumulative Capital Cost ($1,000)	**$300**	**$3,600**	**$3,900**
Average Annual Cost ($1,000)	**$165**	**$235**	**$300**

Longer Term Expansion of ASR

The ASR program could be extended to recharge groundwater through neighboring water systems to the Ellensburg Formation under the current ASR application (e.g., Nob Hill Water System), or to basalt aquifers under a new ASR application (e.g., Nob Hill and Terrace Heights Water Systems).

1.0 Introduction

This technical memorandum presents a programmatic framework for an Aquifer Storage and Recovery (ASR) program in the Ahtanum Valley in the Central Yakima Basin (Figure 2). A key component of this program is use of the existing city municipal drinking water system infrastructure and water rights to provide cost efficiencies, and near-term implementation. Surface water is currently the primary source of municipal water supply for the city. Currently installed and permitted groundwater supply is capable of meeting approximately 60 percent of peak demand.

One objective of the Ahtanum ASR program is to provide the city with permitted and installed groundwater supply capacity capable of meeting 100 percent of peak municipal water supply demand. This will allow the city the option to reduce surface water diversions during water short times, and free that surface water for temporary application to other uses.

Full build-out of an ASR program to allow flexible use of the city's surface water sources during water short times will include the following:

- Acquiring permits for existing, recharge-capable facilities that are already constructed, to enable operations to begin in November 2014
- Installing and acquiring permits for two new ASR wells in the future for recharge and recovery

This technical memorandum describes alternative scenarios for implementation, benefits, permitting, and cost sharing that will meet the objectives of the Integrated Plan. The goals of the Integrated Plan are to protect, mitigate, and enhance fish and wildlife habitat; provide increased operational flexibility to manage instream flows to meet ecological objectives; and improve the reliability of the water supply for irrigation, municipal supply, and domestic uses (Reclamation and Ecology 2012).

Prior work has established that ASR is feasible in the Ahtanum Valley (Golder 2001, Golder and HDR 2011). A four-month-long injection and recovery test conducted in 2001 at the city's Kissel Well resulted in a sustained groundwater level rise. Numerical groundwater flow modeling indicated that most of the water recharged to groundwater remained in storage after 10 years (Golder 2009). Groundwater leaving storage over that period seeped to the Yakima River.

Implementation of an ASR program will provide significant benefits to the city and the regional hydrologic system. The flexible use of the city's surface water rights provides source redundancy. Regional benefits could include stream flow augmentation of the main stem

Yakima River and the lower reaches of tributaries in the Ahtanum-Moxee Subbasin (such as Ahtanum Creek), mitigation of new rural groundwater supply, and the ability to develop a groundwater reservoir that could be drawn upon to augment surface water flow during water short periods.

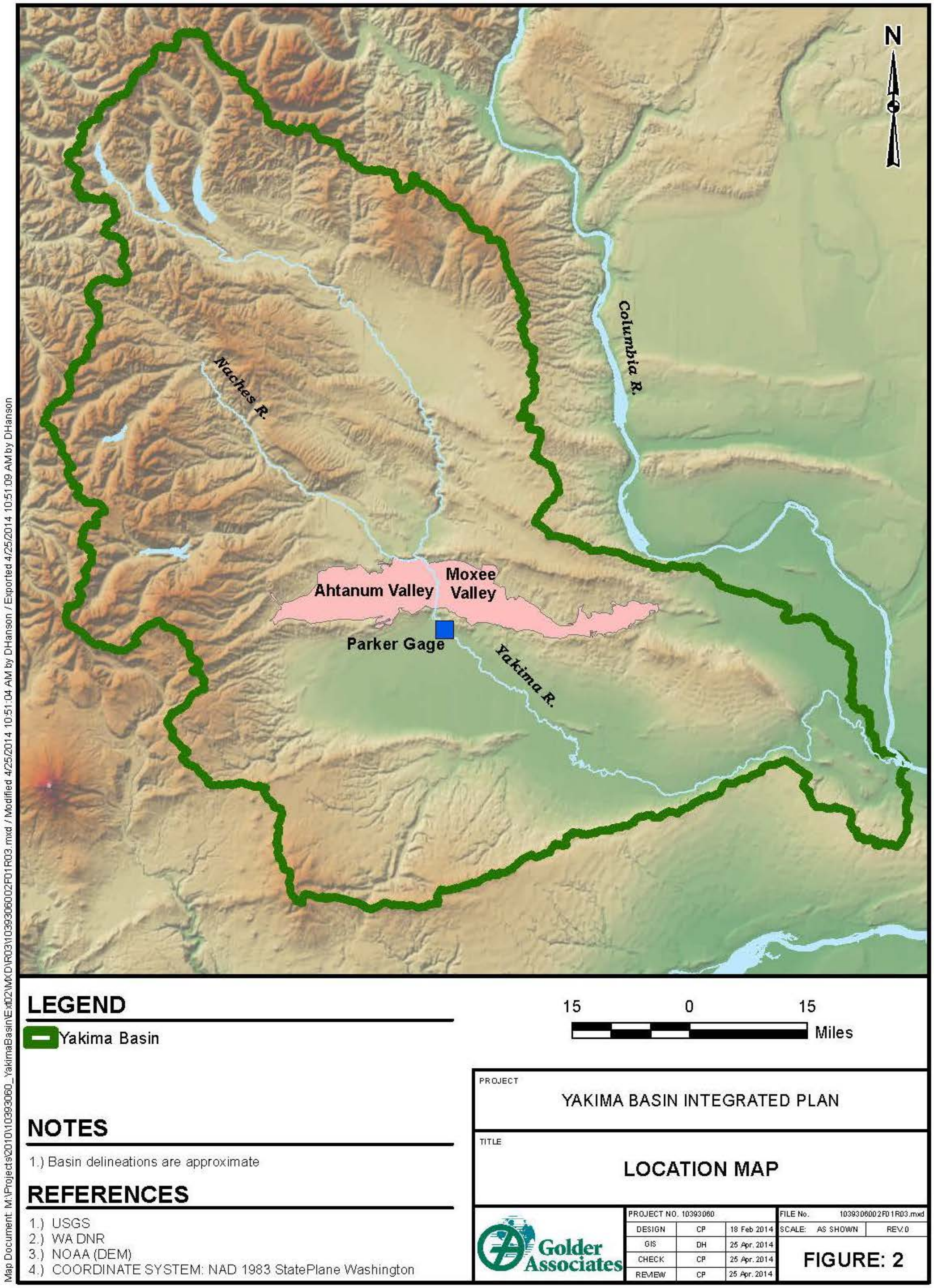

Figure 2. Location Map

2.0 Setting

The Ahtanum and Moxee Valleys are located in the Central Yakima Basin (Figure 2). The area is bounded by Yakima Ridge to the north, and Ahtanum Ridge and Rattlesnake Hills to the South. The valleys are deep basins underlain by Columbia River basalt, and filled with over 2,000 feet of sedimentary sandstone of the Ellensburg Formation.

