WASHOE COUNTY
COMMUNITY SERVICES DEPARTMENT
Engineering and Capital Projects

1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

March 28, 2019

Beverly S. Breen
Grants Management Specialist
Bureau of Reclamation
2800 Cottage Way
Sacramento, California 95825

Re: Washoe County Title XVI Annual Report Agreement R17AP00068

The northern Nevada "OneWater Nevada" team consisting of eight public agencies is jointly conducting a feasibility study (Study) to evaluate whether the State of Nevada's newly adopted "A+" reclaimed water category offers significant water resource management benefits including improving efficiency, providing flexibility during periods of water scarcity, and diversifying the region's water supply portfolio. Category A+ reclaimed water quality requirements meet all Federal and State of Nevada drinking water standards and is intended for indirect potable reuse. It is anticipated A+ quality will be achieved from a combination of advanced water treatment processes and soil-aquifer-treatment and storage.

This Study consists of multiple elements including a project rationale and justification analysis, regulatory formulation, public engagement, advanced water treatment technology pilot testing, geotechnical investigations, and field-scale indirect potable reuse demonstration trials. The Study will likely take 3-to-4 years and approximately $7 million to complete.

Bureau of Reclamation Title XVI funding agreement R17AP00068 has enabled a substantially more robust analysis relating to the project rationale and justification work which occurred in calendar year 2017 and early 2018, specifically enhancing the Study in the following focus areas:

- Developing a water market value impact study.
- Evaluating methods acceptable to the Nevada State Water engineer to create and account for a "new" A+ water right.
- Evaluating if indirect potable reuse enables the region's water resource portfolio with greater resiliency with respect to climate change.
- Evaluating less energy intensive water treatment technologies suitable for potable reuse, compared to reverse osmosis.

1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

The above listed focus areas have complemented the project rationale and justification work already envisioned. Developing knowledge in these focus areas has created a body of work that can be easily transferrable to future projects in Nevada and other states.

The following document includes four (4) reports that cover each of the Study focus areas. Each report begins with the specific task description from the initial proposal along with performance information. A comparison of actual accomplishments to the objectives is outlined prior to each of these reports.

Washoe County would like to thank the Bureau of Reclamation for this opportunity. The northern Nevada region has benefitted tremendously from this effort as potable reuse demonstrations begin to take form. The information discovered in this Study is invaluable not only to Washoe County and the Northern Nevada agencies but also to the international potable reuse industry.

Thank you,

Lydia Peri, PE
Environmental Engineer II
Washoe County Community Services Department
(775) 954-4626
LPeri@washoecounty.us

Northern Nevada Indirect Potable Reuse Feasibility Study

Bureau of Reclamation Title XVI Annual Report
Agreement R17AP00068

Final Report

Prepared by:
Washoe County Community Services Department
1001 E Ninth Street
Reno, NV 89512

March 2019

Contents

Bureau of Reclamation Final Report R17AP00068

Executive Summary

The northern Nevada "OneWater Nevada" team consisting of eight public agencies is jointly conducting a feasibility study (Study) to evaluate whether the State of Nevada's newly adopted "A+" reclaimed water category offers significant water resource management benefits including improving efficiency, providing flexibility during periods of water scarcity, and diversifying the region's water supply portfolio. Category A+ reclaimed water quality requirements meet all Federal and State of Nevada drinking water standards and is intended for indirect potable reuse. It is anticipated A+ quality will be achieved from a combination of advanced water treatment processes, aquifer storage and recovery and soil aquifer treatment.

This Study consists of multiple elements including a project rationale and justification analysis, regulatory formulation, public engagement, advanced water treatment technology pilot testing, geotechnical investigations, and field-scale indirect potable reuse demonstration trials. The Study will likely take 3-to-4 years and approximately $7 million to complete.

Bureau of Reclamation Title XVI funding agreement R17AP00068 has enabled a substantially more robust analysis relating to the project rationale and justification work which occurred in calendar years 2017 and 2018, specifically enhancing the Study in the following focus areas:

- Developing a water market value impact study.
- Evaluating methods acceptable to the Nevada State Water engineer to create and account for a "new" A+ water right.
- Evaluating if indirect potable reuse enables the region's water resource portfolio with greater resiliency with respect to climate change.
- Evaluating less energy intensive water treatment technologies suitable for potable reuse, compared to reverse osmosis.

Although the potential use of A+ reclaimed water to augment groundwater sources in Northern Nevada is viewed favorably by water managers, the OneWater Nevada is crafted to more fully develop an understanding of the social, economic and environmental elements.

The Study was conducted and drafted to meet the requirements of a feasibility study as defined under section 1604 of Pub. L. 102-75, and conformed to the suggested outline found in Section 4.B of the Bureau of Reclamation (BOR) Title XVI Feasibility Study Directives and Standards. Washoe County was the lead agency and designated project sponsor with respect to the BOR funding opportunity. Funding from the BOR has enabled a substantially more robust analysis relating to the project rationale and justification work occurring in calendar years 2017 and 2018, specifically enhancing the water markets evaluation; water rights; climate change; and

low energy water treatment solutions.

Crafting a triple bottom line analysis unique to the Reno, Nevada area is envisioned to help align the Study activities, and more clearly articulate the project purpose, goals, and metrics to the public and policy makers in the Northern Nevada community. Field demonstration-scale projects are intended to prove IPR planning concepts, measure treatment technology performance, and verify ability to meet regulatory compliance. BOR funding supports a more critical review of regional water resource management alternatives, particularly with respect to if indirect potable reuse can have a positive impact upon the region's water portfolio for drinking water resiliency or addition recreational and environmental benefits.

Study Description

A Reno, Nevada regional team (OneWater Nevada) consisting of eight public agencies is jointly conducting a feasibility study (Study) to evaluate whether the State of Nevada's adopted "A+" reclaimed water category offers significant water resource management benefits. Although indirect potable reuse (IPR) alternatives have been included in previous Northern Nevada water master planning efforts, IPR has historically not been considered viable largely because there was not a clear regulatory pathway established in Nevada. In December 2016, following a comprehensive two year state-wide collaborative process, the State of Nevada adopted revised reclaimed water regulations, which for the first time establishes a regulatory framework for implementing indirect potable reuse for groundwater augmentation. The newly adopted Nevada regulations permit two methods of indirect potable reuse:

1) Utilizing spreading basins receiving Nevada Category A reclaimed water, which is the highest category for unrestricted non-potable uses. Natural treatment within a suitable unsaturated zone can effectively produce Category A+ quality upon introduction to the saturated zone (soil aquifer treatment).

2) Aquifer storage and recovery utilizing Nevada Category A+ reclaimed water, which is achieved by advanced water treatment processes and suitable for direct injection to groundwater aquifers.

One of the most comprehensive water management plans developed to date is titled North Valleys Effluent Disposal Options, dated 2005. The plan evaluated numerous water supplies, wastewater treatment scenarios, and effluent management options for an area located approximately 10 miles north of Reno, Nevada, commonly referred to the North Valleys. The plan continues to serve as a water, wastewater, and reclaimed water roadmap for the region.

Water resources within the Truckee River watershed are primarily derived from snowpack accumulated during the winter season. Although the regional effects of climate change are uncertain, the region expects to incur more frequent or extended drought periods and a transition from river flows derived from melting snowpack to rainfall. The potential shift in precipitation patterns from snowfall to rainfall may have dramatic impacts on future water planning due to effects on water storage and quality; currently surface water supply primarily originates from snowmelt during spring and summer months. Concern over quantity and quality of water supplies within the region also drives competition between downstream and upstream users that rely largely on the Truckee River to support sensitive ecologies, agricultural uses, industrial development, and diverse communities.

Water resources within the Truckee River watershed are fully allocated and several basins within the region are closed, relying on groundwater flows, inter-basin transfers of surface water from the Truckee River, and imported water to meet water demand. If the water portfolios of these closed-basins are not expanded, imported water may play an increasing role in satisfying water demand. However, the local water authority has limited control over imported water resources, and it is also an expensive resource that requires significant elements to manage and is associated with a large carbon footprint due to pumping requirements.

Bureau of Reclamation Title XVI funding agreement R17AP00068 has enabled a substantially more robust analysis relating to the project rationale and justification work which occurred in calendar years 2017 and 2018, specifically enhancing the Study in the following focus areas:

- Report 1: Developing a water market value impact study.
- Report 2: Evaluating methods acceptable to the Nevada State Water engineer to create and account for a "new" A+ water right.
- Report 3: Evaluating if indirect potable reuse enables the region's water resource portfolio with greater resiliency with respect to climate change.
- Report 4: Evaluating less energy intensive water treatment technologies suitable for potable reuse, compared to reverse osmosis.

Report 1

Water Market Value Impact Study

BOR funding has supported a water markets study for the North Valleys that could potentially be applied regionally. The scope of this work is intended to provide a potential mechanism to promote efficient water uses and minimize the economic impacts of periodic drought conditions. This project activity provides a case study analysis of water markets to inform the OneWater Nevada team of potential options for development of an expanded water market as an alternative or companion to other opportunities to improve regional water supply conditions. Conceptually, the water markets work has considered the regulatory conditions, water supply and demand, market participation, and water pricing and cost of alternatives.

This report examines the potential benefits of indirect potable reuse (IPR) to the North Valleys area of Reno-Sparks and Washoe County through a cost-benefit analysis approach. This report includes a review of the economic benefits of fresh water and reclaimed water in the North Valleys region by identifying key drivers favoring economic growth, restraints to economic growth, recent trends, and similar findings from other regions. A cost-benefit analysis is conducted to evaluate if IPR is likely to generate greater benefits for the region than an alternative, lower cost effluent management strategy.

Despite limited groundwater resources and capacity to discharge reclaimed water, the North Valleys region of Reno-Sparks is among the fastest growing in the region. The growing demand for water has also resulted in increased flows of reclaimed water from local WRF. Water reuse is already occurring in the study area, reducing demand for potable water resources by utilizing reclaimed water for uses like irrigation and construction. However, the volume of reclaimed water generated annually is expected to exceed local effluent management capacity within a 20-year planning period.

This research focused on two key aspects to evaluate the potential net benefits of potable reuse. The first was the economic productivity of water resources, which characterized how water resources are used in the economy of the Reno-Sparks metropolitan area. This provided an understanding of how increasing water resources through IPR may generate unmeasured benefits when the water is used as an input into the broader economy. Second, a cost-benefit analysis was used to evaluate if IPR was likely to generate a net benefit for the region.

Regional studies related to water resources management were reviewed to establish the potential role of category A+ reclaimed water in the water portfolio of the Reno-Sparks metropolitan area. The University of Nevada, Reno was tasked to perform this water market value study. Scope of work included the review of current market dynamics and driving factors for market growth. The analysis from this study was presented at a regional Water Rights Workshop (a component of this Title XVI Scope) in October 2018 where local stakeholders and regional water rights experts were present. The attendees offered comments and input on the market value study.

Northern Nevada Indirect Potable Reuse Feasibility Study

Category A+ Reclaimed Water Market Value Study

Final Report

Prepared by:

Krishna Pagilla, PhD, PE, Professor
Laura Haak, PhD Candidate

University of Nevada, Reno

March 2019

Submitted to:

Lydia Peri, P.E., Environmental Engineer
Washoe County CSD

Contents

Category A+ Reclaimed Water Market Value Study

Tables

Figures

Section 1

Introduction

1.1 PURPOSE

This report examines the potential benefits of indirect potable reuse (IPR) to the North Valleys area of Reno-Sparks and Washoe County through a cost-benefit analysis approach. This report includes a review of the economic benefits of fresh water and reclaimed water in the North Valleys region by identifying key drivers favoring economic growth, restraints to economic growth, recent trends, and similar findings from other regions. A cost-benefit analysis is conducted to evaluate if IPR is likely to generate greater benefits for the region than an alternative, lower cost effluent management strategy.

1.2 REPORT ORGANIZATION

The report consists of the following sections:

- **Section 1 - Introduction:** This section describes the project background, goals and objectives.
- **Section 2 – Economic Benefits of Water Resources:** This section identifies the role of fresh and recycled water resources in the regional economy.
- **Section 3 – Scenario for IPR in the North Valleys:** This section reviews research for how IPR may conceptually be implemented in the region to identify the most likely potable-reuse scenario.
- **Section 4 – Market Attractiveness of IPR:** This section encompasses a cost-benefit analysis of IPR based on projections for population growth and water demand. The net benefits/costs generated by IPR over a twenty-year planning period are compared to status-quo water management strategies.
- **Section 5 – Summary and Next Steps**
- **Section 6 – References**

1.3 BACKGROUND

The metropolitan area of Reno-Sparks, located in Northern Nevada, has a semi-arid climate that faces challenges to sustainably manage water resources. Challenges in future water management include the growing demands for residential and commercial uses, requirements for high quality discharge with limited options to dispose of reclaimed water, and competition between residential, commercial, agricultural, and ecological demands. The region has adopted several water management strategies to enhance the resilience of water resources, including storage in upstream reservoirs, aquifer storage and recovery (ASR) with surplus surface water supplies, and utilization of reclaimed water for local irrigation and industrial processes.

The Truckee River is supplied by reliable water supplies that are generated from snowpack stored across the northern Sierra Nevada Mountains. The Truckee Meadows Water Authority (TMWA) is the primary water supplier within the municipal services area, which supplies water resources to the incorporated and surrounding areas near the cities of Reno and Sparks. TMWA utilizes conjunctive management of water resources to optimize storage of water resources in upstream reservoirs and aquifers throughout the service area. Upstream reservoirs provide a drought supply for municipal needs as well as storage to support riparian species and habitats (NNWPC, 2017). However, water availability within the region is expected to become less resilient and more stressed into the future due to uncertainty in climactic patterns of precipitation, and water needed to replenish reservoirs and groundwater supplies after dry periods (TMWA, 2016). Concern over the quantity and quality of water supplies within the region also drives competition between downstream and upstream users that largely rely on the Truckee River to support sensitive ecologies and aquatic species, agricultural uses, industrial development, and communities.

The State of Nevada in 2016 adopted the “A+” category of reclaimed water, which can provide benefits in regional water management by improving the efficiency and enhancing the flexibility of the role of reclaimed water in regional water resources. The Category A+ requirements provide a regulatory path for indirect potable reuse (IPR) through advanced treatment to a quality standard that meets all Federal and State of Nevada drinking water standards.

This study examines the potential role and net benefits of pursuing IPR in the North Valleys area through a cost-benefit approach. The cost-benefit approach is grounded in the perspective that water resources act as an input to economic growth in a region. Thus, the economic value of increasing water resources through IPR can be evaluated by determining the net benefits of different scenarios of water resource management or infrastructure investments. This approach requires accounting of internal costs and benefits to the water and wastewater utilities as well as valuation of external costs and benefits, such as pollution and flood risk to produce an analysis that considers the overall value of water and wastewater resource management to the study area. A key focus of these analyses are to incorporate socio-environmental parameters into decision making, such as the equity, affordability, and net social benefits generated by a project or management strategy (Savenije & van der Zaag, 2002).

In the Truckee Meadows watershed, the finite supply of water resources has been litigated and negotiated to ensure an equitable distribution of resources between competing stakeholders including ecosystems and endangered species, municipal and industrial (M&I) sectors at water demand sinks across the watershed, and agricultural uses. This study focuses on the water resources available to meet M&I demand in the North Valleys area, and the potential impact/value of increasing future water supplies through IPR.

1.4 TASK OBJECTIVES

The cost-benefit analysis encompasses the potential impacts of water resource management alternatives, including:

- Restraints to regional growth
- Cost of operating and maintaining water and wastewater infrastructure
- Cost of service
- Water and wastewater connection fees

Section 2

Economic Benefits of Water Resources

2.1 PURPOSE AND SCOPE

The purpose of this section is to identify the role water resource management and availability in promoting regional growth and to review economic growth trends in the region.

The remainder of this section is organized in the following subsections:

- Future Water Resource Availability
- Water Resource Limitations on Growth
- Economic Characterization of the Region

2.2 FUTURE WATER RESOURCE AVAILABILITY

In the Reno-Sparks metropolitan area, Lemmon Valley and Stead make up closed sub-basins that lie in the Honey-Eagle Lakes watershed. Despite limited groundwater resources and capacity for reclaimed water discharge, these sub-basins are among the fastest growing in the region. This area is expected to increasingly rely on imported water resources, which include surface water from the Truckee River and groundwater from Fish Springs to meet growing water demands and to recharge aquifers through ASR as part of a program administered by the State of Nevada (TMWA, 2016). The growing demand for water has also resulted in increased flows of reclaimed water from local water reclamation facilities (WRF). Reclaimed water is beneficially reused in the basin to support a wetland in Swan Lake and to provide irrigation with non-potable, category A reclaimed water. However, the volume of reclaimed water generated annually is expected to exceed local effluent management capacity within a 20-year planning period (NNWPC, 2017).

Demands for non-potable uses are limited by the costs of additional service connections and the demand from commercial and recreational users. Additionally, the increasing demand for potable water for residential uses may cause potable reuse to have a greater value for the local community than allocating reclaimed water for non-potable uses. Thus, expanding potable water resources through investment in an advanced water treatment (AWT) processes to highly treat reclaimed water to a quality that meets or exceeds drinking water standards. To achieve water for potable reuse, AWT incorporate multiple barriers against microorganisms and chemical contaminants to achieve resiliency, redundancy, and robustness. This strategy is increasingly applied for indirect potable reuse, which can be used to augment a community's potable water resources. In the study area, this strategy can produce a potable water resource for the future which may provide an optimal solution for management of both effluent and water supplies as well as an opportunity for water banking and drought storage.

The supply of water resources, discharge of reclaimed water, and potential scenarios of AWT or exporting of surplus reclaimed water are illustrated in the nodal network depicted in **Figure 1**. Existing water resources available to the North Valleys study area from local aquifer and imported from the Truckee River are assumed to remain constant, while imported groundwater supplies can increase up to 8,000 acre-feet annually (AFA) in the future. The study assumes that the user base for non-potable water resources could be expanded to include several large volume customers such as parks. Beyond that, the purple pipe system could be expanded to deliver the non-potable reclaimed water resources for irrigation in new residential developments. Swan Lake and evaporation ponds are the largest sink for reclaimed water within the study area. Reclaimed water that is discharged to the Swan Lake playa and wetlands provides important habitat for migratory birds. Swan Lake is required to receive a minimum of 490 AFA and a maximum of 2,630 AFA to ensure adequate flows for habitat maintenance while reducing flood risk. Discharge into these sinks is assumed to increase up to their respective capacities.

Two alternative scenarios for reclaimed water management are illustrated in Figure 1 by the dashed lines. Surplus reclaimed water is any reclaimed water that exceeds the capacity of the local reclaimed water sinks that are currently in place. The two scenarios explore different approaches to manage the 2 mgd in surplus reclaimed water that may be generated as the local population expands. Under both options, the first 0.5 mgd of surplus reclaimed water would be used under a current plan to expand non-potable reuse for large volume customers. Each scenario is described below.

Export scenario

After the first 0.5 mgd expansion of non-potable reuse, this scenario then expands the purple pipe distribution system to new residential developments for irrigation. The potential build-out capacity for this purple pipe system was assumed to be 1.0 mgd. The final 0.5 mgd increase in reclaimed water would then be exported out of the region to Long Valley creek. This step was selected based on a previous regional study on effluent management (Eco:Logic, 2010). In summary, this scenario would manage the 2 mgd effluent increase through a 1.5 mgd increase in non-potable reuse occurring over the first 20 years, followed by a 0.5 mgd system to export the water.

Indirect potable reuse (IPR) scenario

As described previously, the IPR scenario also assumes that the first 0.5 mgd increase in effluent would be addressed by expanding non-potable reuse to large volume customers. Following that, the next 1.5 mgd increase in effluent would be addressed by sending the water for AWT followed by injection into a local aquifer. The 1.5 mgd of flow for advanced treatment and groundwater augmentation was estimated to increase at approximately a linear rate over twenty years. The specific scenario for advanced treatment processes is beyond the scope of this study but were assumed based on other local reports for effluent management (Stantec, 2018). This study does not assume hydrologic characteristics of the aquifer that may be utilized for IPR, nor quantified beneficial water loses as a result of administrative requirements from operating a permitted ASR program. Not all of the water injected into the aquifer can be recovered. This study assumes that 80% of the water injected can later be recovered.

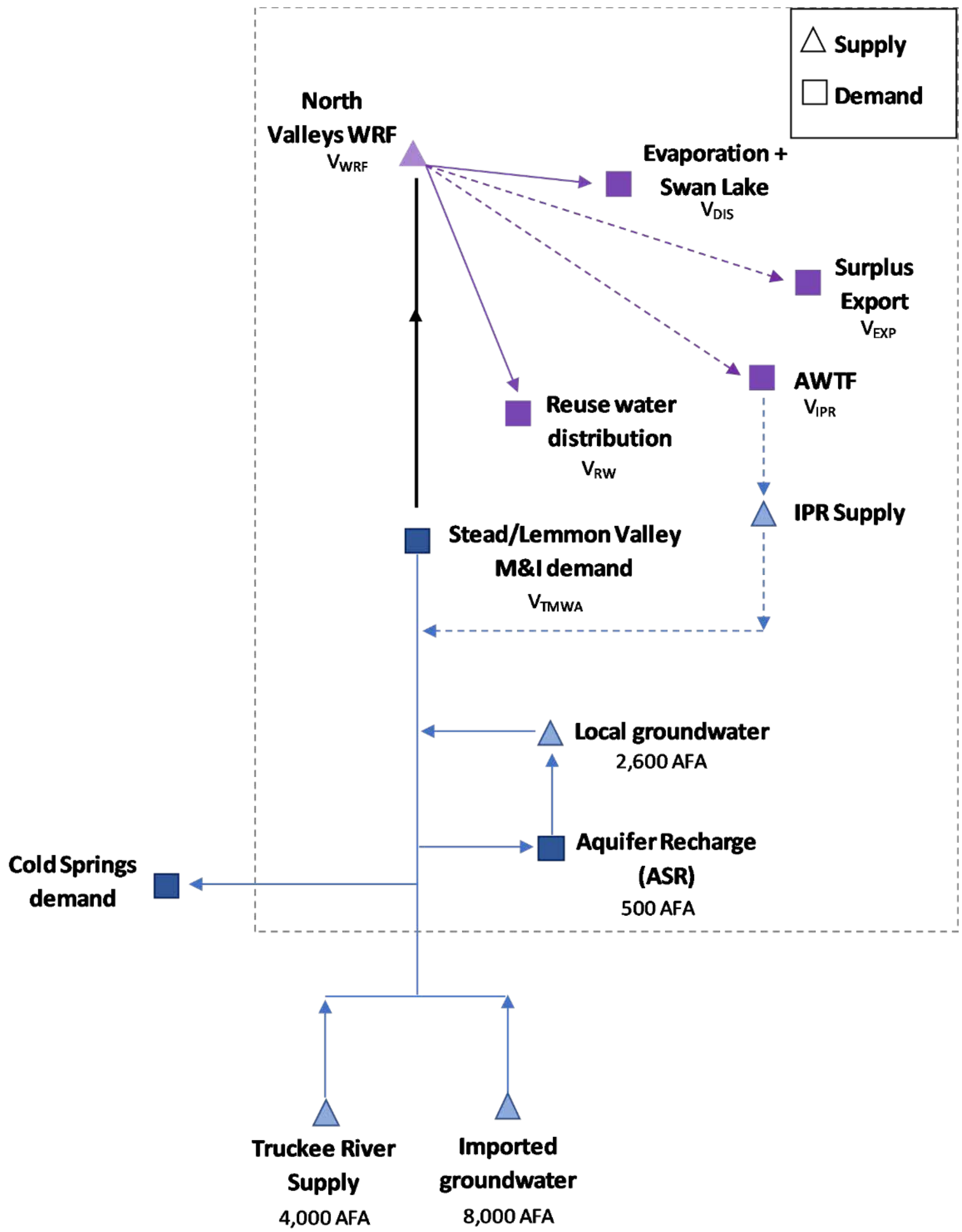


Figure 1. Nodal network depiction of North Valleys (Stead/Lemmon Valley) water resources

2.3 ECONOMIC CHARACTERIZATION OF THE REGION

The cost-benefit analysis carried out in Section 3 evaluates the feasibility of either water management scenario based on parameters that are internal to the finances of the water and wastewater utilities. However, water resource management may also impact the economy of the region. For example, non-potable reuse and potable reuse can increase the local water resources available to support a growing population. Additionally, end-user water conservation, utility investment in water meters and leak detection, and changes within the local economy may help to lower the water demand intensity, which is the average annual gallons of water demanded per capita or per employee. While these characteristics are not included in a cost-benefit analysis, they can help to demonstrate the potential value that water resources have within the community and local economy.

The water use for non-residential purposes in the Reno-Sparks metropolitan area was analyzed from water billing data for the general metered water service customer class served by TMWA. The water use data was then compared to several socio-economic characteristics of the region, including population, employment, and gross domestic product (GDP). GDP measures the value of goods and services produced within the study area; this was selected as an indicator of socio-economic well-being and economic productivity. This data was obtained from the U.S. Bureau of Economic Analysis (Bureau of Economic Analysis, 2019) for 2004 through 2017 in the Washoe County area, which largely corresponds to the metropolitan area of Reno-Sparks. Employment data for the Reno-Sparks metropolitan area was obtained from the U.S. Bureau of Labor Statistics for 2004 through 2017 across the sectors of government, mining, construction, manufacturing, trade and transportation, information, professional, education and healthcare, leisure and hospitality, and other miscellaneous sectors for the years 2013 through 2017 (Bureau of Labor Statistics, 2018).

Figure 2 illustrates trends in employment and GDP over the previous 14 years. Overall employment in the regional economy has grown by 15% as the economy has recovered from the economic recession of 2007-2008. The largest sectors include trade and transportation, business and professional services, and leisure and hospitality. Together, these three sectors comprise nearly 60% of the regional economy. The regional economy is largely comprised of service providing industries. More water intensive goods producing sectors make up nearly 15% of regional employment; these sectors include utility providers in the natural resources and mining sector, construction, and manufacturing. Overall, industries in the service sectors have grown by an average of 15% over the last 5 years. Among service providing industries, trade & transportation and the financial, professional & business sectors are driving growth at 16% over the past five years. The aggregate regional trends in GDP illustrated in Figure 2 show an increase of more than 30% since recovery from the economic recession took accelerated after 2012. Overall, the service sectors accounted for more than 75% of regional GDP.

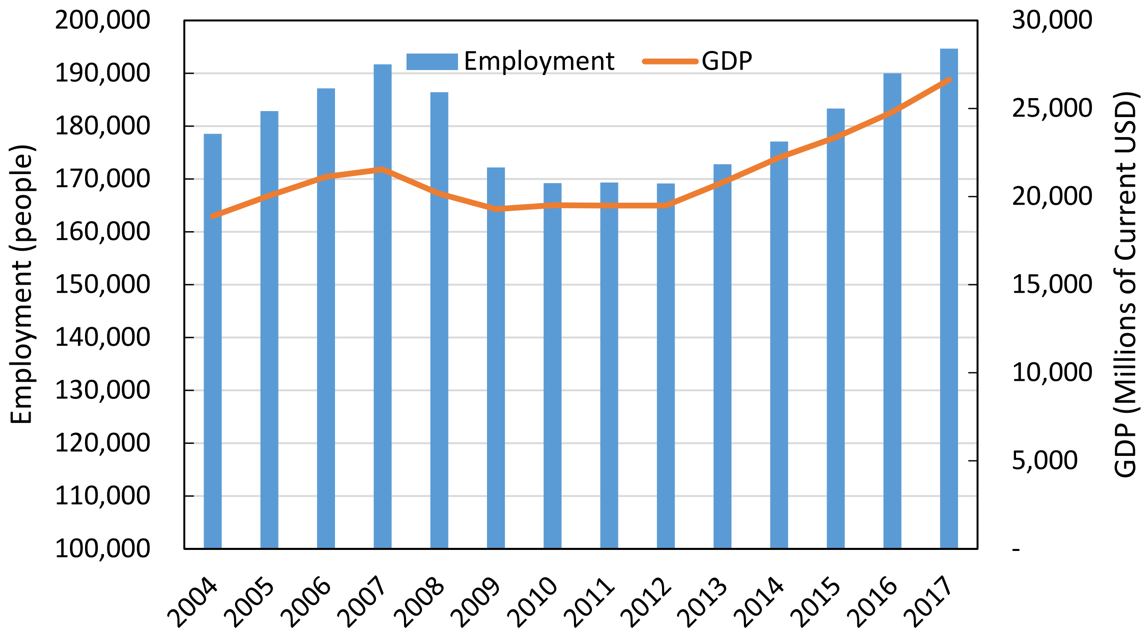


Figure 2. Change in employment and GDP in the Reno-Sparks metropolitan area

2.4 WATER USE IN THE LOCAL ECONOMY

To examine the characteristics of water demand within the economy of the Reno-Sparks metropolitan area, sectors were aggregated based on land use characteristics: offices, warehouses and industrial land use, and hospitality land uses like resorts. This analysis utilized the Washoe County Assessor's database (https://www.washoecounty.us/assessor/online_data/) to determine the land use characteristics of commercial land parcels serviced by the local water authority, TMWA. Annual water demand data for these parcels were then aggregated by land use, resulting in an estimate of total annual water demand for the aggregated economic sectors, as described in Table 1. These sectors were then matched to the employment statistics for the aggregated sectors.

Table 1. Summary of sector aggregation for water demand analysis

Aggregated Sector Name	Sub-Sectors	Land Use Characteristics
Professional and government	Government, information, financial, professional, business education, healthcare	Commercial, office, professional, bank, retail, real estate, mixed, government, hospital, school
Leisure and hospitality	Arts, entertainment, recreation, accommodation	Hotel, motel, casino, hotel casino, commercial resort, museums, golf courses, health clubs, amusement and recreation services
Trade, Transportation and Warehouse	Wholesale trade, retail trade, transportation, warehousing	General industrial, warehouse, equipment, materials, electrical goods, machinery, engineering, auto repair and services
Total Non-Residential	All sectors	All non-residential

This study normalizes water demand based on employment with gallons of water demand per employee per day (GED) as a general indicator of non-residential water demand intensity. GED was calculated by taking the ratio of water demand to employment for the aggregated sectors described above. The GED indicator is widely used for urban planning, and conservation planning. Table 2 highlights the water demand and employment statistics for each sector, which are then used to derive the water demand intensity, GED, for each sector based 2016 water demand and employment data. Overall, the trade and transportation sector had the lowest water demand intensity followed by the office-based industries in the professional and government sector.

Table 2. GED of economic sectors for Reno-Sparks in 2016

Sector	Water demand (x 1,000 gal)	Employment	GED
Professional and government	1,933,306	94,188	91
Leisure and hospitality	1,243,684	36,813	150
Trade, Transportation and Warehouse	568,440	58,547	43
Total Non-Residential	3,765,336	189,971	88

Next, these trends can be compared to social welfare statistics to indicate if the water demand intensity trends that indicate increased conservation correlate to social welfare in the municipal area. Gross domestic product (GDP) is a common measure of social welfare that is readily available for urban areas across the U.S. from the Bureau of Economic Analysis database (https://apps.bea.gov/itable/). GDP measures the value generated by a variety of economic activities within the urban area. The total GDP produced by economic activity within the Reno-Sparks metropolitan area was evaluated on an annual basis and compared to the average annual GED to evaluate if water conservation appeared to impact economic productivity. Figure 3 illustrates the trend in total non-residential GED since 2004, which has declined 23%. The decline in GED indicates water efficiency improvements across sectors, which have increased economic output by 18% since 2013.

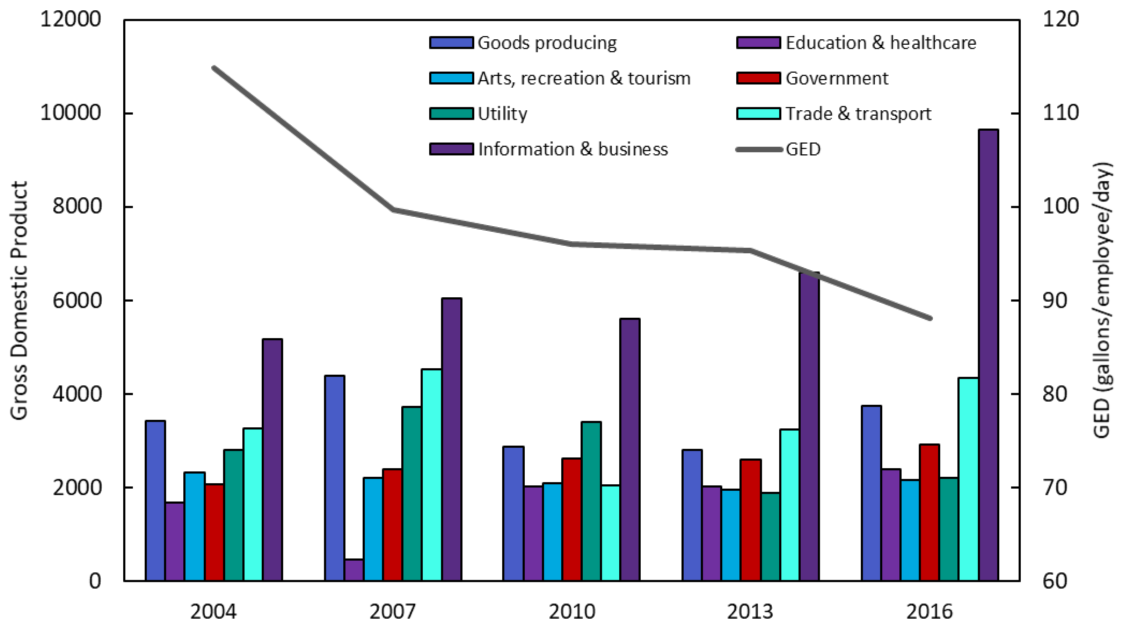


Figure 3. Change in aggregate GED with economic growth (GDP)

2.5 ECONOMIC PRODUCTIVITY OF WATER

The GED analysis above illustrates how the supply-management strategies that have been undertaken by TMWA helped to reduce the water intensiveness of water demand by commercial customers. In turn, this may have resulted in an increase in the value that water resources generate as an input to the local economy. One strategy to analyze the impacts of water use efficiency in the economy is to examine the economic productivity of water. This is calculated on an annual basis by comparing the GDP generated in the local economy to total annual non-residential water demand, resulting in the GDP produced per 1000 gallons of water demand. Other studies have used this indicator to examine water conservation in agriculture (NRDC, 2014) or in state economies (Gleick, 2003).

Figure 4 illustrates the trends in GDP, total water production, and water demand over the study period. Water demand decreased most significantly from 2007 to 2010, which corresponds closely to the economic recession as illustrated by the decreased employment rates over the same period (refer to Figure 2). Adoption of water conservation was most notable between 2004 to 2007 and 2013 to 2016 (Figure 3). This correlated to periods where total non-residential water demand remained steady or decreased despite increasing population and economic productivity (Figure 4).

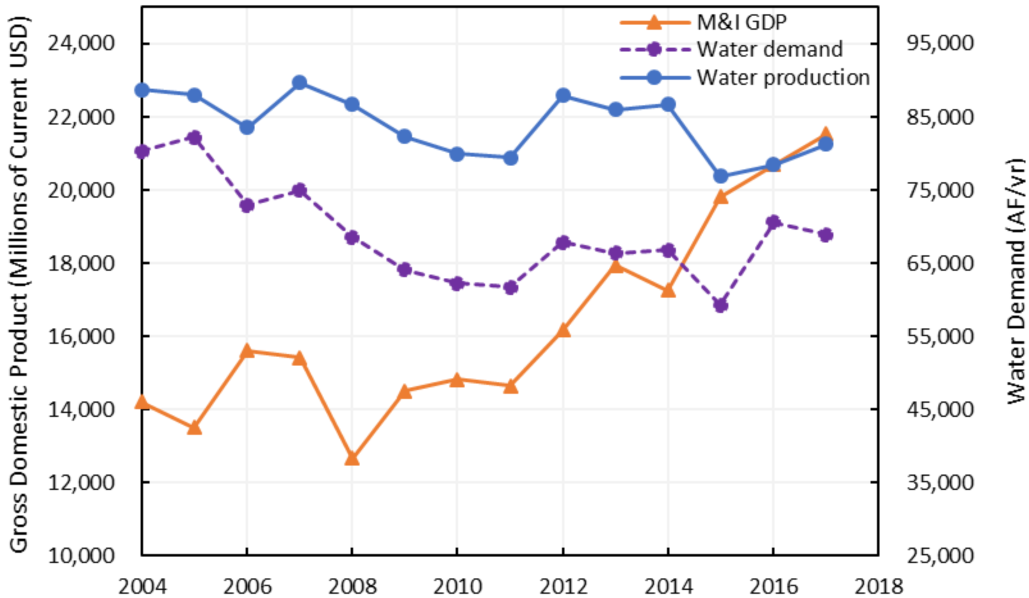


Figure 4. Annual trends for GDP and water demand in the Reno-Sparks metropolitan area

The resulting trend in economic productivity of water demand is illustrated in Figure 5. Economic productivity of water was calculated as the ratio between GDP and total annual water production by TMWA, which includes non-metered use of water resources and system losses. The overall economic productivity of water nearly doubled since 2004. A steep increase is shown in 2015, which coincided with a severe drought and a request by the water authority for customers to reduce water use during the summer irrigation season. This illustrates that the cutback request did not have a direct negative effect on the economy. In the long-term, water efficiency measures have been adopted by non-residential customers, reducing the water use intensity of the economy while maintaining economic growth.