Both the Ellensburg Formation and the underlying basalt are productive aquifers. The Ellensburg Formation is used in the Ahtanum Valley for groundwater supply by the Cities of Yakima and Union Gap, and the Nob Hill Water Association, as well as for irrigation and other uses. Individual well yields can exceed 3,000 gallons per minute. The Upper Ellensburg Formation is not as widely used where it extends into the Moxee Valley because the formation is finer-grained and wells have lower yields.

The basalt aquifer system is used for water supply in the Moxee Valley and around the periphery of the Ahtanum Valley. Basalt wells in the Moxee Valley were historically and famously high-yield wells with strong flowing artesian conditions. One example is Moxee Well #1, featured on the cover of the United States Geological Survey report series of the Yakima Basin groundwater study. Water levels in these wells have decreased several hundred feet over a century of groundwater production in the basin.

The Yakima River enters the Ahtanum and Moxee Valleys through Selah Gap, and exits through Union Gap (Figure 3). The Naches River enters the Northwest corner of the valleys and flows into the Yakima River immediately after the river passes through Selah Gap. The Parker Gage, which is used in managing the U.S. Department of the Interior Bureau of Reclamation’s Yakima River Basin Project and in defining the annual Total Water Supply Available, is located approximately 3 miles downstream of Union Gap. Therefore, any water balance effects occurring in the Ahtanum-Moxee Valleys will affect the Parker Gage and Total Water Supply Available.

The United States Geological Survey groundwater study estimated that groundwater withdrawals in the Yakima Basin have resulted in a cumulative decrease in the Yakima River flow on the order of 100 cubic feet per second at the Parker Gage (Ely and others 2011).

3.0 City of Yakima Water System

The city operates two parallel water systems, both of which divert Naches River surface water: a treated water municipal drinking water system, and a raw water irrigation system. Only the city’s treated drinking water system is considered for use in an ASR program at this time.

The drinking water system diverts up to 25 million gallons per day (MGD; 39 cubic feet per second [cfs]) from the Naches River approximately 8 miles upstream from the confluence with the Yakima River (Figure 3). The drinking water system also has four large capacity groundwater wells as backup to the surface water system. Initial development of an ASR program uses the existing drinking water system infrastructure, including treatment, transmission, and well facilities.

The irrigation system has water rights for the diversion of 27 cfs (17.5 MGD) from the Naches River at the Nelson Diversion located approximately 3.5 miles upstream of the Yakima River confluence. Irrigation system assets that may be useful for potential future ASR program expansion include water rights and a surface water diversion structure. Significant capital investment for water treatment would be needed to incorporate components of the irrigation system into an ASR program. Therefore, consideration of irrigation system components in an ASR program is deferred at this time.

An objective of the ASR program is to establish groundwater supply capacity that can meet 100 percent of the city's peak demand. This will improve the reliability and redundancy of the municipal water supply, and possibly make the permitted surface water diversions available for other uses. A description of the city's water system is provided here to identify what is needed to provide 100 percent groundwater supply capacity.

The city's current maximum day demand is 22.4 MGD, which is closely matched by the Naches River Water Treatment plant nominal capacity of 25 MGD. The surface water source is sometimes not available for the following reasons:

- Physical constraints, such as high turbidity, ice, or debris jams
- Maintenance and upgrade operations
- Pro-rationing in water short years. (Water entitlements served by the Yakima Project are divided into two classes: proratable and nonproratable. Under drought conditions, proratable entitlements receive reduced (prorated) supplies. This is referred to as "prorationing.")

Four groundwater wells with a combined capacity of 15.7 MGD are used to meet municipal demand when the Naches River Water Treatment Plant is not operational or when diversion is prorated. The wells can meet demand during the winter months when all wells are operational. Higher summer demand can be met for several days without the Naches River Water Treatment Plant by using groundwater wells and drawing down 32 million gallons in storage in conventional municipal storage reservoirs.

New groundwater supply capacity of 9 MGD, or two wells of approximately 3,000 gpm each, would provide groundwater supply capacity to meet 100% of peak demand and allow the city the option of not diverting surface water diversion temporarily during peak demand periods. New wells can be authorized as additional points of withdrawal under an ASR program.