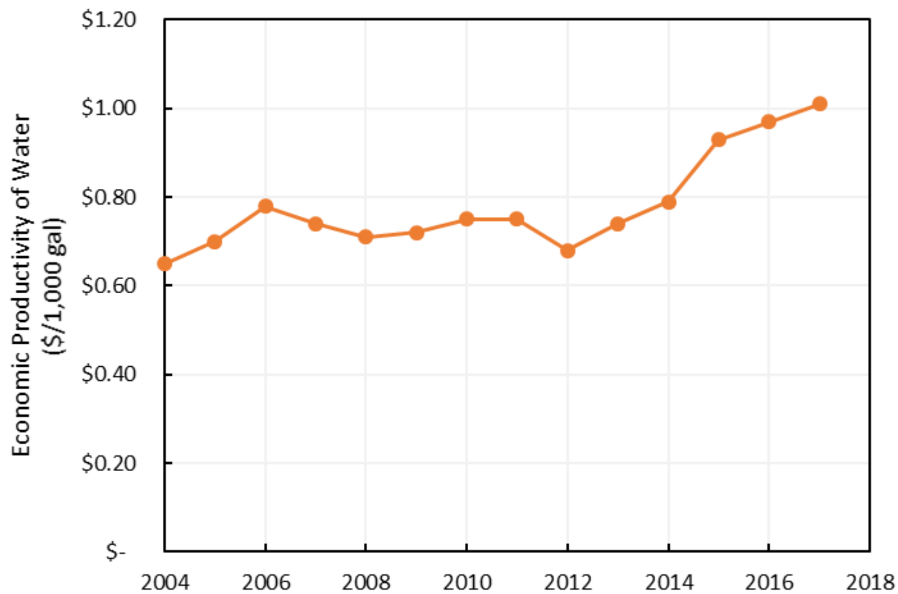


Figure 5. Economic productivity of water in the Reno-Sparks metropolitan area

Section 3

Scenario for IPR in the North Valleys

3.1 PURPOSE AND SCOPE

Indirect potable reuse in the State of Nevada is regulated through Nevada Administrative Code (NAC) 445A.425, which defines a water reuse category A+ (exceptional quality) as suitable for groundwater augmentation through spreading basins or injection wells. These standards require that the advanced treated reclaimed water meet the National Primary Drinking Water Standards (NAC 445A.4525) and the Secondary Maximum Contaminant Levels (NAC 445A.450, NAC 445A.455).

3.2 CURRENT REGULATIONS AND CRITERIA FOR POTABLE REUSE

Regulation of recycled water for PR applications is managed in the state of Nevada by the Nevada Division of Environmental Protection. The criteria currently apply to IPR, including groundwater augmentation through spreading basins or through advanced water treatment (AWT) followed by direct injection into an aquifer. IPR can utilize a combination of advanced treatment processes, which together provide multiple barriers against pathogens, regulated and unregulated contaminants of concern. Specific IPR treatment system designs may be driven by specific contaminants of concern or other constraints and objectives. A feasibility study for indirect potable reuse in the study area has identified two potential treatment strategies, through soil-aquifer treatment or through an advanced water treatment facility that utilizes ozone and biological active carbon (BAC) filtration. Criteria specified in these regulations are summarized in Table 3.

3.2.1 Reclaimed Water in the North Valleys Study Area

The North Valleys region of Reno-Sparks metropolitan area includes two water reclamation and reuse facilities. The Reno-Stead Water Reclamation Facility is the largest in the region, receiving an average annual flow over 1.5 mgd. Treatment processes include screening, grit removal, secondary biological treatment, filtration, chlorine disinfection, and dechlorination as well as solids pumping. Approximately 28% of the reclaimed water treated at this facility is reused for demands including golf courses, parks, and construction (NNWPC, 2017). During the winter season reclaimed water is largely discharged to the Swan Lake playa to sustain wetland habitat. The Lemmon Valley Water Reclamation Facility treated an average flow of 0.2 mgd in 2015, which was disposed of through evaporation from on-site ponds. Treatment includes grit removal, contact stabilization, secondary clarification, and aerobic sludge digestion.

3.2.2 Strategy for IPR in the North Valleys Study Area

This study assumes that the IPR approach utilizes direct injection to deliver water directly from advanced treatment processes to the saturated zone. Regulatory requirements specify the water must meet category A+ requirements prior to injection. Enteric virus reduction of 1-log can be credited per month when the reclaimed water is retained in the saturated zone. Other guidance to evaluate reclaimed water for potable reuse applications has been proposed by the National Research Council (NRC), including approaches to evaluate public health risks from pathogens and chemical contaminants, design recommendations for multiple barriers, and to ensure system robustness, reliability, and resilience (NRC, 2012).

This study does not explore the potential impacts of multiple IPR treatment strategies. The IPR scenario examines a case where AWT utilizes ozone-BAC technology followed by disinfection and direct injection, as illustrated in Figure 6. The injection well treatment strategy presently being investigated and validated includes granular media filtration with coagulation/flocculation and sedimentation pretreatment, ozonation of filtered effluent followed by BAC treatment. UV treatment will be used to provide an additional pathogen barrier after BAC.

Table 3. Pathogen and contaminant requirements (NAC 445A.425) for groundwater augmentation

Item	Treatment required
Water quality category	A+
Enteric virus reduction	12-log reduction
Giardia cyst reduction	10-log reduction
Cryptosporidium oocyst reduction	10-log reduction
Regulated contaminants	Must meet all drinking water MCLs (NAC 455A.4525, NAC 445.450, NAC 445.455)
Unregulated contaminants	Site-specific monitoring and detection program for NDEP approval

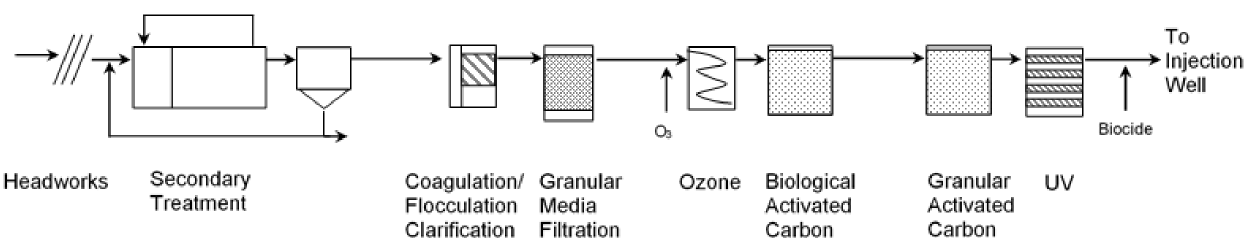


Figure 6. Treatment processes for injection well scenario

3.2.3 Preliminary Review of Costs for IPR

This study builds on the cost analysis presented in several preliminary studies for regional water resource management including Eco:Logic (2010), Stantec (2018), and Farr West (2019). The total cost of IPR includes the AWT system described above as well as the costs for pump stations, conveyance systems, and wells for injection and monitoring of the water to an aquifer. Although the operating and maintenance (O&M) costs to manage an IPR system may be larger than alternative effluent management scenarios, these costs are not included in the cost-benefit analysis because it is assumed that the revenues generated from wastewater and water use would be controlled to balance these costs. Instead, the analysis focuses on the capital costs for developing the IPR water resource and the potential benefits (water rights) that this scenario would generate compared to an alternative scenario of effluent management.

To accomplish the treatment goals for IPR, upgrades to existing WRF facilities would need to increase system capacity and address treatment objectives including removal of biochemical oxygen demand, total suspended solids, nutrient removal, and pathogen reduction. Specifications for these upgrades and estimates for cost were provided in Stantec (2018). A recent technical memo updated the costs for the IPR scenario with a 2 mgd capacity with costs for WRRF upgrades, AWT, pump stations, transmission main, and wells for injection and monitoring (Farr West, 2019).

Section 4

Market Attractiveness Study of IPR

4.1 PURPOSE AND SCOPE

The purpose of this section is to assess environmental, social, and financial aspects that indicate the optimality of water reuse options for the Truckee Meadows region.

The remainder of this section is organized in following subsections:

- Cost-benefit approach
- Costs of IPR and Exporting
- Benefits of IPR and Exporting
- Net value of wastewater management strategy

4.2 COST-BENEFIT APPROACH

Cost-Benefit analysis is an analytical technique used to determine if a proposed project is part of an efficient water management policy within a region. A key component of this analysis is determining the net present value of possible investments, with the goal of identifying which option presents the greatest benefit to the study area within budgetary restrictions. Calculation of net present value does not encompass all notable impacts that a project may have, particularly on social and environmental dimensions. Changes to water infrastructure and allocations can have an array of impacts across socio-economic and environmental systems. Substantial costs may include land, project planning and design services, salaries and wages, construction materials, equipment, borrowing costs, losses of recreation/habitat. Many of these costs are non-financial, such as considerations like ease of management, or impacts to the environment. However, the most important consideration is often determining if a project is cost-efficient, with a focus on the financial tradeoffs between water management scenarios. Budgeting for water infrastructure projects is largely driven by the capital costs, or construction costs, which are often orders of magnitude larger than operation and maintenance costs. This study focuses on the tradeoffs between the capital costs to pursue either of the water management scenarios and the potential benefit (water rights) that could be generated.

Regional studies have identified the need to adopt new effluent management strategies. Previous studies have identified the potential for IPR to address this need and also produce a valuable water resource (Eco:Logic, 2010). To accomplish the treatment goals for IPR, upgrades to existing WRF facilities would need to increase system capacity and address treatment objectives including removal of biochemical oxygen demand, total suspended solids, nutrient removal, and pathogen reduction. Specifications for these upgrades and estimates for cost were provided in Stantec (2018).

Alternatively, these water resources could be exported to Long Valley Creek, which is outside the municipal area of Reno-Sparks. Discharge to Long Valley Creek would require upgrades to the existing WRF to reduce nutrient loads prior to discharge of reclaimed water. To meet these treatment goals for the export scenario, the research assumes that the same WRF upgrades would be needed to satisfy either the IPR or Export scenarios.

4.3 COSTS OF IPR AND EXPORTING WATER

This research focuses on the financial tradeoffs, but there are some important considerations that are not easily quantified in a cost-benefit analysis. Some non-financial costs are unlikely to be impacted by water management strategies. For example, this research is in response to planned changes in land use that will result in increased development and housing in an outlying neighborhood of the Reno-Sparks metropolitan area. Urban sprawl can encompass numerous costs that are derived from losses in ecosystem services as land is converted from natural habitat to housing. However, this study neglects such potential costs because it assumes that under any water management scenario, the planned development would be unchanged. Another important non-financial cost is the ease of managing water resources. This can include the presence of regulations to guide the water management scenario, political opposition or support for a scenario, and the need for an institution to coordinate with other utilities or additional regulations.

Financial costs such as construction materials, equipment, borrowing costs, and project planning and design services, are items that can be assessed based on their market rate. This assumes that the project will not impact the market prices for these cost categories; resulting in an estimate that the marginal cost of any of these items will follow a linear trend. Both the scenarios were designed to manage 2 mgd in reclaimed water, with system components illustrated in Figure 7.

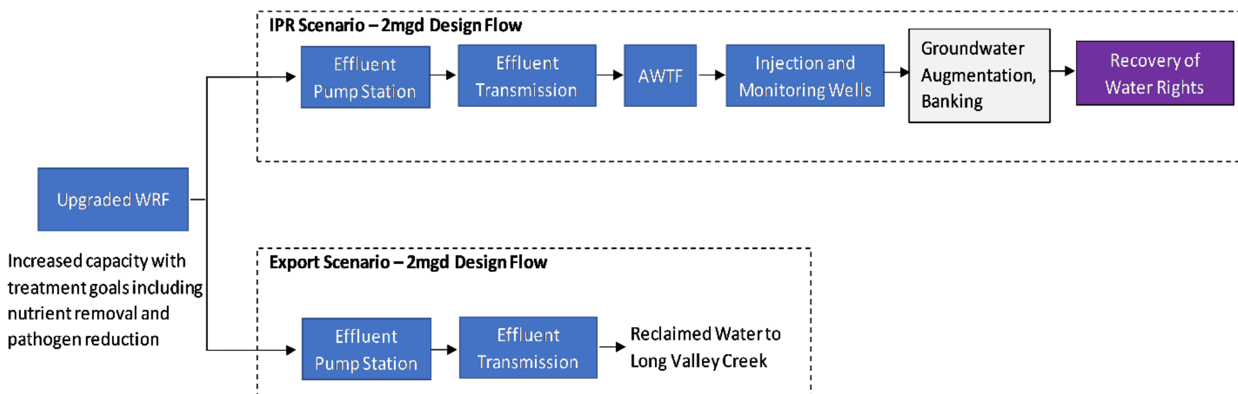


Figure 7. Overview of effluent management costs (blue) and benefits (purple) by scenario

Costs for the IPR scenario and upgrades to the WRF were based on the opinion of probable costs reported in Stantec (2018), and Farr West (2019). The capital costs associated with the Export scenario were updated from Eco:Logic (2010) based on an ENR CCI of 11013. The capital cost estimates for both scenarios are presented below in Table 4. Overall, the IPR scenario was expected to result in larger capital costs than exporting the water resources.

Table 4. Summary of capital cost estimates for effluent management scenarios

Capital cost parameters	Capital Cost	
	IPR Scenario	Export Scenario
WRF Upgrades[1]	$17,875,000	$17,875,000
Effluent Transmission Main to AWTF[2]	$15,984,000	
Effluent Pump Station to AWTF[2]	$2,588,000	
Advanced Water Treatment Facility[2]	$14,625,000	
Injection & Monitoring Wells[2]	$4,341,000	
Effluent Transmission Main to LVC[3]		$21,135,000
Effluent Pump Station to LVC[3]		$1,890,000
Total Capital Cost	**$55,400,000**	**$40,900,000**
Effluent Management Capital Cost (neglects WRF costs)	**$37,500,000**	**$23,000,000**

Notes:

1. From Stantec (2018), which estimates costs to upgrade WRF for larger flow with treatment objectives of BOD & TSS removal, partial nitrification-denitrification, and pathogen reduction. Although treatment objectives will differ between scenarios, costs are assumed to not be impacted. Cost includes 25% contingency.
2. From Farr West (2019), which updates Stantec (2018) costs based on ENR CCI of 11013 and adapts costs for a 2.0 mgd design flow. Note that the cost shown in the table above separates the costs for WRF upgrades and AWTF. Costs include 25% contingency and 25% engineering and inspection.
3. Costs for exporting reclaimed water to Long Valley Creek from Eco:Logic (2010) report. Costs include 25% contingency and 25% engineering and inspection, updated with ENR CCI of 11013.

Operation and maintenance (O&M) of water reclamation facilities (WRFs) and water treatment plants include energy, staff, chemical, maintenance, and waste management expenses. Capital improvement costs are not included in the internal costs. The annual costs incurred in the IPR scenario include replacement of media and UV lamps, maintenance, chemical costs, pumping, cooling, and power. The annual costs incurred in the Export scenario include replacement of UV lamps, pumping, cooling, and power. Total O&M costs for each scenario are summarized in Table 5. Despite the large costs to pump effluent to Long Valley Creek under the Export scenario, the IPR scenario was also expected to present larger O&M, largely due to power requirements associated with the proposed AWTF.

Next, the comparative cost of the IPR scenario based on costs averted by not pursuing the Export scenario. This approach identified the difference in costs for effluent management under each scenario, resulting in the IPR cost comparative (Table 5). This value was determined for capital costs and O&M costs from the difference between the IPR scenario cost and the Export scenario cost. This was used to determine the average cost of developing the IPR water rights based on the IPR cost comparative.

Table 5. Summary of O&M costs for effluent management scenarios

Total Treatment Cost	IPR Scenario[1]	Export Scenario[2]	IPR Cost Comparative[3]
Estimated Project Capital Cost	$37,500,000	$23,000,000	$14,500,000
Annual O&M Cost ($/year) [3]	$2,542,000	$596,000	$1,946,000

1. From Stantec (2018), scaled to 2 mgd flow.
2. Costs for exporting reclaimed water to Long Valley Creek from Eco:Logic (2010) report, updated with ENR CCI of 11013.
3. The difference in costs between the two scenarios.

4.4 POTENTIAL BENEFITS OF IPR AND EXPORTING

The proposed IPR scenario would produce additional water resources to the region, which are assumed to be 80% of the total 2 mgd injected into the aquifer, resulting in an estimated 1792 AF of water rights. Although available water supplies currently exceed total demand, the region is facing increasing water stress due to population growth. In the North Valleys area a recent forecast of water demand identified a need to identify additional water resources to support population growth (NNWPC, 2017). The IPR project could thus be used to supplement available water supplies for new housing developments that have been proposed.

A recent sale of water rights in the North Valleys was used as a reference point for water rights values in this region; this sale was from Vidler Water Company to a developer in the North Valleys at a rate of value of $35,000 per AF. This water right value is substantially larger than the rate charged by TMWA ($7,6000) but factors in additional cost considerations for water rights purchases in the North Valleys. The $35,000 per AF, subject to a 2% inflation rate, was thus taken as the potential value of developing water rights in the North Valleys, although it may be larger than the value that the rights would be sold at. The next section presents an assessment to identify if the discounted average cost to develop the water rights through IPR is greater or less than the comparable water rights recently sold in the region. The sale of water rights was assumed to occur at a constant rate over the last ten years of the project, with no sales occurring over the first 10 years while the aquifer is developed.

In a water scarce region, the largest benefit is likely to be the increase in water supply. However, non-financial costs and benefits were not included in the benefit analysis but can be important considerations for decision making. These benefits may include recreation, flood control, hydropower, navigation, water quality, and environmental service benefits if ecosystem restoration is pursued. Trade-offs of non-financial benefits are summarized in the final section.

4.5 NET PRESENT VALUE OF EFFLUENT MANAGEMENT STRATEGY

The net present value (NPV) of each effluent management strategy can be derived from the costs and benefits described previously and an assumed discount rate. In the Export scenario, all costs under consideration are incurred in year 0 of the project. In the IPR scenario capital costs are incurred in year 0; benefits from water rights sales begin in year 10 (t_i) and continue through year 20 (t_f). Equation 1 describes calculation of net present value for this scenario. Table 6 summarizes other assumptions used in the cost-benefit analysis.

Equation 1

$$NPV = P_{WR}\left[\frac{1-(1+i)^{-t_f}}{i}\right] - P_{WR}\left[\frac{1-(1+i)^{-t_i}}{i}\right] - P_{CC} - P_{O\&M}\left[\frac{1-(1+i)^{-t_f}}{i}\right]$$

Table 6. Assumptions for estimating net present value of projects

Assumption	Value
Discount rate (*i*)	3.0%
Project life (years) (t_f)	20
Project design flow	2 mgd

Equation 1 was first used to derive the break-even price for water rights; which was the cost per AF that could be charged to generate a neutral NPV with the time-preference for revenue taken into consideration. This break-even price was then compared to the potential benefit of water rights in the North Valleys, to determine if it was likely that the project would produce a net benefit for the region. Table 7 summarizes the price at which water rights would need to be sold to generate benefits approximately equal to the costs of pursuing IPR over effluent export based on NPV.

Table 7. Analysis of minimum benefits to generate a positive NPV

Assumption	Comparative IPR Costs/Benefits		
	Capital Cost	O&M Cost	WR Benefits
Break-even water rights value ($/AF)	-	-	$26,000
Comparative cost/benefit per year	$14,500,000	$1,946,000	$4,659,000
Total cost/benefit (discounted)	$14,500,000	$28,952,000	$44,165,000
NPV	**$710,000**		

To generate a small net benefit for the region, water rights developed through IPR would have to be valued at $26,000 per AF. The potential value of water rights in the study area was estimated to be as high as $35,000 per AF based on a recent sale. If water rights were sold at this rate, the NPV generated would be nearly $16M. Thus, IPR was estimated to generate a water resource with a local value that exceed the additional costs that would be incurred compared to the alternative effluent management scenario.

Section 5

Findings and Conclusions

5.1 POTENTIAL BENEFITS OF IPR IN THE LOCAL ECONOMY

In addition to the potential financial benefits that are expected to make IPR a net benefit to the region, IPR may also have several non-financial benefits over exporting the water. These may include:

- Increasing resilience and decreased water stress through a larger water supply
- Increasing protection of water quality
- Enhancing local control of water resources and water supply
- Reducing reliance on imported water resources

Additionally, the water resources produced through IPR are expected to generate additional benefits for the region when they are input into the economy. Section 2.5 described that water resources currently generate approximately $0.33 per AF water production ($1.01 per 1,000 gal). This indicator of the value of water resources in the local economy has increased by 55% since 2004.

Despite limited groundwater resources and capacity to discharge reclaimed water, the North Valleys region of Reno-Sparks is among the fastest growing in the region. The growing demand for water has also resulted in increased flows of reclaimed water from local WRF. Water reuse is already occurring in the study area, reducing demand for potable water resources by utilizing reclaimed water for uses like irrigation and construction. However, the volume of reclaimed water generated annually is expected to exceed local effluent management capacity within a 20-year planning period.

This research focused on two key aspects to evaluate the potential net benefits of potable reuse. The first was the economic productivity of water resources, which characterized how water resources are used in the economy of the Reno-Sparks metropolitan area. This provided an understanding of how increasing water resources through IPR may generate unmeasured benefits when the water is used as an input into the broader economy. Second, a cost-benefit analysis was used to evaluate if IPR was likely to generate a net benefit for the region.

5.2 WATER IN THE RENO-SPARKS ECONOMY

Economic sectors were grouped into three categories based on land-use characteristics to derive estimates for each sectors water demand intensity: professional and government; leisure and hospitality; trade, transportation and warehouse. The water demand intensity was then calculated from annual employment and water demand statistics, resulting in an estimate for the average the gallons of water demand per employee per day (GED) for each sector. Overall, the trade and transportation sector had the lowest water demand intensity (43 GED) followed by the office-based industries in the professional and government sector (91 GED). The average GED across all sectors was measured to decrease 23% over the study period of 2004 to 2017. This indicated increased water conservation across all sectors but driven by the office-based sectors (professional and government).

Non-residential water demand decreased most significantly from 2007 to 2010, which corresponds closely to the economic recession as illustrated by the decreased employment rates over the same period (refer to Figure 2). Non-residential water demand was responsive to drought restrictions. The total water production by the water authority was then used to evaluate trends in the economic productivity of water within the municipal area. Economic productivity of water resources is an indicator of the water use efficiency of the regional economy, calculated as the ratio between GDP and total annual water production. The overall economic productivity of water nearly doubled since 2004. Additionally, a drought period in 2015 resulted in a large increase in economic productivity of water. This indicated that water conservation during the drought was achieved without significant economic detriment. The increase in economic productivity was then measured to continue increasing after the drought, indicating that the conservation measures that were adopted during the drought had lasting effects.

5.3 COST-BENEFIT ASSESSMENT OF IPR

Several regional studies presented estimates for the costs of two alternative scenarios. Exporting reclaimed water was identified as a solution that would satisfy effluent management goals but would not bring any greater benefit to the region. IPR was identified as a strategy to satisfy both effluent management goals and generate regional benefits by increasing the local water supply. The increased water supply would have measurable benefits through the creation of water rights.

The IPR scenario was expected to result in larger capital and O&M costs compared to exporting the water resources. These costs were compared to determine the comparative cost of pursuing IPR, which was the additional investment that IPR would require beyond the costs of exporting (the lower-cost effluent management scenario). IPR was estimated to have capital costs $14.5M above exporting and O&M costs nearly $2M above exporting. These comparative costs were then used to evaluate if IPR would generate a net benefit for the region relative to exporting due to the benefits that could be generated by creating new water rights. The 2 mgd IPR system was assumed to produce 1792 AF of water rights. Additionally, the research assumed that these water rights would be sold at a constant rate over the final 10 years of the project life. To achieve a positive NPV on investment, the water rights would require a minimum value of $26,000 per AF sold. Recent sales of water rights in the North Valleys have been valued up to $35,000 per AF. Thus, the cost-benefit analysis identified that the water rights generated through IPR were likely to have values exceeding the additional costs of this effluent management strategy.

Additional benefits that were not measured are expected due to the value of the water resources in the economy as an input to human needs and products. Much of the regions water resources are also allocated to outdoor irrigation, producing potential environmental benefits such as recreation and urban wildlife habitat. Overall, the cost-benefit assessment demonstrated that IPR is likely to be an economically feasible solution for the water utilities in the region, producing greater net value for the region than the alternative effluent management strategy.

Section 6

References

Bureau of Labor Statistics. (2018). *Quarterly Census of Employment and Wages.* [Data file]. Retrieved from https://www.bls.gov/cew/

Eco:Logic. (2010). *The North Valleys Initiative: Advancing Solutions to Regional Water Issues*. Retrieved from Western Regional Water Commission website: http://documents.wrwc.us/files/Norrth%20Valleys%20Initiative%20-%20Eco%20Logic%202010.pdf

Gleick, P. H. (2003). Water use. Annual review of environment and resources, 28(1), 275-314.

NNWPC. (2017). *Comprehensive Regional Water Management Plan: 2016-2035*. Retrieved from Northern Nevada Water Planning Commission website: http://www.wrwc.us/files/_Draft%20Chapters/PDF%20Web%20Draft%20Version.pdf

NRC. (2012). *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*. Retrieved from http://awpw.assembly.ca.gov/sites/awpw.assembly.ca.gov/files/hearings/NAS%20water%20reuse%20article.pdf

National Resource Defense Council (NRDC) (2014). *Agricultural Water Conservation and Efficiency Potential in California*. NRDC. IB: 14-05-F.

Savenije, H. H. G., & van der Zaag, P. (2002). Water as an Economic Good and Demand Management Paradigms with Pitfalls. *Water International*, *27*(1), 98–104. https://doi.org/10.1080/02508060208686982

Stantec. (2018). *LVWRF Conceptual Study Life-Cycle Cost Memo.*

Farr West Engineering. (2019). *Technical Memorandum #4: Lemmon Valley-Stead Wastewater Facility Plan*

TMWA. (2016). *2016-2035 Water Resource Plan Volume II*. Retrieved from Truckee Meadows Water Authority website: http://tmwa.com/wp-content/uploads/docs/your_water/2035WRP/__2035_WRP_VolumeI_Abstract_Final.pdf

Report 2

A+ Water Rights and Reuse Permitting Process

The OneWater Nevada study is exploring water resource availability, quality, and other characteristics throughout the watershed, and targeting key basins that are focal points of residential, economic and ecosystem water demands for review of water security over the next 20 years. Through this Study, methods acceptable to the Nevada State Water engineer to create and account for a “new” A+ water right were evaluated. BOR funding was allocated for water rights analysis to support the generation of a potable water supply originating from reuse projects. This water rights analysis is intended to develop a blue print for the water rights application and permitting process relative to A+ reclaimed water.

The expected outcome is simple: make certain that A+ reclaimed water projects are creating water supplies that are well managed and water rights associated with these types of projects are well understood by regional utilities, Nevada State Engineer, stakeholders, and other regional water rights holders. A series of workshops and meetings were conducted in October 2018 with the Nevada State Engineer and regional agencies to create a blue print for the water rights application and permitting process for Category A+ reclaimed water. Experts from the Water Research Foundation helped facilitate this workshop.

The objectives of the workshop were as follows:

- Review current effluent management permitting processes and discuss water rights permitting requirements for groundwater augmentation of advanced purified water for indirect potable reuse.
- Define the water rights permitting pathway for groundwater augmentation and indirect potable reuse.
- Update attendees on water market analysis project (Report 1).

A final flowchart was created that all parties agreed upon. An informational powerpoint was also created to offer to the State of Nevada as a guide for any new A+ reclaimed water projects that may occur in the future. This work can be viewed as somewhat collaborative and may not require extensive use of water rights expert consultants.

1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

March 14, 2019

Tim Wilson, P.E.
State Engineer
Nevada Division of Water Resources
901 South Stewart Street, Suite 2002
Carson City, NV 89701-2811

Subject: Effluent Management Strategies and Procedures for Issuance of Will Serve Letters against Secondary Permits to Appropriate Treated Effluent

Dear Tim:

In December 2016, the State of Nevada modified NAC445A to create Reuse Category A+ reclaimed water (A+), which creates the pathway for indirect potable reuse through groundwater augmentation. This letter is intended to memorialize the procedures outlined in an October 18, *2018 Indirect Potable Reuse Water Rights and Permitting Workshop*, which was held to brief water resource agencies, including the Nevada Division of Water Resources (NDWR) staff, in effluent management strategies and procedures to issue potable water will serve letters against secondary permits to appropriate treated effluent.

The most significant procedures may be summarized as:

1) Potable water passing through a water service point of connection or water meter is considered the end of the potable / M & I water supply cycle; raw wastewater exiting a residential or other development is the beginning of the effluent supply cycle.

2) Treated effluent appropriated in accordance with NRS 533.440(3) is a distinct and separate water resource than the water resources and water rights associated with the municipal water supply cycle.

3) Treated effluent appropriated in accordance with NRS 533.440(3) is not (administratively) a derivative or a remnant or a byproduct of the water rights which supported the M&I water supply cycle.

4) NDWR provides deference to the owner / operator / the NDEP discharge permit holder of the reclamation facility in the appropriation process. (See NRS 533.440 and State Engineer Ruling numbers 4561, 4569 & 4587).

5) Typical primary storage permit approved in accordance with NRS 533.440(3) will have the following components:
   a) The proposed source of appropriation is "Effluent."
   b) Manner of Use (MOU) is "Storage."

1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

c) Point of Diversion (POD) is usually the point of discharge of treated effluent from the water reclamation facility.
d) Place of Use (POU) is to be determined under the secondary permit.
e) Proof of Completion (POC) is required under the primary storage permit.
f) Proof of Beneficial Use (PBU) is required under the secondary permit.
g) A water rights map depicting the POD and storage site is required.

6) Workshop participants agreed on key implementation considerations:
   a) The storage reservoir may be an above ground reservoir (Reuse Category A and A+ reclaimed water) ***or*** aquifer storage (Reuse Category A+ only reclaimed water).
   b) For aquifer storage, A+ regulations are applicable, and aquifer storage and recovery (ASR) permitting through NDWR will be required.
   c) Description and size of the storage facility together with the dam permit (J-xxx) is required for above ground storage reservoirs.
   d) For ASR, the description of the recharge area, including the hydrographic basin, location of the recharge wells, and the applicable ASR permitting is required.
   e) ASR permitting requires the applicant to show that it has the technical and financial capability to construct and operate the project and the project is hydrologically feasible. The feasibility is demonstrated by a rigorous hydrogeological report.

7) Typical Secondary permits under NRS 533.440(3) will have the following components:
   a) The proposed source of appropriation remains as "Treated Effluent."
   b) MOU may include, but are not limited to, Irrigation, Wildlife/Instream Flow, Recreation, Recreation (Golf Course Irrigation), Construction (dust control), Industrial, Groundwater Augmentation in support of Environmental ***or*** Municipal.
   c) POD may be the discharge point of the above ground storage reservoir, discharge point of the water reclamation facility, ***or*** the ASR recovery well.
   d) POU is the legal description of the places the treated effluent will be placed to beneficial use, including the established municipal water service area of a water purveyor.
   e) The NDEP discharge permit shall be considered in the designation of MOU.
   f) A POU map depicting the effluent reuse site is required.

8) Beneficial use under the secondary permit may include the following:
   a) The municipal water supply MOU will be pursuant to an aquifer storage alternative in accordance with both ASR and the applicable A or A+ treatment regulations.
   b) The POD for traditional reclaimed water (i.e. purple pipe) systems will be the discharge point of the storage reservoir ***or*** discharge point of the water

1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

reclamation facility. Operational parameters may allow the treated effluent to flow directly into the reuse distribution system and bypass the storage reservoir.

c) For the Municipal Water Supply alternative the POD will consist of the Recovery wells of the ASR program and in accordance with the ASR and applicable A or A+ regulations and permitting parameters.
d) It's envisioned the injection well(s) and recovery well(s) will likely be some distance apart.
e) The POU may consist of the established municipal water service area of a water purveyor.
f) The existing Municipal service area maps on file at NDWR will satisfy the POU map requirement.

9) Regardless of the MOU, if return flow is required, said requirements have to be met to the satisfaction of the Nevada State Engineer and the Federal Water Master as a condition of the implementation of the reuse program.

10) Reuse pursuant to NDEP Reuse Category A+ Treatment Regulations will be subject to:
  a) The NDEP A+ regulations which are new and there are few, if any, past precedents in implementation projects pursuant to these regulations.
  b) There are two alternative methods of category A+ reclaimed water implementation envisioned:
    1) ***Spreading Basins*** may be used to serve a dual purpose:
      a) treatment of category A reclaimed water to achieve A+ classification. and
      b) as means of recharge of the aquifer. The treated resource stored in the aquifer may then be extracted through ASR recovery wells.

    2) ***Direct Injection***:
      a) pursuant to both A+ and ASR regulations with the intent to extract from the ASR recovery wells in the same manner as a municipal potable water supply production well, and
      b) to create a barrier against contaminated groundwater intrusion into municipal water supply well fields.

11) Workshop participants reached consensus on the following national and regional water sector considerations:
  a) Indirect Potable Reuse or IPR is more often being implemented as a municipal water supply alternative.
  b) In Nevada, IPR requires treatment of effluent to A+ classification standards prior to direct injection, or use of a spreading basins to both further treat and polish the A class effluent to A+ quality.

WASHOE COUNTY
COMMUNITY SERVICES DEPARTMENT
1001 EAST 9TH STREET
RENO, NEVADA 89512
PHONE (775) 328.3600
FAX (775) 328.3699

c) The recharged water under both options (spreading basins and direct injection) will be stored in an underground aquifer, and may be recovered for potable municipal water supply purposes from ASR recovery wells.

d) It's envisioned the injection wells and recovery wells will be some distance apart to provide travel time, as may be required. This IPR alternative will be implemented pursuant to A+ and ASR regulations. Implementation of IPR projects within Nevada will include rigorous treatment and water quality monitoring of injection water, a comprehensive hydrogeological report of the host aquifer including a monitoring program for water quality post injection, water level gradients, transmissivity, and travel times from injection points to recovery points. Upon successful implementation, the recovered water supply may be integrated into existing potable water supply infrastructure.