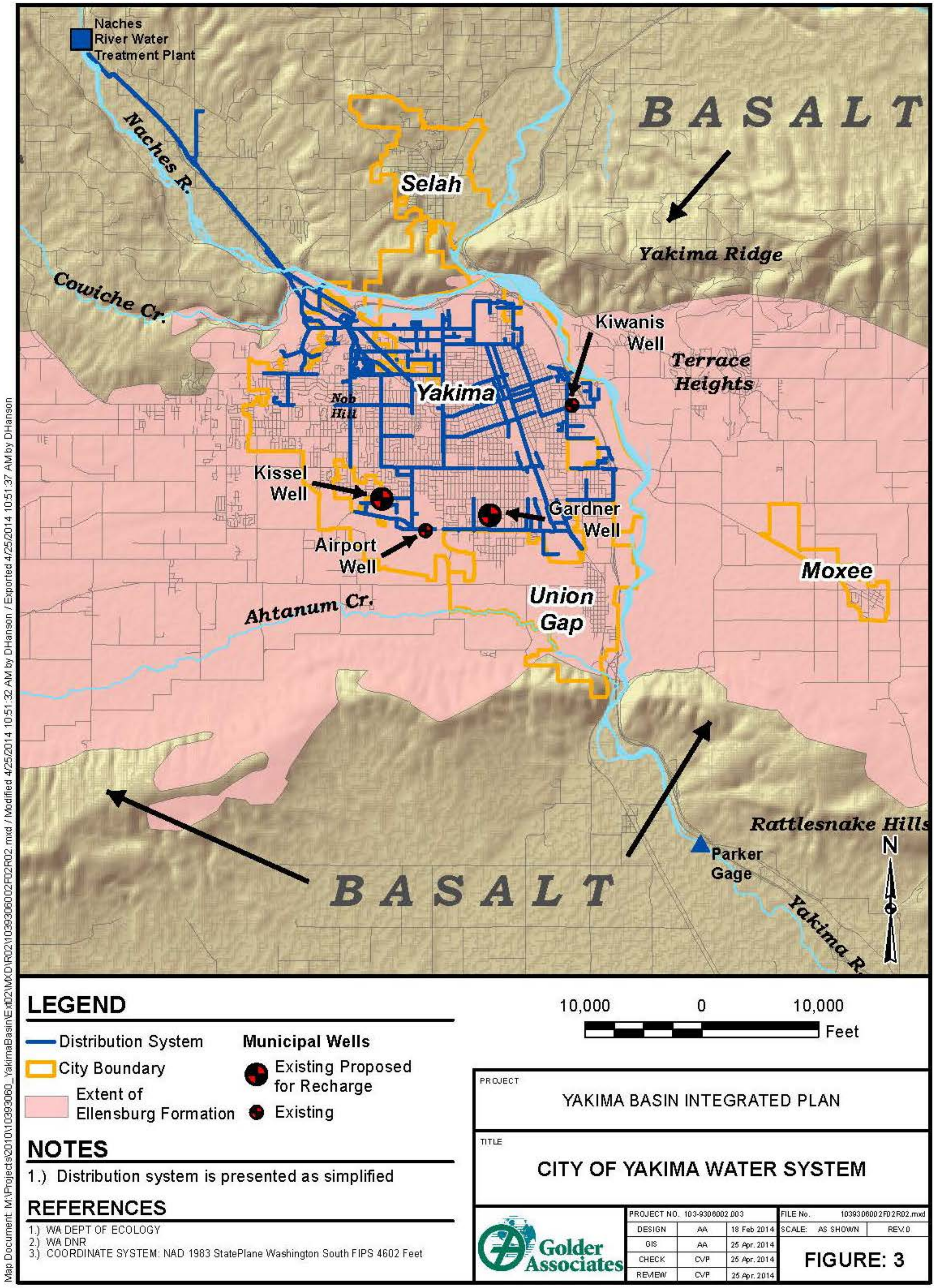

Figure 3. City of Yakima Water System

4.0 Establishing ASR in the Ahtanum Valley

All infrastructure is currently in place for the City to start the recharge operations of an ASR program. Existing wells may be used for recharge when there is available supply from the Naches River Water Treatment Plant, and when the wells are not being used to meet demand (Figure 4). To meet the objective of developing 100 percent groundwater supply capacity, two new wells are needed to recover recharged water, because the production capacity of existing wells is already committed to withdrawing groundwater under existing groundwater rights to meet municipal demand. Groundwater recharge can start in 2014, and recovery capacity will need to be established through installation of recovery wells and the ASR permitting process.

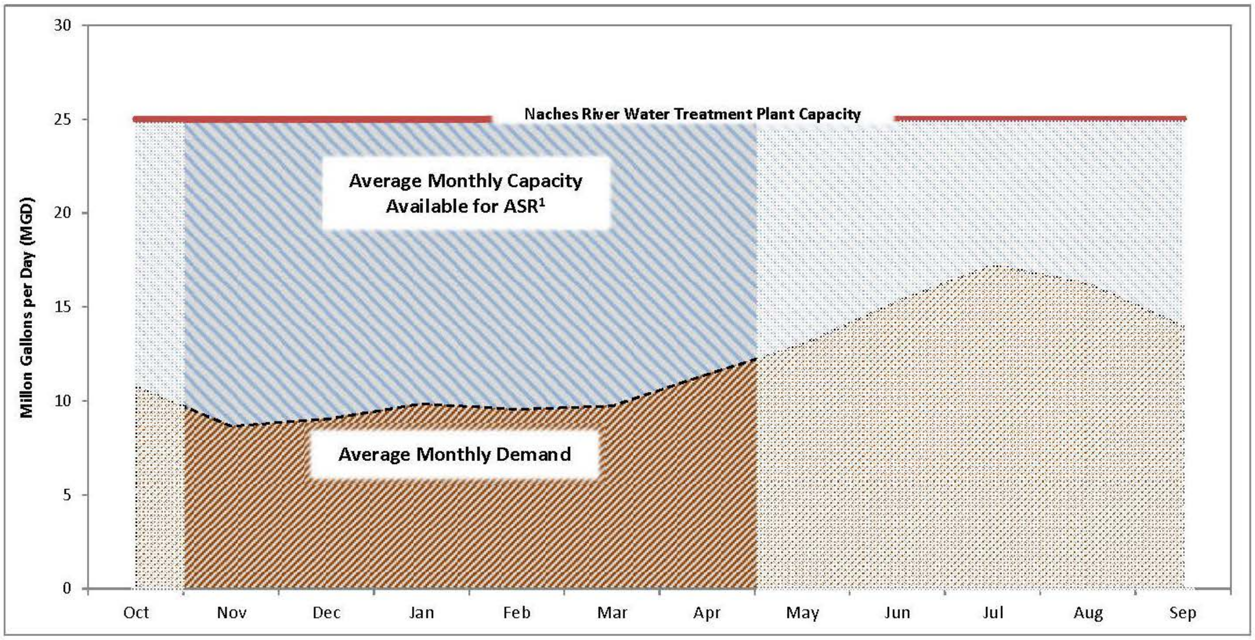

Figure 4. Naches River Water Treatment Plant Capacity and Average Monthly City of Yakima Drinking Water Demand

4.1 Recharge Operations

The following infrastructure is in place to start an ASR recharge program in the Ahtanum Valley using the city's water system:

- A surface water diversion and treatment plant on the Naches River
- Transmission from the plant to wells distributed in the Ahtanum Valley
- Two wells that may be capable of recharging on the order of 3,500 gpm

The Kissel and Gardner wells are configured for recharge and recovery. The Kissel Well was tested in 2001 with a four-month recharge and recovery cycle. The Gardner well is operational as a municipal supply well, but has not been tested with a recharge and recovery cycle. A recharge and recovery cycle test of the Gardner well is scheduled for May 2014. Operational recharge to the Kissel and Gardner Wells under an ASR permit is scheduled to start in November 2014, assuming Ecology issues an ASR permit.