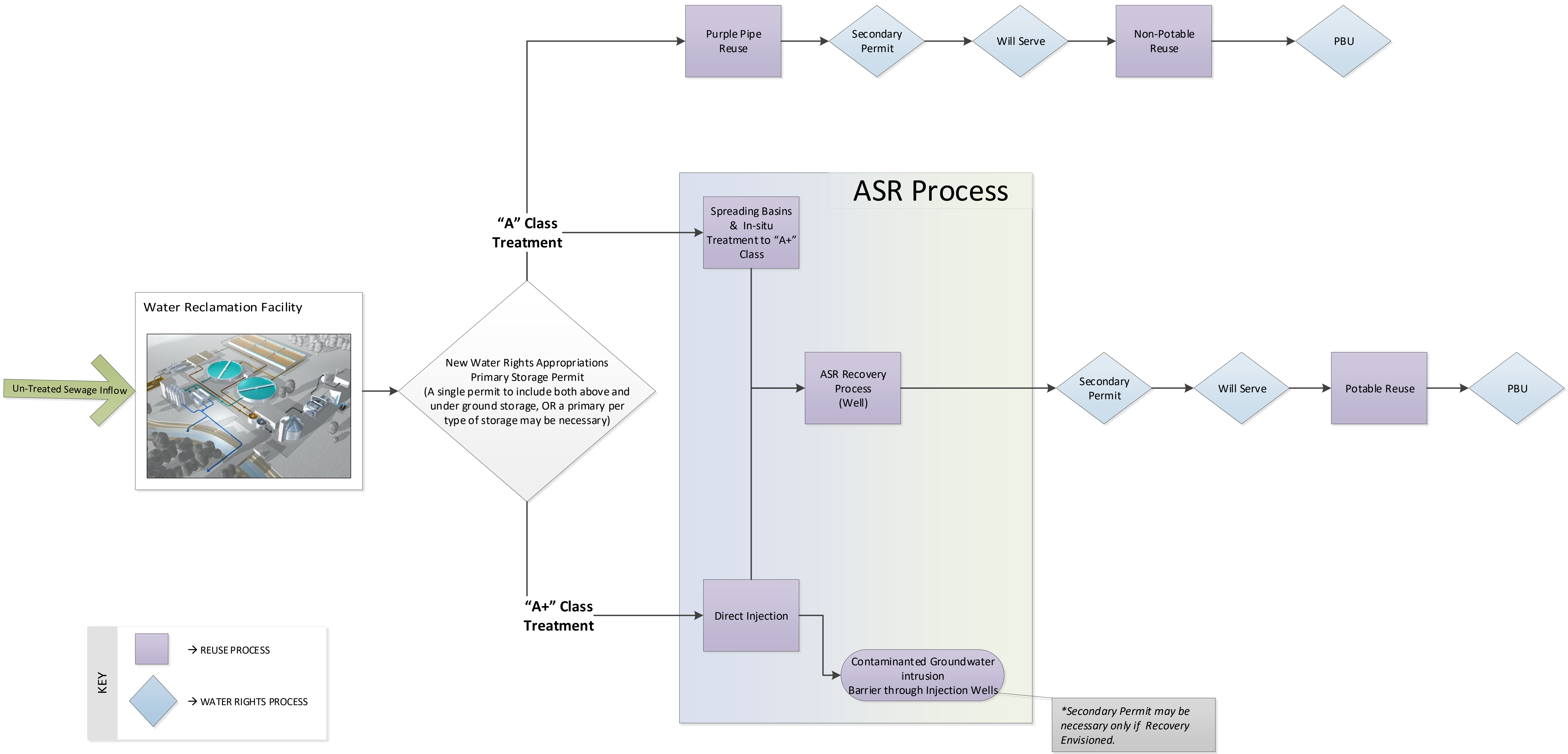
12) Will serves in a traditional manner may be issued against secondary permits associated with this IPR alternative.

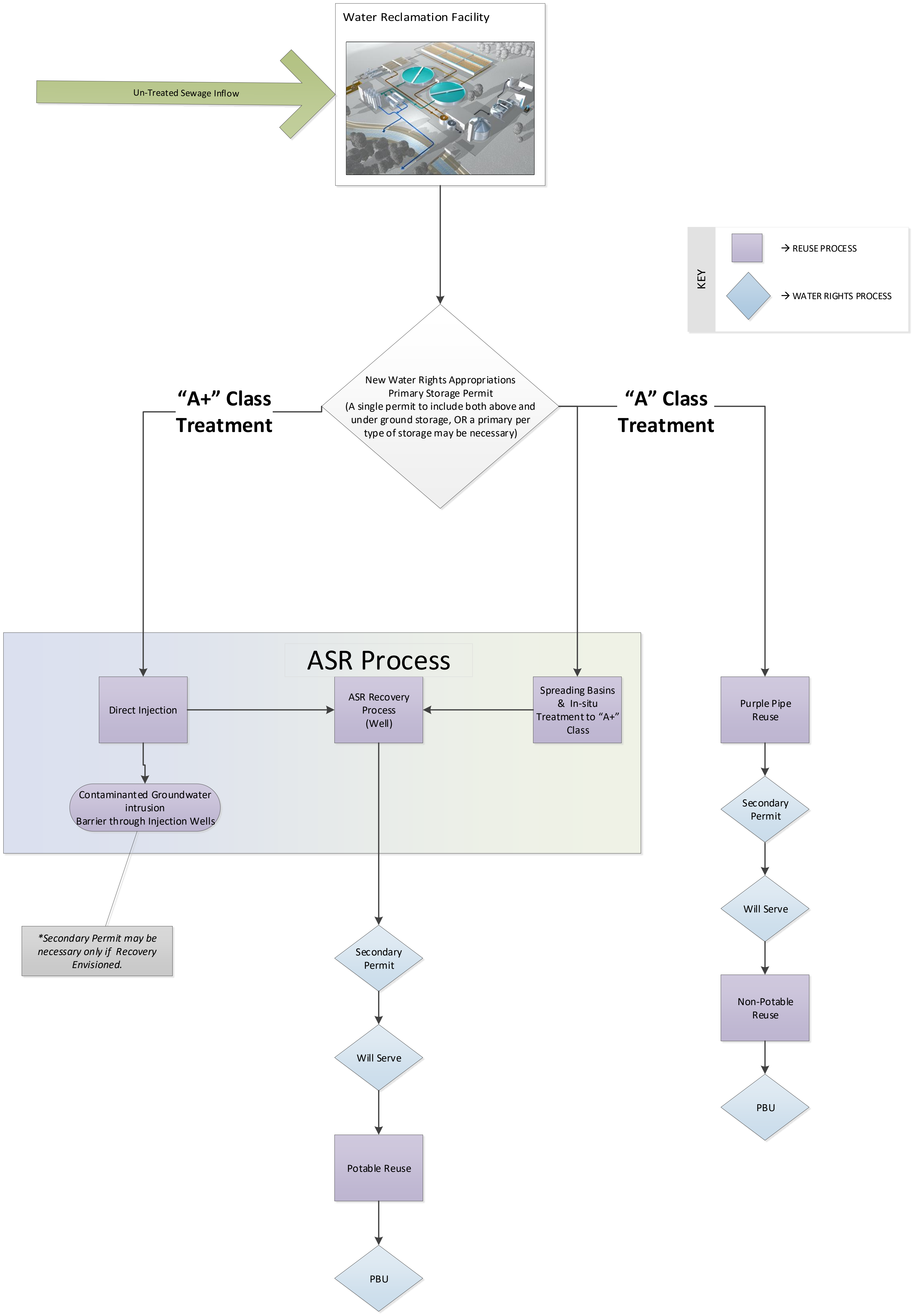
The attached flow chart is a generalized diagram of the protocol and procedures above. Please do not hesitate to contact me at 954-4647 with any questions on this matter.

Sincerely,

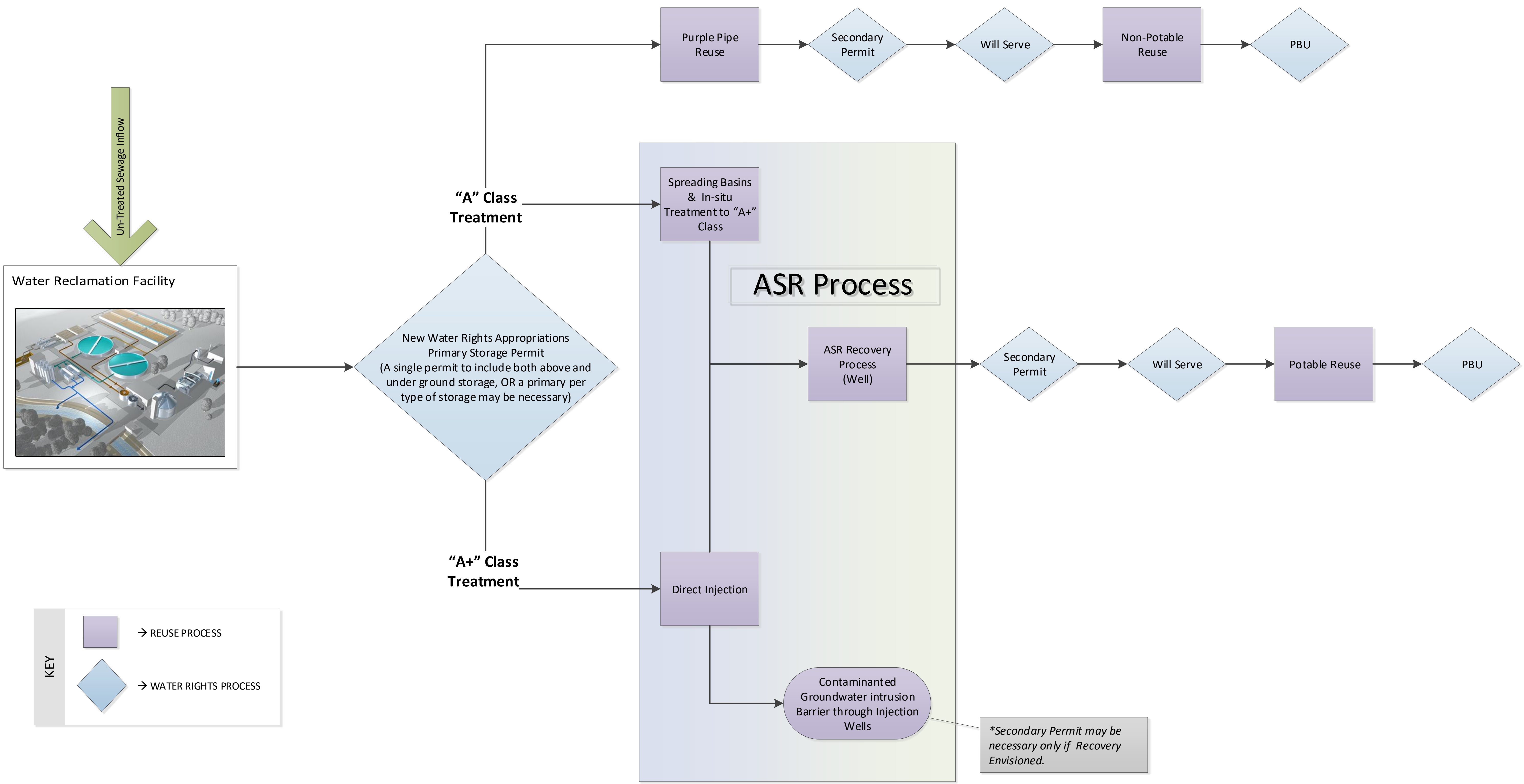
Vahid Behmaram
Water Management Planner Coordinator

cc. Adam Sullivan, P.E., Deputy Administrator, SEO
Jon Benedict, Hydrogeologist, SEO
Lydia Peri P.E, Washoe County CSD
Rick Warner, P.E., Warner and Associates LLC
David Solaro, P.E., Assistant Washoe County Manager
Dwayne Smith, P.E., Engineering and Capital Projects Director
John Enloe, P.E., TMWA
John Zimmerman, TMWA
John Martini, P.E., City of Sparks
Kerri Lanza, P.E.. City of Reno
John Flansberg, P.E., City of Reno


Purple Pipe Reuse
Secondary Permit
Will Serve
Non-Potable Reuse
PBU
ASR Process
"A" Class Treatment
Spreading Basins & In-situ Treatment to "A+" Class
Water Reclamation Facility
Un-Treated Sewage Inflow
New Water Rights Appropriations Primary Storage Permit (A single permit to include both above and under ground storage, OR a primary per type of storage may be necessary)
ASR Recovery Process (Well)
Secondary Permit
Will Serve
Potable Reuse
PBU
"A+" Class Treatment
Direct Injection
Contaminanted Groundwater intrusion Barrier through Injection Wells
*Secondary Permit may be necessary only if Recovery Envisioned.
KEY
→ REUSE PROCESS
→ WATER RIGHTS PROCESS



Water Reclamation Facility
Un-Treated Sewage Inflow
KEY
→ REUSE PROCESS
→ WATER RIGHTS PROCESS
New Water Rights Appropriations
Primary Storage Permit
(A single permit to include both above and under ground storage, OR a primary per type of storage may be necessary)
“A+” Class Treatment
“A” Class Treatment
ASR Process
Direct Injection
ASR Recovery Process (Well)
Spreading Basins & In-situ Treatment to “A+” Class
Contaminanted Groundwater intrusion Barrier through Injection Wells
*Secondary Permit may be necessary only if Recovery Envisioned.
Secondary Permit
Will Serve
Potable Reuse
PBU
Purple Pipe Reuse
Secondary Permit
Will Serve
Non-Potable Reuse
PBU



Un-Treated Sewage Inflow
Water Reclamation Facility
New Water Rights Appropriations Primary Storage Permit (A single permit to include both above and under ground storage, OR a primary per type of storage may be necessary)
"A" Class Treatment
"A+" Class Treatment
Purple Pipe Reuse
Secondary Permit
Will Serve
Non-Potable Reuse
PBU
ASR Process
Spreading Basins & In-situ Treatment to "A+" Class
ASR Recovery Process (Well)
Secondary Permit
Will Serve
Potable Reuse
PBU
Direct Injection
Contaminanted Groundwater intrusion Barrier through Injection Wells
*Secondary Permit may be necessary only if Recovery Envisioned.
KEY
→ REUSE PROCESS
→ WATER RIGHTS PROCESS

OneWater Nevada
Our Sustainable Water Future

An Overview of the Reuse Permitting Process

Vahid Behmaram, Water Management Planner Coordinator (Water Rights Manager)
Washoe County Community Services Department

October 23, 2018

University of Nevada, Reno · City of Reno · Washoe County, Nevada 1861 · Truckee Meadows Water Authority, Quality. Delivered. · Western Regional Water Commission / Northern Nevada Water Planning Commission · Truckee Meadows Water Reclamation Facility · City of Sparks

M&I Water Supply Sources

Surface Water

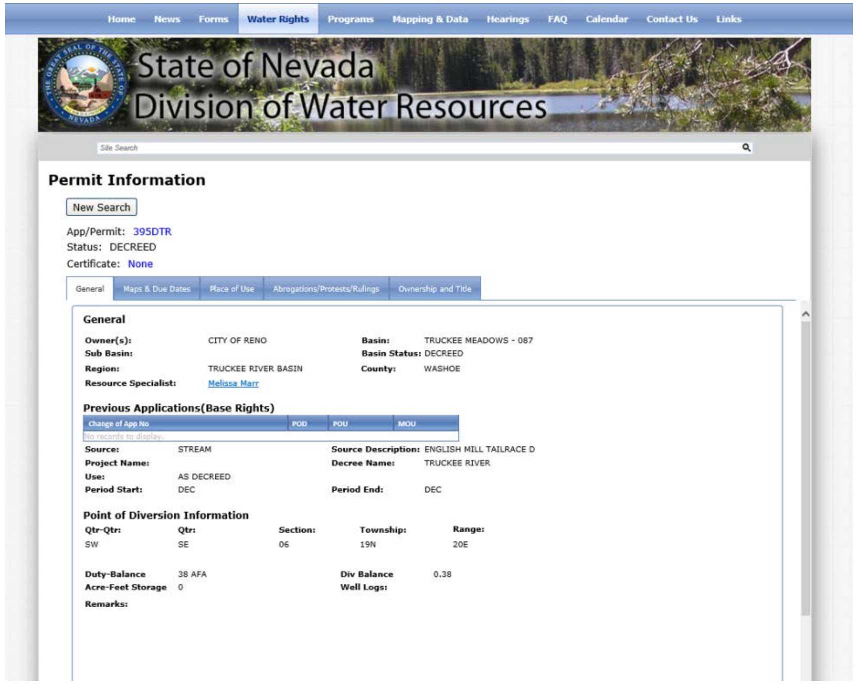
Truckee River at Lake Tahoe

Ground Water

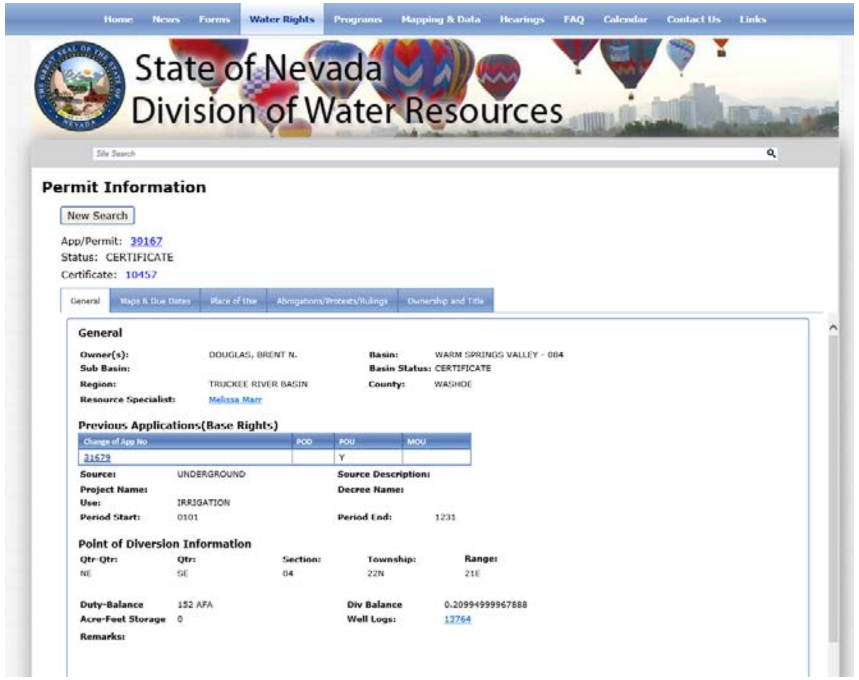
Municipal Water Production Well

- Court Decrees and State of Nevada Appropriations create an annual entitlement to a volume of water, i.e. “Water Right”

  - **Decreed Truckee River Water Right**

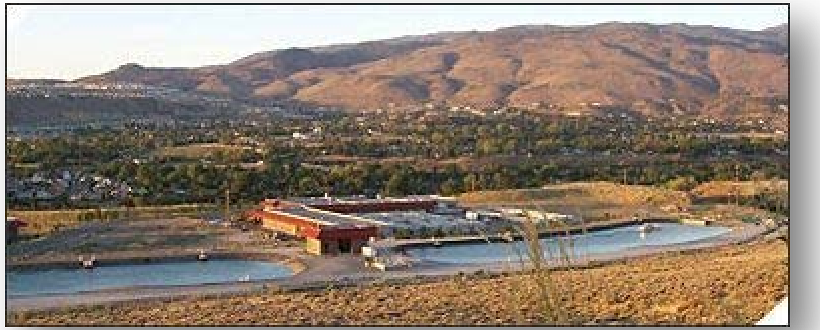


- **State of Nevada Groundwater Appropriation Water Right**



- Storage and diversion infrastructure are used to capture water supply sources for treatment and delivery process

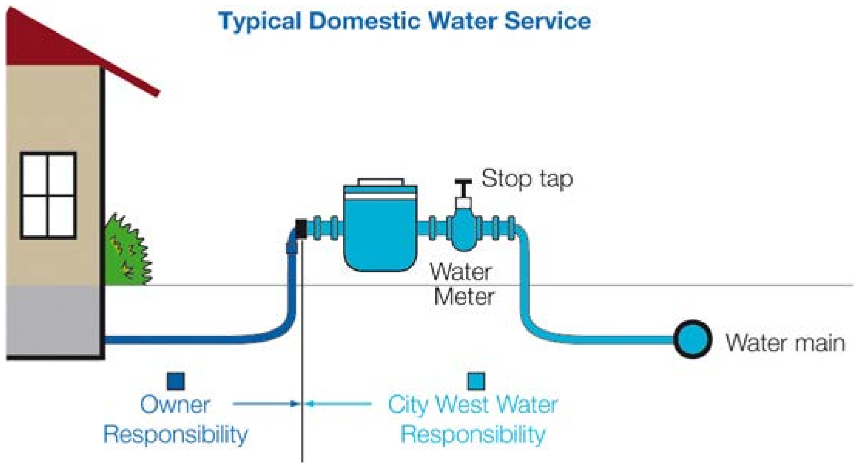
- **Chalk Bluff Treatment Facility**



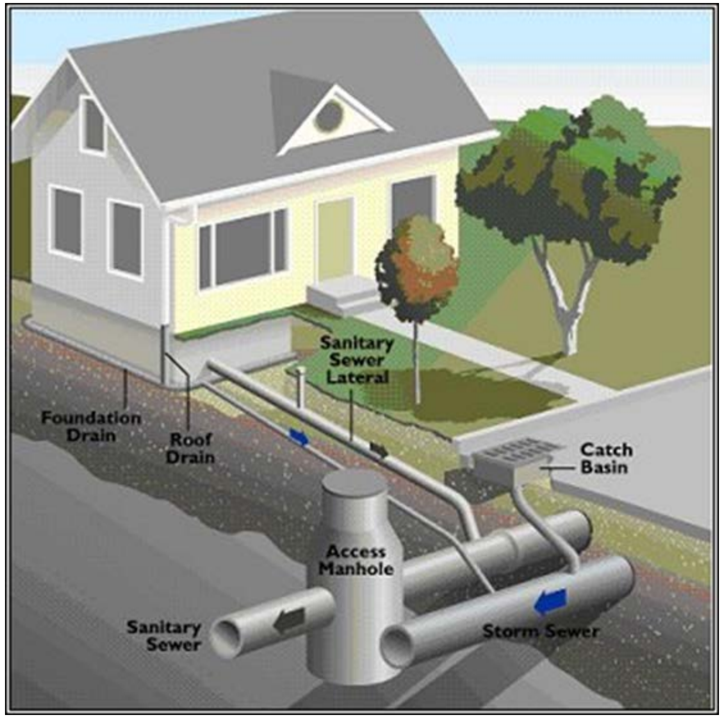
- **Groundwater Production Well**

Transition

- End of potable / M & I water Supply Cycle



- Beginning of Effluent Supply Cycle



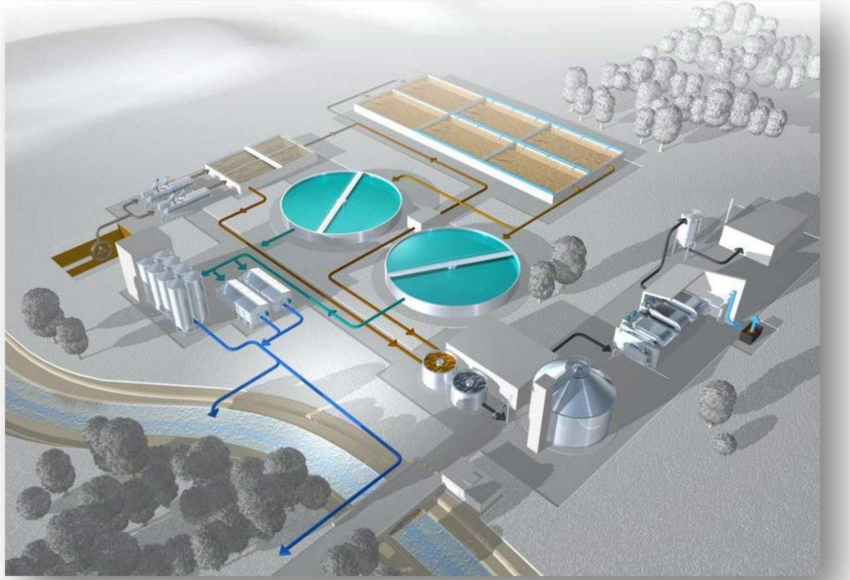
A New Source of Water

- Treated effluent appropriated in accordance with NRS is a distinct and separate water resource than the water resources and water rights associated with the water supply cycle.

- Treated effluent appropriated in accordance with NRS is not (***administratively***) a derivative or a remnant or a byproduct of the water rights which supported the M&I water supply cycle.

- NDEP regulations are applicable in all aspects of effluent management.

- Untreated Sewage inflow to a reclamation facility is treated and the discharge from the facility is a new water resource subject to appropriation process per NRS 533.440.3.
- State of Nevada DWR provides deference to the owner / operator / the NDEP discharge permit holder of the reclamation facility in the appropriation process.



Statutory Effluent Appropriate Process

NRS 533.440 States:

RESERVOIRS

- **NRS 533.440 Permits: Primary and secondary; application; issuance of certificates.**
- 1. All applications for reservoir permits shall be subject to the provisions of NRS 533.324 to 533.435, inclusive, except those sections wherein proof of beneficial use is required to be filed. The person or persons proposing to apply to a beneficial use the water stored in any such reservoir shall file an application for a permit, to be known herein as the secondary permit, in compliance with the provisions of NRS 533.324 to 533.435, inclusive, except that no notice of such application shall be published.
- 2. The application shall refer to the reservoir for a supply of water and shall show by documentary evidence that an agreement has been entered into with the owner of the reservoir for a permanent and sufficient interest in such reservoir to impound enough water for the purpose set forth in the application.
- 3. *Effluent discharged from the point of the final treatment from within a sewage collection and treatment system shall be considered water as referred to in this chapter*, and shall be subject to appropriation for beneficial use under the reservoir-secondary permit procedure described in this section. Nothing in this section shall preclude appropriation in accordance with and subject to the provisions of NRS 533.324 to 533.435, inclusive.
- 4. When beneficial use has been completed and perfected under the secondary permit, and after the holder thereof shall have made proofs of the commencement and completion of his or her work, and of the application of water to beneficial use, as in the case of other permits, as provided in this chapter, a final certificate of appropriation shall issue as other certificates are issued, except that the certificate shall refer to both the works described in the secondary permit and the reservoir described in the primary permit.
- [76:140:1913; 1919 RL p. 3245; NCL § 7962] — (NRS A 1971, 1060)

- (underline & italic font added by W. Co. for emphasis only)

Typical Effluent Appropriation Permit

- Primary Storage Permit

State of Nevada
Division of Water Resources

Site Search

Permit Information

New Search

App/Permit: 55534
Status: PERMIT
Certificate: None

General | Maps & Due Dates | Place of Use | Abrogations/Protests/Rulings | Ownership and Title

General

Owner(s):	WASHOE COUNTY	**Basin:**	TRUCKEE MEADOWS - 087
Sub Basin:		**Basin Status:**	PERMIT
Region:	TRUCKEE RIVER BASIN	**County:**	WASHOE
Resource Specialist:	Melissa Marr		

Previous Applications(Base Rights)

Change of App No	POD	POU	MOU
No records to display.			

Source:	EFFLUENT	**Source Description:**	S. TRUCKEE MEADOWS PLNT
Project Name:		**Decree Name:**	
Use:	STORAGE		
Period Start:	0101	**Period End:**	1231

Point of Diversion Information

Qtr-Qtr:	Qtr:	Section:	Township:	Range:
SE	NW	04	18N	20E

Duty-Balance	3100 AFA	**Div Balance**	7.19199993087219
Acre-Feet Storage	0	**Well Logs:**	

Remarks:

Typical Effluent Appropriation Permit

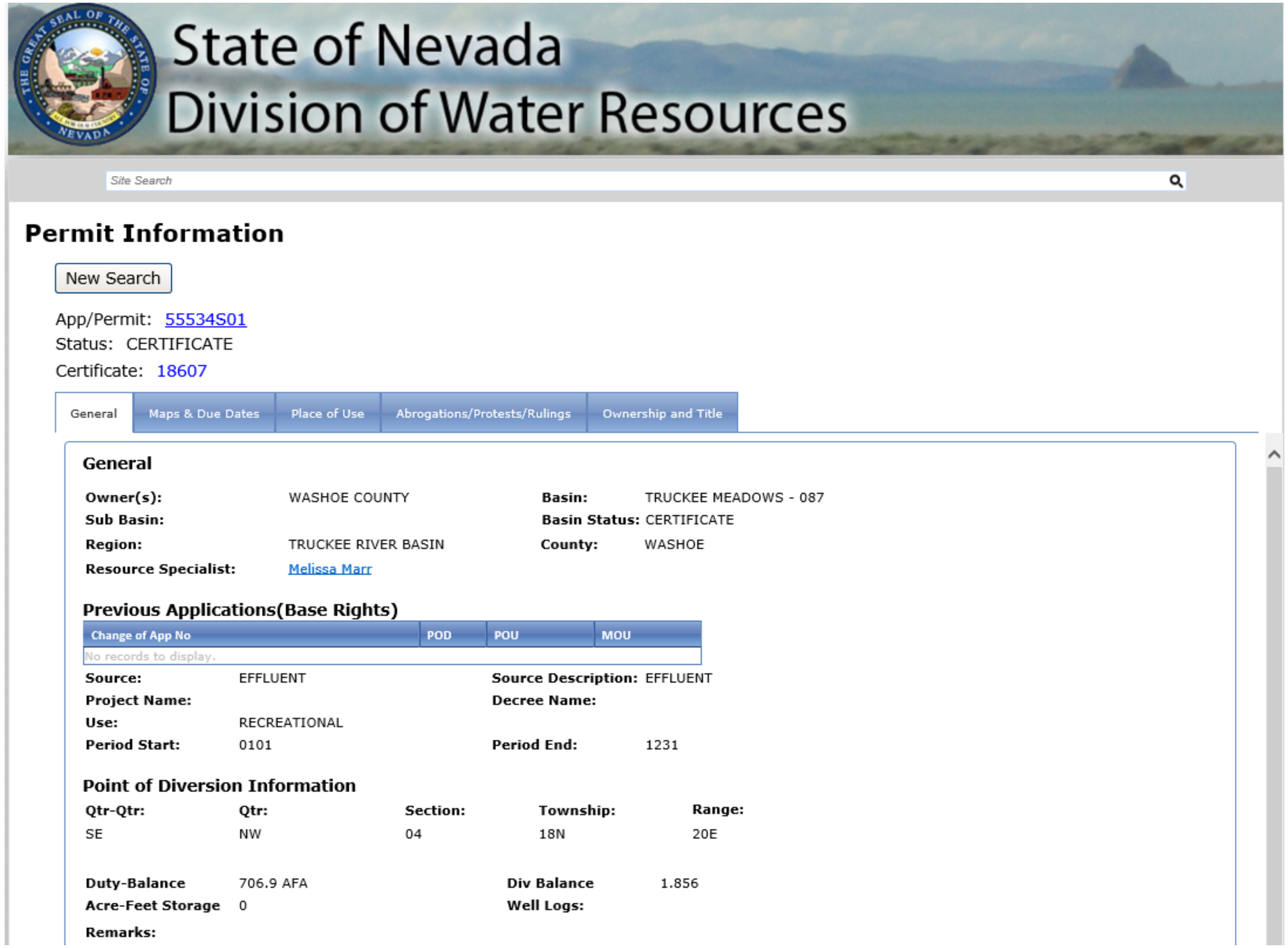
- **Primary Storage Permit** necessary components:
- The proposed source of appropriation is “Effluent”.
- Manner of Use (MOU) is “Storage”.
- Point of Diversion (POD) is usually the point of discharge of treated effluent from the water reclamation facility.
- Place of Use (POU) is determined under the secondary permit.
- Proof of Completion (POC) is required under the primary storage permit.
- Proof of Beneficial Use (PBU) is required under the secondary permit.
- A water rights map depicting the POD and the Storage site is required.

Primary Storage Permit

- The storage reservoir may be above ground reservoir OR aquifer storage (A+ only)
- For aquifer storage, A+ Regulations are always applicable, ASR permitting will most likely be required.
- Description and size of the storage facility together with the Dam Permit # (J-xxx) is required for above ground storage reservoirs.
- For A+ (treated water) aquifer storage and recovery the description of the Recharge area, including the hydrographic basin, location of the recharge wells, and the applicable ASR permitting is required.
- ASR permitting includes a rigorous Hydrogeological report.
- A primary Storage permit together with a secondary permit for “Environmental” or “Ground Water Augmentation” manner of use (MOU) in accordance with the A+ regulations may be required to create an aquifer recharge program for the sole purpose of creating a contaminated ground water intrusion barrier. The stored water in this manner may or may not never be extracted. ASR permitting will be required for all aquifer recharge projects.

Typical Effluent Appropriation Permit

- Secondary Permit designating beneficial use



State of Nevada
Division of Water Resources

Site Search

Permit Information

New Search

App/Permit: 55534S01
Status: CERTIFICATE
Certificate: 18607

General | Maps & Due Dates | Place of Use | Abrogations/Protests/Rulings | Ownership and Title

General

Owner(s):	WASHOE COUNTY	**Basin:**	TRUCKEE MEADOWS - 087
Sub Basin:		**Basin Status:**	CERTIFICATE
Region:	TRUCKEE RIVER BASIN	**County:**	WASHOE
Resource Specialist:	Melissa Marr		

Previous Applications(Base Rights)

Change of App No	POD	POU	MOU
No records to display.			

Source:	EFFLUENT	**Source Description:**	EFFLUENT
Project Name:		**Decree Name:**	
Use:	RECREATIONAL		
Period Start:	0101	**Period End:**	1231

Point of Diversion Information

Qtr-Qtr:	Qtr:	Section:	Township:	Range:
SE	NW	04	18N	20E

Duty-Balance	706.9 AFA	**Div Balance**	1.856
Acre-Feet Storage	0	**Well Logs:**	

Remarks:

Typical Effluent Appropriation Permit

- **<u>Secondary Permit designating beneficial use</u>** necessary components:
- The proposed source of appropriation remains as “Effluent”.
- MOU may be Irrigation, Golf Course Irrigation, Recreation, Construction (dust control), Industrial, Ground Water Augmentation, Environmental OR Municipal Water Supply.
- POD may be the discharge point of the above ground storage reservoir OR discharge point of the water reclamation facility OR the ASR recovery well.
- POU is the legal description of the places the treated effluent will be placed to beneficial use OR the established municipal water service area of a water purveyor.
- The NDEP discharge permit shall be considered in the designation of MOU and POU.
- A POU map depicting the effluent reuse site is required.

Secondary Beneficial Use Permit

- The Municipal Water Supply Manner of Use will be pursuant to an aquifer storage alternative and in accordance with both ASR & the A+ treatment regulations.
- The POD for traditional purple pipe systems will be the discharge point of the storage reservoir OR discharge point of the water reclamation facility. Operational parameters may allow the treated effluent to flow directly into reuse distribution system and bypass the storage reservoir and pumping costs.
- For the Municipal Water Supply alternative the POD will consist of the Recovery wells of the ASR program and in accordance with the ASR and A+ regulations and permitting parameters. We envision the injection well(s) and recovery well(s) to be some distance apart.
- The POU may consist of the established municipal water service area of a water purveyor. The existing Municipal service area maps will satisfy the POU map requirement.
- The POU for contaminated ground water intrusion barrier may be areas described under the associated ASR permit for this alternative.

Effluent Reuse Alternatives

1. Return Flow Discussion.
2. Traditional "Purple Pipe" Reuse system.
3. Las Vegas Valley Model.
4. Reuse pursuant to A+ treatment regulations.

Evaporation basins in the traditional sense are NOT treated as a reuse alternative in this presentation.

1. Return Flow Discussion

- Return Flow (RF) is the concept that recognizes the consumptive use nature of a water right. If a water right is deemed to be a fully consumptive appropriation of a water source of supply, then RF is a moot issue.
- This presentation will not attempt to present all scenarios on when and how and for which sources of water supply Return Flow is required.
- This presentation acknowledges that in certain cases RF is required and assumes that said requirements have been met to the satisfaction of the Nevada State Engineer and the Federal Water Master as a condition of the implementation of the reuse program.

2. Traditional “Purple Pipe” Reuse system

- Subject to the NDEP Discharge permit conditions, and the Primary / Secondary permit conditions, Effluent resources appropriated under the Primary Storage and Secondary Use scheme is available to meet certain water demands.
- Traditionally these reuse programs apply treated effluent to non-potable applications such landscape irrigation, Golf Course or School turf Irrigation, Dust Control and Construction water supply, Industrial uses, etc.
- Most land applications in this alternative (in our region) are seasonal in nature, which limit year around reuse.

3. Las Vegas Valley Reuse Model

Colorado River apportionment

In 1922, seven western states negotiated the Colorado River Compact, which divided the states into two basins: Upper Basin and Lower Basin. The Upper Basin includes Colorado, New Mexico, Utah and Wyoming. The Lower Basin includes Arizona, California and Nevada.