A detailed test plan is being prepared for testing of the Gardner Well in May 2014. The following general steps are planned:

- **Step-rate Recharge:** Evaluate the well recharge efficiency by recharging at various rates over one or two days.
- **Constant Rate Recharge:** Introduce a volume of water to the aquifer over several days.
- **Storage:** Monitor water levels and water quality for up to two months.
- **Production Recovery:** Pump the well to recover recharged water to evaluate water quality for drinking water uses and to address groundwater antidegradation regulations.

This test will be conducted using existing surface and groundwater water rights already held by the city and a preliminary ASR permit from Ecology. Recharge water will be drawn from the city's municipal water supply provided by surface water rights associated with the Naches River Water Treatment Plant. The Gardner and Kissel Wells are registered with Ecology's Underground Injection Control program. A State Environmental Policy Act (SEPA) checklist is being prepared, as is an All Known, Applicable and Reasonable Technologies (AKART) analysis relating to the recharge of drinking water to the groundwater aquifer system.

It is anticipated that Ecology will issue a preliminary permit associated with reservoir permit application R4-34552 to allow testing of the Gardner Well in May 2014, subject to SEPA and AKART reports, and an acceptable test plan including a Quality Assurance Project Plan.

A reservoir permit has been requested from Ecology to allow operational recharge to start in November 2014. The permit will be based on results of the 2001 Kissel pilot test and the May 2014 Gardner Well test. The recharge capacity will be approximately 3,500 gpm for six months of the year (November-April) or approximately 2,800 acre feet per year. Data collected during the first few years of operation will be used to determine the quantity of recharged and stored water that may be recovered.

4.2 Recovery Capacity

The city does not currently have the infrastructure capacity in groundwater wells to recover stored water because the existing wells have existing groundwater rights that authorize withdrawals from the wells. The city will only be able to recover stored ASR water upon installation of new wells authorized for groundwater withdrawal under an ASR permit. Candidate locations for two new ASR wells installed as part of the city's municipal drinking water system are in the north end of the city, and between the Kiwanis and Gardner Wells (Figure 5).

The locations are recommended based on the following factors:

- The locations are within the area identified for candidate ASR wells by Golder (2001).
- The locations achieve separation among the ASR recharge wells to avoid high water level buildup interference between recharge wells.

- These locations fit well into the distribution system pressure zones to maintain recharge pressures.

Golder recommends well siting studies to address the following factors:

- Avoid locating a well near geological faults that may contribute to difficult drilling conditions or limit well production and recharge rates. Siting studies may include geophysical surveys.
- Run distribution system modeling to ensure there is adequate system pressure to maintain desired recharge rates and adequate pressure for fire protection.
- Confirm that the hydrogeology of a specific location meets the objectives of the well (e.g., potential degree of hydraulic continuity with surface water).

The budgeted cost for a new municipal well is $3.2M, including engineering design, installation, testing, and permitting, based on installation of similarly sized wells in recent years (Coleman, 2011).

Until a new well is installed and permitted under the ASR permit, recharge of water will build up a storage reservoir for future recovery, and provide the benefits of restoring depleted aquifer levels and increasing groundwater seepage and base flows to the Yakima River. Recharging water before installation of new wells will also allow the opportunity to establish and refine operational recharge criteria under an ASR permit.

During the 2014-2015 recharge cycle, the city will gain experience in managing the following aspects of recharge operations:

- Protocols for interrupting recharge, such as in response to unique high demand events
- Monitoring of pressure buildup and frequency of back-flushing in response to well clogging
- Data collection for permitting compliance

Recharge rates are assumed to average 1,600 gpm for the Kissel and Gardner Wells, and 1,200 gpm for new wells. Production rates are assumed to be 3,000 gpm for all wells. Recharge is distributed among multiple wells, including existing wells with associated water rights and new wells. Withdrawal under the ASR groundwater reservoir permit may be from all wells, or primarily in the new wells.