A total of 16.5 million acre feet per year (MAFY) are apportioned as follows:

Upper Basin allocation	Million acre-feet per year (MAFY)
Colorado	3.9 MAFY
Utah	1.7 MAFY
Wyoming	1 MAFY
New Mexico	0.85 MAFY

Lower Basin allocation	Million acre-feet per year (MAFY)
Arizona	2.85 MAFY
California	4.4 MAFY
Nevada	0.3 MAFY

Additional allocations	Million acre-feet per year (MAFY)
Mexico	1.5 MAFY

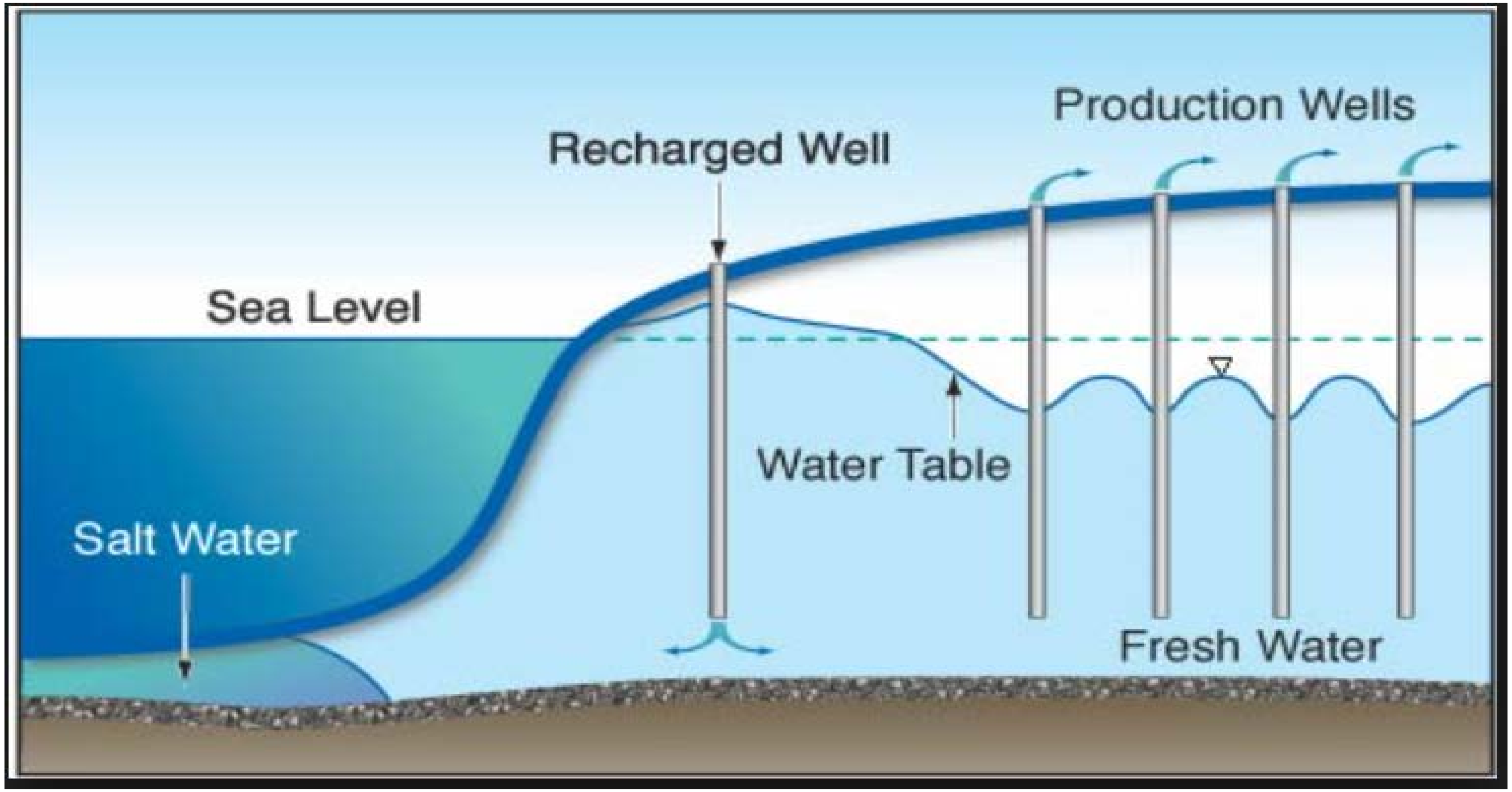
3. Las Vegas Valley Reuse Model

- Nevada’s share under the Colorado River Compact is a fully consumptive allocation.
- Nevada is allowed a net extraction of 300,000 acre-feet per year from Lake Mead.
- Some portion of the Treated Effluent generated in the Las Vegas Valley Metropolitan area is returned to Lake Mead via the Las Vegas Valley Wash subject to all applicable environmental regulations. The quantity of returned water is available for recapture for municipal water supply which is in addition to the 300,000 acre-feet allocation. The net extraction shall not exceed the amount allocated to the State of Nevada.
- This is an abbreviated synopsis of a complex reuse program.

4. Reuse Pursuant to A+ Treatment Regulations

- The NDEP A+ regulations are new and there are few, if any, past precedents in implementation projects pursuant to these regulations.
- There are 2 alternative methods of reuse envisioned:
- 1) Spreading Basins may be used to serve a dual purpose: a) treatment of A classification effluent to achieve A+ classification and b) as means of recharge of the aquifer. The treated resource stored in the aquifer may then be extracted through ASR recovery well(s).
- 2) Direct Injection: a) pursuant to both A+ and ASR regulations with the intent to extract from the ASR recovery well(s) in the same manner as a municipal potable water supply production well and b) to create a "barrier" against contaminated ground water intrusion into municipal water supply well fields.

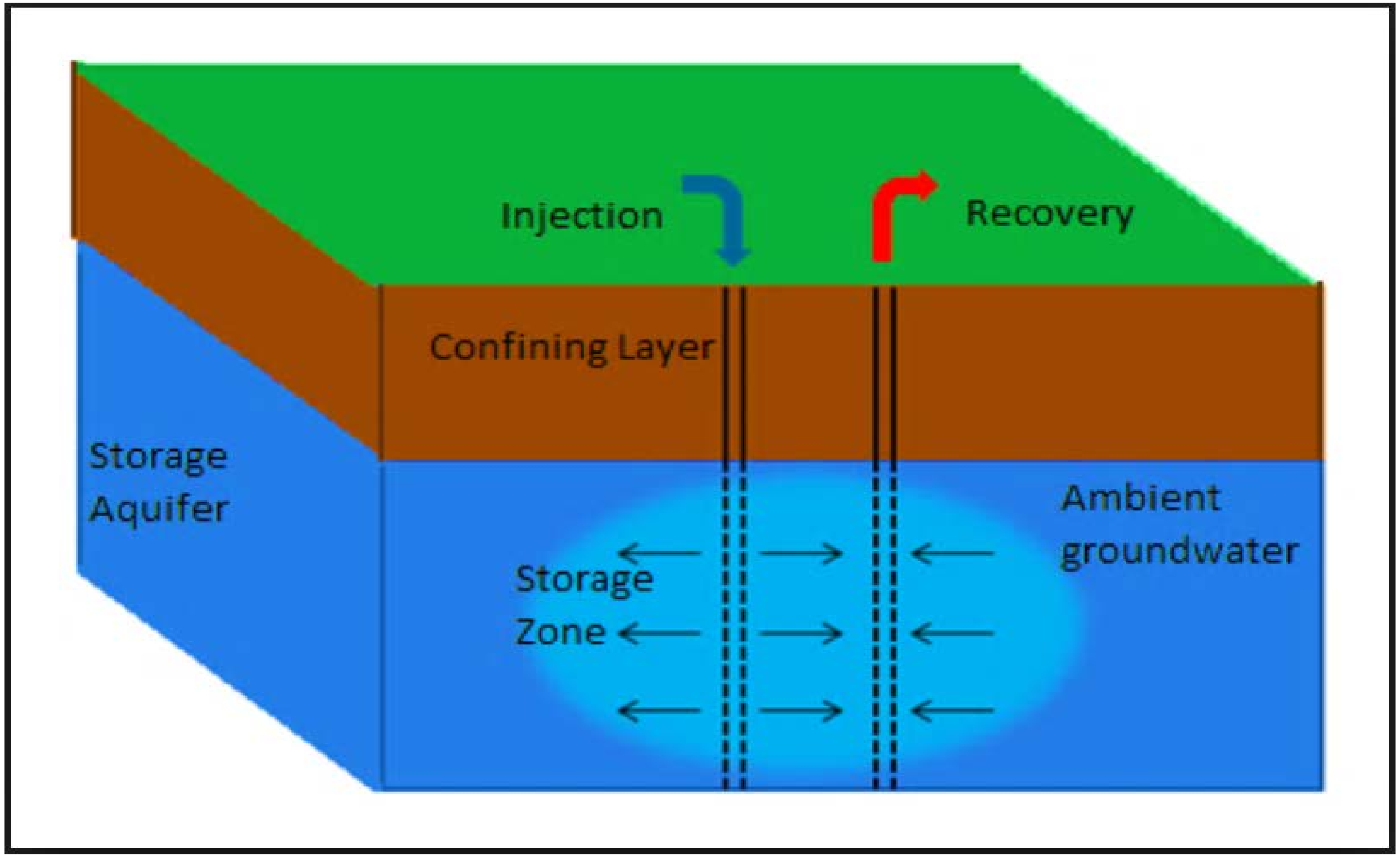
Contaminated Ground Water Intrusion Barrier



Contaminated Ground Water Intrusion Barrier

- This reuse alternative envisions injection of A+ treated water into strategically located injection wells in accordance with A+ regulations, to create a “Barrier” to prevent migration and intrusion of contaminated ground water into a well field. The contamination is ,most often due to Salt Water Intrusion in the coastal areas, however, in our region it is to prevent the intrusion of any contaminated water in the proximity of municipal well field.
- A monitoring program may provide information regards the effectiveness of this method.
- The stored water may or may not be extracted.
- A secondary permit may be required. If such secondary permit is required, then the Secondary permit under this alternative may have “Ground water augmentation ” OR “Environmental” as its MOU.
- Under the terms of a secondary permit, measurements of injected/stored water and a monitoring program may be sufficient to file a PBU.

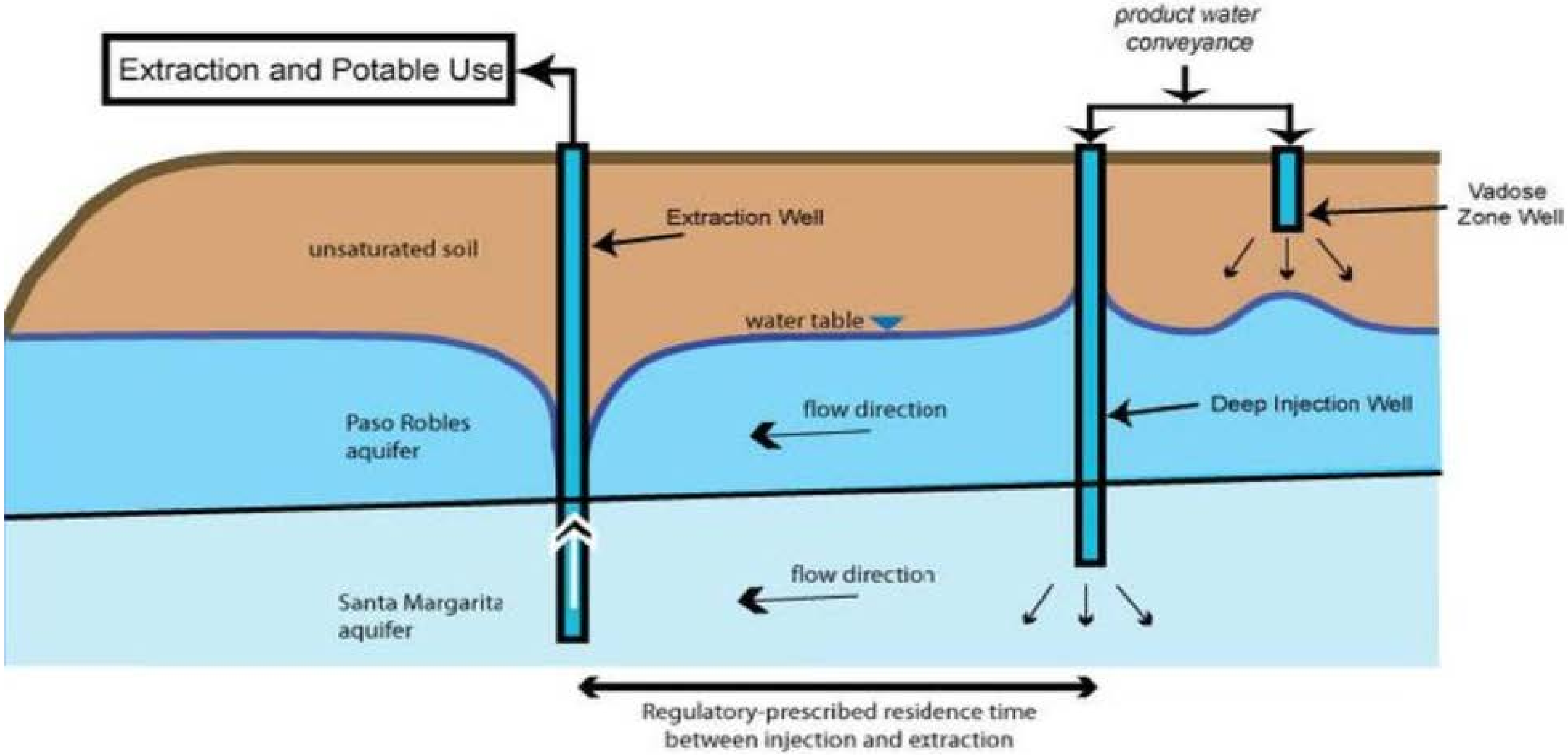
Typical ASR with A+ water



Municipal Water Supply

- This alternative is often referred to as Indirect Potable Reuse or IPR.
- This alternative envisions treatment of effluent to A+ classification standards prior to direct injection or use of a spreading basins to both further treat and polish the A class effluent. The recharged water under both options will be stored in an underground aquifer, and recovered for potable Municipal Water Supply purposes from and ASR recovery well(s). We envision the injection well(s) and recovery well(s) to be some prescribed distance apart.
- This alternative will be implemented pursuant to A+ and ASR regulations.
- Implementation of this alternative will include rigorous treatment and water quality monitoring of injection water, a comprehensive hydro-geologic report of the host aquifer, including a monitoring program for water quality post injection, water level gradients, transmissivity and travel times from injection points to recovery points, which are some distance apart.
- Upon a successful implementation, the recovered water supply may be integrated into existing potable water supply infrastructure.
- Will serves in a traditional manner may be issued against secondary permits associated with this alternative.

Typical ASR with A+ water



Discussion

Vahid Behmaram

Water Management Planner Coordinator – Washoe County

vbehmaram@washoecounty.us

University of Nevada, Reno | City of Reno | Washoe County, Nevada 1861 | Truckee Meadows Water Authority — Quality. Delivered. | Western Regional Water Commission | Northern Nevada Water Planning Commission | Truckee Meadows Water Reclamation Facility | City of Sparks

Report 3

Impacts of Climate Change on Water Resources in the Truckee Meadows

This report reviews the potential impacts of climate change on the Reno-Sparks metropolitan area of Northern Nevada to develop a better understanding of water supply and demand challenges that water resource management practices must address. The goal is to evaluate what the key concerns are and to evaluate the potential role of indirect potable reuse (IPR) in addressing these challenges in the North Valleys, which is a closed basin within the Reno-Sparks metropolitan area. Although the effects of climate change on the Reno-Sparks metropolitan region are uncertain, a review of published literature on the probable effects can be used to evaluate future hazard exposure.

The metropolitan area of Reno-Sparks has a semi-arid climate that faces challenges to sustainably manage water resources for resiliency. Challenges in future water management include the growing demands for residential and commercial uses, requirements for high quality treated effluent discharge with limited traditional options to utilize reclaimed water, and competition between residential, commercial, agricultural, and ecological demands. The region has adopted several water management strategies to enhance the resilience of water resources, including storage in upstream reservoirs, aquifer storage and recovery (ASR) with surplus surface water supplies, and reuse of reclaimed water for local irrigation.

The Truckee Meadows Water Authority (TMWA) is the primary water supplier within the municipal services area. TMWA conjunctively manages water resources to optimize storage of in upstream reservoirs and aquifers throughout the service area, ensuring a drought supply as well as storage to support riparian species and habitats (NNWPC, 2017). However, water availability within the region is expected to become less resilient and more stressed into the future due to uncertainty in climactic patterns of precipitation, needed to replenish reservoirs and groundwater supplies after dry periods (TMWA, 2016). Concern over the quantity and quality of water supplies within the region also drives competition between downstream and upstream users that largely rely on the Truckee River to support sensitive ecologies and aquatic species, agricultural uses, industrial development, and communities.

A literature review was carried out to identify the potential regional impacts of climate change in published studies. This analysis complemented a review of regional water resources to highlight potential risks associated with changes to temperature and precipitation characteristics. The study also evaluated trends in local water demand to evaluate vulnerability and the role of potable reuse/A+ in enhancing resilience. Analysis from this study was presented at the Advanced Reclaimed Water Rights Workshop (October 18, 2018).

Northern Nevada Indirect Potable Reuse Feasibility Study

Impacts of Climate Change on Water Resources in the Truckee Meadows

Final Report

Prepared by:

Krishna Pagilla, PhD, PE, Professor
Laura Haak, PhD Candidate

University of Nevada, Reno

March 2019

Submitted to:

Lydia Peri, P.E., Environmental Engineer
Washoe County CSD

Contents

Climate Change Study

Tables

Figures

Section 1

Introduction

1.1 PURPOSE

This report reviews the potential impacts of climate change on the Reno-Sparks metropolitan area of Northern Nevada to develop a better understanding of water supply and demand challenges that water resource management practices must address. The goal is to evaluate what the key concerns are and to evaluate the potential role of indirect potable reuse (IPR) in addressing these challenges in the North Valleys, which is a closed basin within the Reno-Sparks metropolitan area. Although the effects of climate change on the Reno-Sparks metropolitan region are uncertain, a review of published literature on the probable effects can be used to evaluate future hazard exposure.

1.2 REPORT ORGANIZATION

The report consists of the following sections:

- **Section 1 - Introduction:** This section describes the project background, goals and objectives.
- **Section 2 –Regional Water Resource Characterization:** This section evaluates the water portfolio for the Reno-Sparks metropolitan area and the North Valleys sub-area. Potential future scenarios for integrated management of water and wastewater resources are identified.
- **Section 3 – Review of Climate Change Literature:** This section conducts a comprehensive review of literature that examines the potential impacts of climate change on water resources in the region.
- **Section 4 – Adaptations and Transformations to Address Climate Change Risks:** The historical adoption of strategies such as water conservation, drought restrictions, water pricing, and reuse are examined.
- **Section 5 – Potential Impact of Indirect Potable Reuse (IPR) on Climate Change Resiliency:** This section first characterizes the potential increase in available water resources through IPR. Then, the impact of IPR on climate change resiliency is evaluated based on the reliability, quantity, and quality of potable water resources into the future.
- **Section 6 – References**

1.3 BACKGROUND

The metropolitan area of Reno-Sparks is located in Northern Nevada, which has a semi-arid climate that faces challenges to sustainably manage water resources for resiliency. Challenges in future water management include the growing demands for residential and commercial uses, requirements for high quality treated effluent discharge with limited traditional options to utilize reclaimed water, and competition between residential, commercial, agricultural, and ecological demands. The region has adopted several water management strategies to enhance the resilience of water resources, including storage in upstream reservoirs, aquifer storage and recovery (ASR) with surplus surface water supplies, and reuse of reclaimed water for local irrigation.