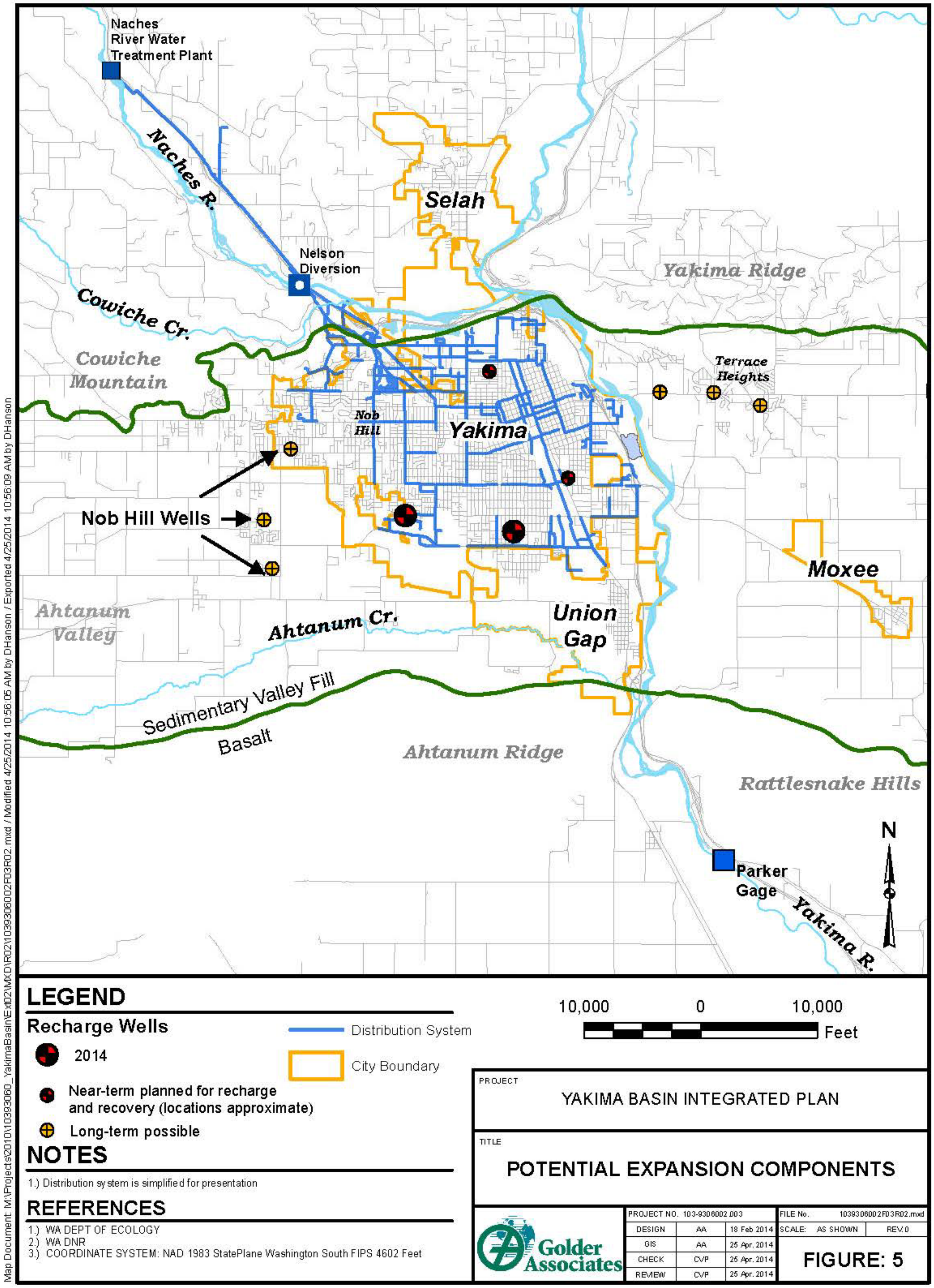

Figure 5. Potential Expansion Components

5.0 Quantification of Benefits

Benefits from an ASR program are estimated by extrapolation from numerical modeling of groundwater recharge in the Ahtanum-Moxee Subbasin by Golder (2009). The FEFLOW software package was used to build a three-dimensional, finite element model consisting of:

- Six layers: one basalt layer, four Ellensburg Formation layers, and, one alluvial layer
- A constant head boundary condition, representing the Yakima River
- Monthly resolution transient time step
- Recharge of water into the three wells for six months (e.g., November-April) at a constant rate of 2,000 gpm each for an annual recharged volume of 4,800 acre-feet to the layer representing the lower part of the Ellensburg Formation.
- Recharge ceased for six months (, and the cycle was repeated for subsequent years.

It is anticipated that recovery of water stored in the aquifer by the city would occur only during drought years – i.e., years in which pro-rationing occurs. Diversion data by the city from the Naches Drinking Water Treatment Plant for the period 2000-2013 was reviewed. In this period, pro-rationing occurred in four years, or approximately every 3 years. Therefore, benefits from an ASR program are estimated over a 3-year recharge cycle. The city diverted on average 6,000 acre-feet during the period May through October in each of those years, under pro-rationing conditions (Table 2).

Table 2. Naches River Diversions by the City in Pro-rationed Years for Municipal Use (acre-feet)

Pro-rationed Year	Volume Diverted May thru October
2001	5,802
2003	5,787
2004	5,848
2005	6,612
Average	**6,012** (16.5 cfs)

Golder developed the following scenarios to estimate benefits:

Scenario 1. Current conditions, with recharge occurring through existing wells every year (November-April; 2,800 acre-feet), with no recovery

Scenario 2. One new well in approximately 2016, with recharge occurring through existing and new wells every year (3,800 acre-feet), and recovery through the new well every third year during drought (May-October; 3,000 acre-feet every third year, or an average of 1,000 acre-feet per year)

Scenario 3. A second new well, in approximately 2025, with recharge occurring through existing and new wells every year (4,800 acre-feet), and recovery through the two new wells every third year during drought (6,000 acre-feet every third year, or an average of 2,000 acre-feet per year)

The benefits are estimated by scaling the output data obtained at an annual recharge rate of 4,800 acre-feet per year (Golder 2009), to the recharge rates for each scenario (Table 3).

Table 3. Water Balance Estimates for Three-year ASR Cycles (acre-feet)

Year	Annual Recharge (Nov-Apr)	Seepage to River Flow		Increase in Groundwater Storage from Recharge		Recovery Every 3rd Year for Municipal Supply During Drought (May-Oct)	Net Residual Increase in Groundwater Storage
		Nov-April	May-Oct	Net Annual	Cumulative		
Scenario 1: Current Infrastructure (2014)							
1	2,800	60	180	2,560	2,560	-	2,560
2		230	350	2,220	4,780		4,780
3		410	470	1,920	6,700		6,700
Total	8,400	1,700		6,700			6,700
Average Annual	2,800	230	330	2,200			2,200
		570					
Scenario 2: Current Infrastructure + 1 New ASR Well (approximately 2016)							
1	3,800	80	240	3,480	3,480	-	3,480
2		320	480	3,000	6,480		6,480
3		550	630	2,620	9,100	3,000	6,100
Total	11,400	2,300		9,100		3,000	6,100
Average Annual	3,800	320	450	3,000		1,000	2,000
		770					
Scenario 3: Current Infrastructure + 2 New ASR Wells (approximately 2025)							
1	4,800	100	300	4,400	4,400	-	4,400
2		400	600	3,800	8,200		8,200
3		700	800	3,400	11,600	6,000	5,600
Total	14,400	2,800		11,600		6,000	5,600
Average Annual	4,800	390	560	3,900		2,000	1,900
		950					

Data extrapolated from Golder (2009). Estimates are representative and subject to change. Estimates do not reflect effects of recovery on seepage rates or multiple ASR cycles. Totals may add up to other than 100 percent due to rounding.

The benefit to streamflow is estimated to be approximately 2 cfs in the third year of an ASR cycle from groundwater seepage, and an average of 16.5 cfs from the City relying on groundwater during a drought period. Surface water diversions, and streamflow benefits derived from avoiding such diversion, peak at approximately 39 cfs. These benefits to streamflow accrue to approximately 8 miles of the Naches River from the NDWTP to the confluence with the Yakima River, and along the Yakima River to the Parker Gage.

The increased streamflows could be accounted to meeting target flows at the Parker Gage, and allow an equivalent volume of water to be retained in Yakima Project storage and increase

TWSA. This in turn, could reduce high streamflows below the reservoirs that adversely affect aquatic habitat.

6.0 Water Rights

Water rights for an ASR program can include the following components:

- A primary diversionary water right
- A storage or reservoir water right
- A secondary use water right. A secondary use water right is only needed if the recovered water is put to a beneficial use that is different than listed on the primary water right.

In this water right structure, the reservoir water right stands alone, and can be filled by any primary water right. This is analogous to using any primary water right to fill a surface water reservoir, or an above-ground storage tank, interim to the application of water to beneficial use.

6.1 Primary and Storage Water Rights

The ASR framework presented develops sufficient groundwater supply capacity to allow the city to forego use of some of its surface water supply temporarily. The primary benefit of this is that up to 39 cfs (25 MGD) that may otherwise be diverted from the Naches River during summer flow or drought periods could potentially be left in the river for other uses.

The only water right the city needs to establish an ASR program is a reservoir permit because the city can use existing primary diversionary rights, and the secondary purpose of use water right is not needed for the municipal purpose of use. Surface water rights held by the city for year-round use would be used to divert water from the Naches River during the winter time. No new primary water rights are needed. Placing surface water into storage during the winter allows the creation of new summer instantaneous groundwater withdrawal capacity by installing new wells for the withdrawal of water stored under an ASR permit.

Expedited processing of applications for development of storage facilities that will not require a new water right for diversion or withdrawal of the water to be stored is provided for under RCW 90.03.370(1)(b).

Recharge over half a year through four recharge wells is proposed – the Kissel and Gardner wells, and two new wells yet to be constructed (Figure 5). The existing wells have primary water rights associated with them equivalent to the wells' withdrawal capacity. Therefore, the existing wells do not have any withdrawal capacity that is available for the withdrawal of stored ASR water. The new wells are needed to create the additional instantaneous groundwater withdrawal supply capacity to recovery water recharged in an ASR program and increase the groundwater supply to create the 100 percent groundwater supply capacity needed for the city to meet peak demand. These new wells would be authorized under the ASR reservoir permit.

6.2 Recoverable Quantity

The amount of recharged water that will be permitted for recovery will be established through the ASR groundwater reservoir permitting process using available data including monitoring data collected during the pilot phase of the permit. The ASR permitting structure allows for adaptive management over the first few years, possibly 5-10 years, of operation to allow sufficient data to be collected to refine permit parameters.

Water recharged in an ASR program can be actively recovered from storage by wells under an ASR permit, or it may be passively recovered by discharge to surface water. The volume of stored water allowed to be actively recovered under an ASR water right should be the residual increase of storage in the aquifer system resulting from recharge activities. This volume may be a function of time in storage, and may decrease during time in storage if the water placed in storage dissipates.

A common ASR cycle operates on an annual cycle of recharge of water during time of water availability, such as the winter, and recovery during the following drier period. Some of the recharged water may discharge to surface water and is not actively recoverable. The water that discharges from storage may be accounted for through water balance calculations. This water could potentially be used to apply credits for streamflow augmentation and/or mitigation of other impacts, such as those from rural water supply.

Water may remain in storage for more than one year before recovery. However, discharge of water from storage may continue over the time in storage and less water will be available for active recovery in later years. This additional discharge may have benefits such as restoring depleted storage in other parts of the aquifer system or increasing streamflows.

Quantifying the recoverable quantity in an ASR program is most reasonably based on water balance considerations. Aquifer water levels may be used if they can be related to aquifer storage. Detailed water level data are being collected in the Ahtanum Valley through a groundwater monitoring network established by Golder and the city starting in early 2014 for consideration in determining the recoverable quantity. Historical water level data since 1999 have also been plotted (Golder, in preparation).

In some cases, the correlation between water levels and storage may not be easily established for a number of reasons. The complexity of the groundwater flow system, seasonal water level fluctuations, and variable groundwater withdrawals can complicate the interpretation and correlation of water levels with recoverable quantity. The city has been pumping their groundwater wells heavily during the winter of 2013-2014 to provide municipal drinking supply while the Naches Drinking Water Treatment Plant is undergoing maintenance. This heavy pumping of the aquifer may produce effects that complicate data interpretation. The ability to use groundwater level data to determine recoverable quantity for the Ahtanum ASR program will be evaluated during the pilot phase of the ASR permit. An extended time of water level monitoring data may be needed to establish a correlation with changes in aquifer storage resulting from ASR activities and the associated recoverable quantity.

The recoverable quantity can also be determined with a groundwater flow model that accounts for groundwater storage. Groundwater flow modeling of ASR in the Ahtanum-Moxee Subbasin was conducted simulating recharge through three groundwater wells representative of city wells (Golder 2009). The estimated residual increased storage above baseline conditions after the first annual recharge cycle was 92 percent of the recharged water. Cumulative recharge over 10 years without recovery resulted in a total recoverable quantity of approximately 60 percent (Golder 2009). Water that did not remain in storage was simulated to discharge to the Yakima River. The model output data can be used to estimate recoverable quantity for individual intervening years. The model could be run to simulate alternative recharge scenarios such as recharge at one well or recharge at different locations. The model could be recalibrated to new data as it becomes available, and corresponding estimates of recoverable quantity under an ASR program could then be changed, as appropriate.

It is assumed that the instantaneous withdrawal capacity of new ASR wells will be 3,000 gpm, similar to other city municipal supply wells. The rate of recovery of stored water through individual wells should be limited to avoid impairment through the potential interference effects between the recovery well and other groundwater users' wells. Otherwise the recovery rate is limited by the physical capacity of wells. Actual physical well capacity is subject to aquifer conditions encountered and is determined at the time of well installation.

6.3 Points of Recovery

As discussed in the preceding section, the recoverable quantity under an ASR permit is the residual increase in aquifer storage resulting from recharge activities. An ASR operation may involve recharge and recovery through the same well. However, recharge through one well and recovery from another well, as is included in this project, is consistent with the ASR rule (WAC 173-157), and recoverable quantity as defined in the preceding section. This concept is termed Aquifer Storage Transfer and Recovery, and is considered a subset of ASR.

The primary considerations in permitting points of recovery under an ASR permit should be similar to those for a groundwater right. These include the evaluation of potential impairment either by short term well interference, or long term water availability and the potential that water levels may be decreased over the long term ("mining" of water). Short term interference can be evaluated through pumping tests. Long term water availability is not an issue in an ASR permitting if the recovered water is limited to the residual increased storage resulting from associated recharge activities.

The concept of the same body of public groundwater that is applied to changes to groundwater rights (RCW 90.44.100) is an appropriate model for permitting points of recovery under an ASR permit. The definition of the same body of public groundwater is not well established, and has been broadly applied, ranging from the withdrawal points being in the same geological stratum, to the withdrawal points being in the same aquifer system. Ecology determines a "water source" to be an independent water body for the purposes of water right administration (WAC 173-152-020(19)).

Ecology has made groundwater management decisions on groundwater of the Upper Ellensburg Formation of the Ahtanum Valley as being one water source and one body of groundwater on the basis of hydraulic continuity with the same reaches of surface water (i.e., the Naches and Yakima Rivers), common hydraulic gradient, groundwater flow direction and discharge to surface water (water right change G4-*00914C). These decisions similarly support the permitting of the proposed points of recovery under reservoir permit application R4-34552 (Figure 5).

6.4 Passive Recovery

Groundwater recharge during ASR may increase hydraulic gradients and cause an increase in the discharge of groundwater to surface water. This water may not be available for active recovery but would have benefits such as streamflow augmentation, aquatic habitat benefits and mitigation of environmental impacts unrelated to ASR activities.

A new winter water right could be issued to provide additional source water for these purposes to be recharged concurrently and proportional to other water being recharged. The city could recharge this water to offset seepage that may otherwise result in a reduction of recoverable quantity from water recharged under the city's primary diversionary water right.

Water recharged under the new water right would not be actively recovered but would be left in the ground for passive recovery. This would allow a greater portion of water concurrently recharged under other rights to be recovered. Processing of the new rights could be expedited because they would be non-consumptive, dedicated to providing environmental benefit, and in part funded under RCW 90.90 (WAC 173-152-050(2)(g) and WAC 173-152-050(3)).

These new water rights could be held in trust by any entity. Use of the ASR system for management of water under these new water rights could be arranged with appropriate cost-sharing agreements with the city.

7.0 Costs

Costs for an ASR program are developed for each of the three scenarios considered, and include capital costs for establishing operations, and annual operational and maintenance costs.

7.1 Capital Costs

Capital costs considered include construction of facilities and initial permitting costs. No construction is required to start groundwater recharge in the 2014 Scenario 1. Construction of new wells is estimated to be approximately $3.2M each, based on the cost of the Gardner well that was installed in 2009 (Coleman, 2011; adjusted to 2014 dollars).

The cost of initiating ASR is estimated to be approximately $300,000 for testing the Gardner Well in summer of 2014, and start-up operational pilot testing in 2014-2015. These costs include monitoring, water quality laboratory analysis, and the first annual reporting on activities through the end of 2014.

The cost for one time requirements for adding new wells in 2016 and 2025 to the same permit are not known – a placeholder budget of $75,000 in each of 2016 and 2025 is assumed.

7.2 Annual Costs

Annual costs of ASR operations consider production of water at the Naches Drinking Water Treatment Plant (NDWTP), recovery of recharged water from groundwater wells, and annual reporting requirements specified by permits.

Annual maintenance and operation costs are estimated to be approximately $90,000 for chemicals and electrical power at the Naches Drinking Water Treatment Plant for the treatment and production of approximately 3,000 acre-feet per year (approximately 1,000 million gallons per year) for recharge.

Water treatment and production costs at the NDWTP for groundwater recharge:

Chemicals per 1,000,000 gallons	$72
Power per 1,000,000 gallons	$18
Total per 1,000,000 gallons (~3 acre-feet)	$90
Cost for 3,000 acre-feet	$90,000

City staff time is not included because staff will be present to operate the NDWTP regardless of whether ASR operations are occurring.

Recovering water from wells, as may be requested of the city during drought years, is estimated to cost approximately $230,000 for the treatment and production of approximately 6,000 acre-feet of water (approximately 2,000 million gallons). These costs are driven primarily by electrical costs related to pumping the water out of the recovery wells, and subsequent treatment in disinfection, fluoridation and corrosion control, and are offset by the savings of not producing water from the NDWTP. Assuming recovery occurs only every third year during drought conditions, the average annual cost of recovering recharged water is $75,000 at full buildout.

Water treatment and production costs at recovery wells:

Chemicals per 1,000,000 gallons	$25	
Power per 1,000,000 gallons	$180	
Total per 1,000,000 gallons (~3 acre-feet):	$205	
Cost for 6,000 acre-feet	$410,000	
Savings of not producing at NDWTP	$180,000	
Net cost of recovering 6,000 acre feet	$230,000	(every 3 years; $75,000/year)

Annual monitoring, reporting and permitting compliance are not known – a place holder budget of $75,000 is assumed. It is also assumed that the monitoring requirements will ease over time to keep the total cost of compliance constant, even as the size of the operations increase.

A time line of estimated capital and operations and maintenance costs is presented in Table 4.

Table 4. Estimated Costs (2014 dollars).

	Scenario 1	Scenario 2	Scenario 3	Cumulative
Anticipated year of implementation	2014	2016	2025	2025
Average annual recharge (acre feet)	2,800	3,800	4,800	4,800
Average annual recovery (acre feet)	0	1,000	2,000	2,000
Capital Costs ($1,000)				
Permitting	$300	$75	$75	$450
Construction	$0	$3,200	$3,200	$6,400
Total Capital Costs	**$300**	**$3,275**	**$3,275**	**$6,850**
Annual Operations and Maintenance Costs ($1,000)				
Water production at the NDWTP for recharge	$90	$120	$150	$150
Net cost of water recovery from wells	$0	$40	$75	$75
Permitting	$75	$75	$75	$75
Total Annual Operations and Maintenance Costs ($1,000)	**$165**	**$235**	**$300**	**$300**

The full capital outlay for the construction and permitting of two new wells is needed to allow the city to rely on groundwater for 100 percent of municipal supply during drought periods and make surface water that might otherwise be diverted by the city available for other uses. Recharging 2,800 acre feet per year in any scenario is sufficient for municipal supply and attendant instream flow benefits.

Recharge more than 2,800 acre feet during November-April, as in Scenarios 2 and 3, represents maximizing the recharge capacity of the developed system. Recharging more than 2,800 acre feet per year could be justified if a demand for the water can be identified that will provide revenue to offset the cost of greater annual recharge.

8.0 Expansion Beyond the City of Yakima

The largest costs for an ASR program are usually water treatment and injection/recovery wells. The city is fortunate to have water treatment capacity that is not used during the winter and is available for ASR application. While recharge may occur every year, recovery by the city in response to reduced use of surface drinking water diversions would likely only occur periodically. Significantly more water could be recharged than may be recovered by the city. Therefore, there may be ASR system capacity available for use by others.

Entities could enter into appropriate cost-sharing agreements with the city for treatment, storage, and delivery of water through the ASR system. The diversion of source water could be under water rights provided by these entities, which may consist of existing water rights or new winter water rights. New water rights for ASR source water may be interruptible and still be compatible with ASR operations.

Water could be delivered through interties with adjacent water systems, or appropriate credits for recharged groundwater could be made available. Extending the ASR program beyond the city system is a longer-term option introduced here for future evaluation. Consideration is given to the following components:

- Surface water treatment capacity
- Recharge capacity (wells)
- Transmission

The initial focus of ASR in the Ahtanum Valley is on the groundwater wells of the city, which tap the Upper Ellensburg Formation within the footprint of the Ahtanum-Moxee Subbasin. This is the same as the area in the Ahtanum-Moxee Subbasin surrounded by basalt outcrops of Yakima Ridge, Ahtanum Ridge, and the Rattlesnake Hills (Figures 2 and 3). The pending water right application for an ASR groundwater reservoir permit specifies the groundwater reservoir as the "Upper Ellensburg Formation."

The pending groundwater reservoir application could potentially be used for recharge to the Nob Hill water system wells that are completed in the Upper Ellensburg Formation. A new groundwater reservoir application would likely have to be submitted for recharge to wells completed in the basalt aquifer system, such as some of the wells operated by the Nob Hill and Terrace Heights water systems.

8.1 Expanding Surface Water Treatment Capacity

Establishing two new recharge points in addition to the existing two recharge-capable wells will maximize use of the city's existing treatment capacity. If the ASR program is expanded beyond four recharge wells, additional treatment capacity will be required.

Treatment of surface water is needed before recharge to the Upper Ellensburg Formation aquifer for the following reasons:

- To prevent clogging of the aquifer during recharge
- To maintain potable drinking water standards while using the city's drinking water distribution system to deliver surface water to recharge wells

The sandstone aquifer of the Upper Ellensburg Formation is susceptible to clogging from suspended solids, as seen during the 2001 recharge testing of the Kissel Well. Though the recharge water source was filtered by the Naches River Water Treatment Plant during the Kissel Well testing, suspended solids from the distribution system – "system scale" – was sufficient to reduce well efficiency during recharge. The loss of well efficiency was fully recovered upon back-flushing. Filtration treatment of source water and control of suspended solids are considered necessary for an ASR program recharging to the Upper Ellensburg Formation sandstone.

The Nelson Diversion site is identified as a candidate site for building new water treatment capacity for the following reasons:

- A diversion structure exists at this location that serves the city's irrigation system.
- The city owns enough land for siting a new plant.
- A 48-inch transmission line of the city's distribution system passes by the site.

8.2 Recharge Capacity

New points of recharge may be developed by retrofitting existing wells for recharge or installing new wells. Retrofitting existing wells offers efficiencies in avoiding the cost of drilling new wells, and reduced uncertainty risk associated with the variability of aquifer transmissivity when installing a new well. Several wells are identified below as possible candidates for retrofitting as ASR wells based on general considerations of infrastructure and geology.

Nob Hill Water System Wells 5 and 7 have production capacities ranging from 1,800 gpm to 2,500 gpm, which indicate they are capable of sufficiently large recharge rates to be favorably considered as recharge wells. Wells 5 and 7 are completed in the Upper Ellensburg Formation and potentially could be used as recharge points under the city's reservoir permit application R4-34552, which includes recharge to the Upper Ellensburg Formation.

Nob Hill Water System Well 1, completed in basalt, also has good production capacity at 1,600 gpm. A new groundwater reservoir application would likely be needed to permit recharge in this well because it is completed in different stratigraphy than covered by the pending reservoir application that applies only to the Upper Ellensburg Formation.

The Yakima County's Terrace Heights water system also has high capacity wells completed in basalt. Similar to Nob Hill Well 1, recharge to Terrace Heights basalt wells would likely have to be covered under a new groundwater reservoir application for storage in basalt.

8.3 Transmission

Interties connect the water systems of the city with the Nob Hill Water System, and interties could be established between the city and the Terrace Heights water systems, through which water treated at the city's Naches River Water Treatment Plant could be delivered for recharge to wells managed by these water systems. There would be additional costs for infrastructure modifications, such as booster pumps, and pumping to higher pressure zones. These costs and the distribution system pressure under recharge conditions have not been assessed.

9.0 References

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10.0 List of Preparers

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