The Truckee River is supplied by reliable water supplies that are generated from snowpack stored across the northern Sierra Nevada Mountains. The Truckee Meadows Water Authority (TMWA) is the primary water supplier within the municipal services area, which supplies water resources to the incorporated and surrounding areas near the cities of Reno and Sparks. TMWA utilizes conjunctive management of water resources to optimize storage of water resources in upstream reservoirs and aquifers throughout the service area. Upstream reservoirs provide a drought supply for municipal needs as well as storage to support riparian species and habitats (NNWPC, 2017). However, water availability within the region is expected to become less resilient and more stressed into the future due to uncertainty in climactic patterns of precipitation, needed to replenish reservoirs and groundwater supplies after dry periods (TMWA, 2016). Concern over the quantity and quality of water supplies within the region also drives competition between downstream and upstream users that largely rely on the Truckee River to support sensitive ecologies and aquatic species, agricultural uses, industrial development, and communities.

The State of Nevada recently adopted the “A+” category of reclaimed water, which is envisioned to provide benefits in regional water management by improving the efficiency and enhancing the flexibility of the role of reclaimed water in regional water resources. The Category A+ requirements provide a regulatory path for indirect potable reuse (IPR) through treatment to a quality standard that meets all Federal and State of Nevada drinking water standards.

1.4 TASK OBJECTIVES

The potential impacts of IPR on climate change resiliency in the North Valleys region are analyzed through the following objectives:

- Determine the available water resources to the study area and the potential scenarios for water demand.
- Identify the potential effects of climate change on available water resources to the region through a review of literature.
- Determine the potential increases in available water resources for potable use upon developing Category A+ reclaimed water.

- Identify the qualitative enhancements to water supply flexibility, reliability, and quantity through potable reuse of Category A+ reclaimed water for the projected needs in the North Valleys region.

Section 2

Regional Water Resource Characterization

2.1 PURPOSE AND SCOPE

This section evaluates the water portfolio for the North Valleys and identifies potential future scenarios for integrated management of water and wastewater resources. The purpose is to determine the available water resources to the study area and the potential scenarios for water demand.

The remainder of this section is organized in following subsections:

- Regional Water Resources
- Water Resource Availability
- Reclaimed Water Management

2.2 REGIONAL WATER RESOURCES

The state of Nevada is the most arid in the United States, with northern Nevada receiving an average of only 7 inches of precipitation per year. Surface water accounts for approximately 80% of the inflows to the Reno-Sparks municipal region drinking water supply. Originating in the Sierra Nevada Mountains, the Truckee River carries a reliable flow of surface water to the Truckee Meadows region from snowmelt, illustrated in Figure 1. TMWA conjunctively manages annual flows from the Truckee River and creeks with groundwater and surface water stored in upstream reservoirs. Six perennial creeks are tributary to the Truckee River and contribute to TMWA's surface water rights. Upstream reservoirs provide a drought supply for municipal needs as well as storage to support riparian species and habitats (NNWPC, 2017). Within the municipal region, TMWA services six hydrographic basins, three of which are closed and are naturally supplied by groundwater which is conjunctively managed with surface water imported from the Truckee River. The non-TRA region consists of basins that are not served by TMWA surface water treatment plants and are standalone subdivisions with sufficient groundwater resources to meet development requirements (TMWA, 2016a). Figure 2 illustrates the distribution of water resources within the TMWA service area, which are a combination of groundwater, surface water, and privately owned stored water (POSW).

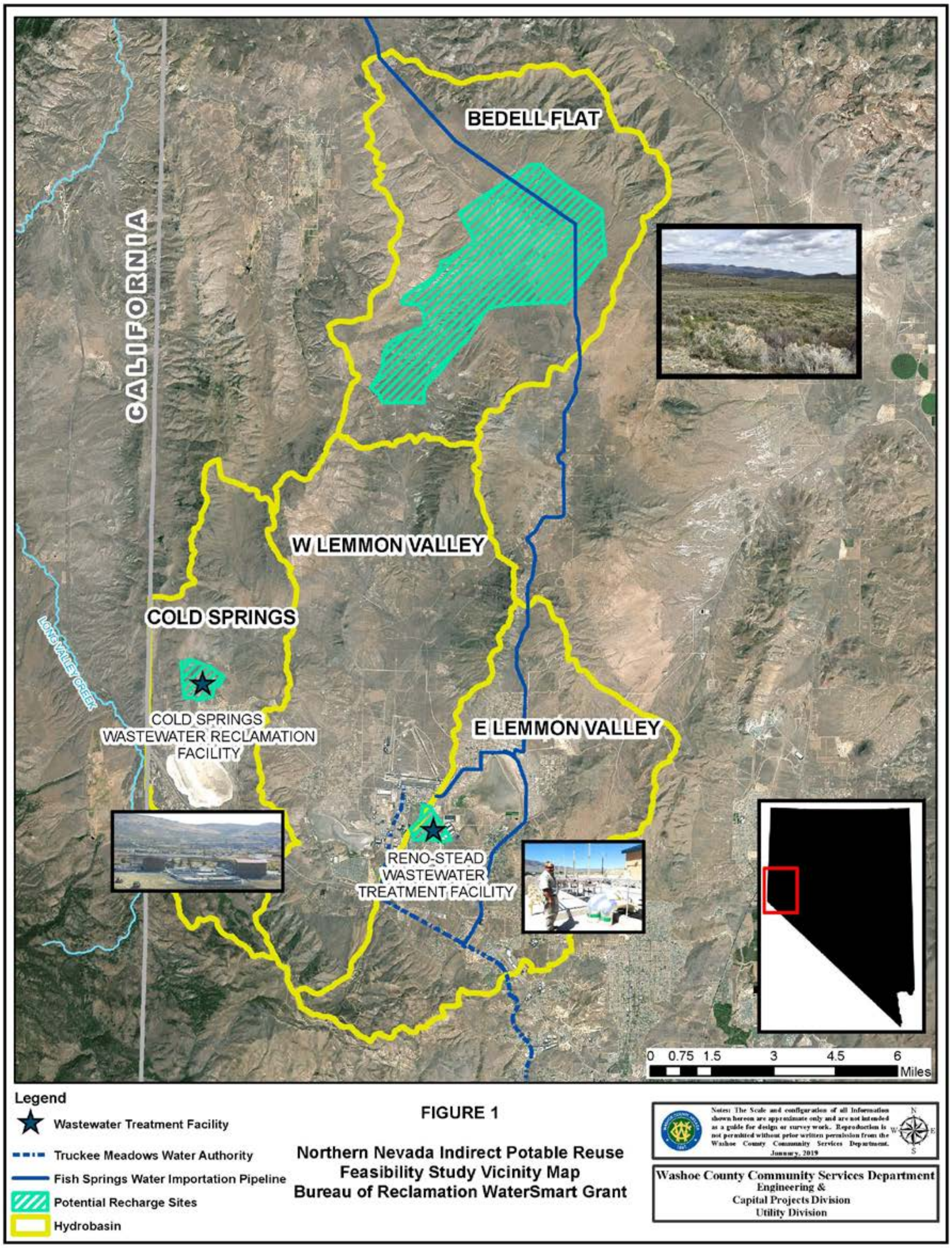


Figure 1. Map of the hydrologic basins in the Reno-Sparks metropolitan area

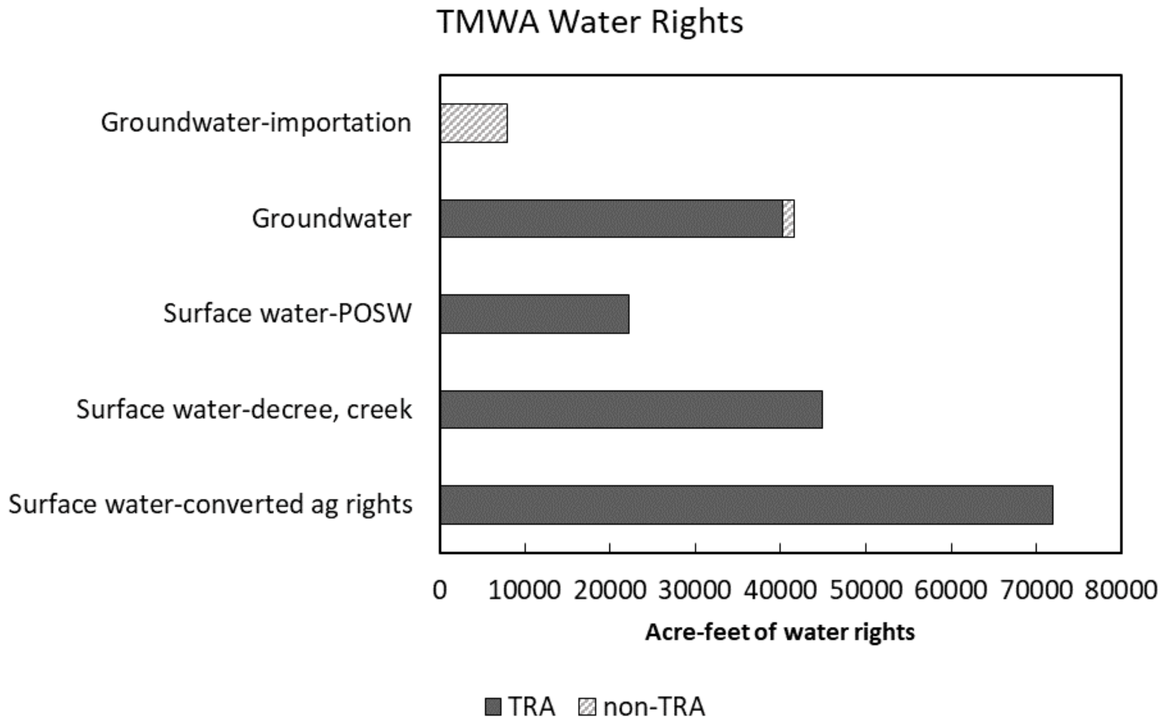


Figure 2. TMWA controlled water rights in the Truckee River Area (TRA) and non-TRA regions. Adapted from TMWA (2016)

Water resources from the Truckee Meadows basin have been used to help meet demands in closed basins within the metropolitan area, which otherwise rely on limited groundwater resources. The effluent generated from water use can also be problematic in these closed basins due to limited opportunities for in-basin disposal, such as for irrigation and ecosystem support. TMWA also augments water resources in stressed aquifers through an aquifer storage and recovery (ASR) program using water from the Truckee River (TMWA, 2016a). Reuse of effluent currently supplies more than 6,000 AFA of non-potable water, reducing both the demand of potable water for irrigation, and the volume of effluent water discharged to wetlands, evaporation ponds, or to the ground (NNWPC, 2017).

The water demands of growing populations in closed basins can make management of both water resources and effluent coupled drivers towards water reuse. These challenges can vary greatly by basin within the Reno-Sparks metropolitan area. While much of the population falls within the Truckee River watershed, the most rapid population growth and land-use change is occurring in smaller closed sub-basins. Most of the reclaimed water originating from urban areas is discharged into the Truckee River, supporting river flows for downstream habitat and fisheries. The Truckee River basin is also closed, with local runoff and river flow supporting downstream communities, important habitat and fisheries as the water flows to the terminus at Pyramid Lake. Management of reclaimed water and stormwater in this basin is largely directed according to the water quality and quantity requirements needed to support the Truckee River ecosystems. For example, the regulations for wastewater effluent discharge in the Truckee River watershed strictly control total maximum daily loads (TMDLs) of nitrogen, phosphorus, and total dissolved solids (TDS) to protect threatened and endangered fish species. In the closed basins that are not connected to the Truckee River, reclaimed water is primarily evaporated, discharged to support wetland ecosystems, or reused for irrigation. In these basins, water quality is generally less of a challenge than managing discharge for numerous seasonal demands. Management of wastewater effluent in these closed basins can present several challenges due to limited outlets for discharge and the sensitivity of closed basins to the volume of inflows. In the urban area, 34,000 AFA of effluent is produced, with approximately 6,000 AFA being used as intentional water recycling; however, expansion of the non-potable effluent reuse system to reach more customers is not a practical long-term solution (NNWPC, 2017). Demands for non-potable uses are limited by the costs of additional infrastructure and the limited seasonal demand from commercial and recreational users. Additionally, there may be a greater value in investing in advanced water treatment processes to generate a new potable water resource from effluent compared to allocating these resources for non-potable uses like landscaping. Thus, expanding potable water resources through investment in advanced water treatment processes may provide an optimal solution for management of both effluent and water supplies. Potable reuse has been envisioned for the last 10-years in Nevada, and the State of Nevada approved regulations for indirect potable reuse in 2016.

2.3 WATER RESOURCE AVAILABILITY

Under current water demands, water supplies to basins within the TRA are not utilized to capacity (Table 1). Treated surface water from the Truckee River are utilized in the ASR program through injection into the Spanish Springs and Lemmon Valley basins, where groundwater levels were previously depleted by over-extraction. The interlinkages between surface water resources, groundwater, and other potable and reclaimed water resources within the TRA service area are illustrated in Figure 3. Imported groundwater supplies have been developed to ensure adequate water resources for the planning area that includes Lemmon Valley, Stead, and Cold Springs. Surface water is stored in upstream reservoirs and is used to augment supplies through the Truckee River.

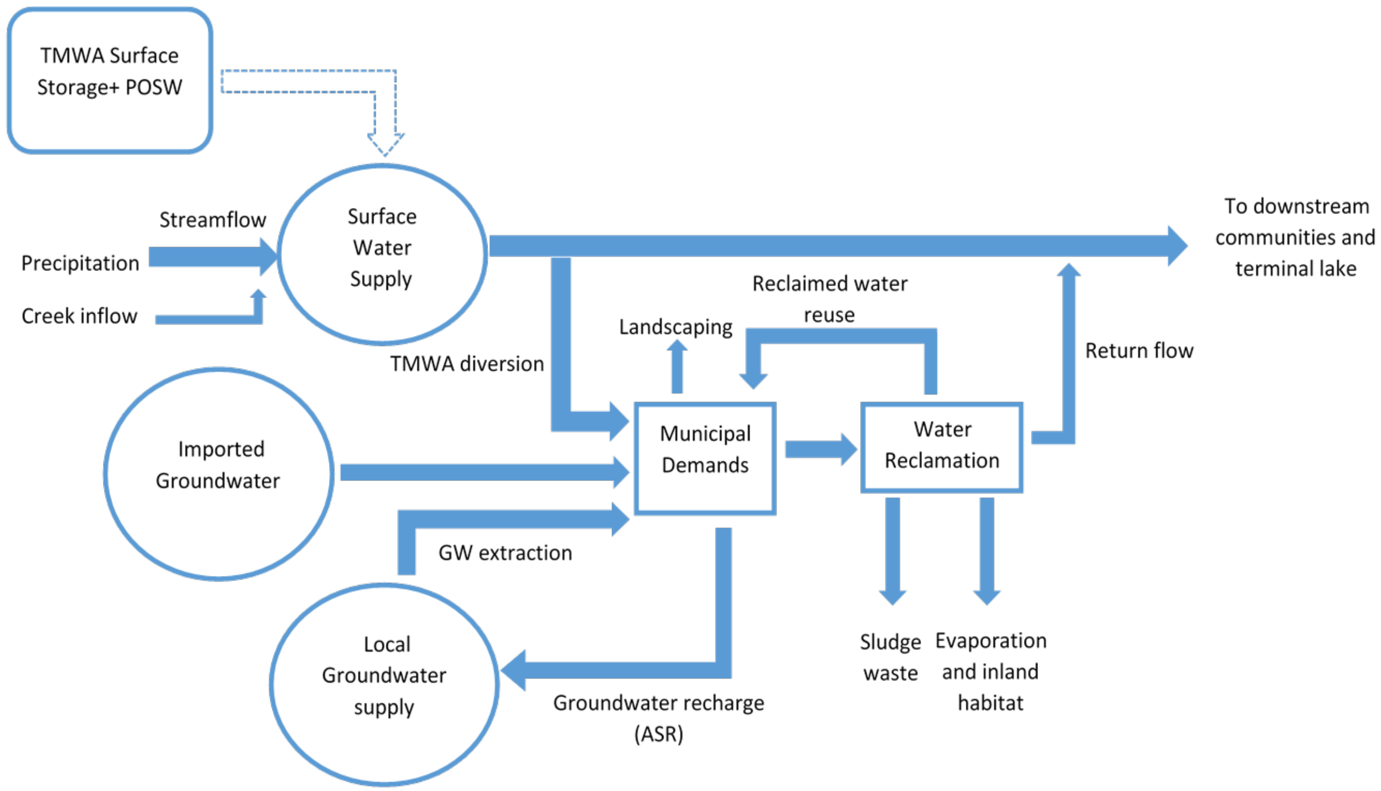


Figure 3. Water resources and storage available within the TRA service area

The current annual supply and demand for water resources managed by TMWA are described in Table 1. These water resources are managed conjunctively, with surface water from basins along the Truckee River being shared with adjacent closed basins that may not have natural surface water supplies. Additionally, some of these closed basins can receive groundwater imported from Honey Lake. This imported groundwater may become an increasingly important resource as population growth drives demand beyond the local water resources available to the closed basins.

Under the Truckee River Operating Agreement, surface water storage available to TMWA is expected to approach 40,000 AF (TMWA, 2016). Acquisition of irrigation rights have played a large role in enhancing TMWA's water supply beyond groundwater and storage rights; additional water rights from agriculture could be attained in the future to supplement urban water demands.

Groundwater comprises approximately 20% of the water resources managed by TMWA and is the sole supply of municipal water to several basins. Many groundwater wells throughout the TRA have experienced declining water levels due to an array of factors such as municipal withdrawals, domestic well density, recent drought, evapotranspiration, and properties of the aquifers. Several basins historically incurred significant deficits in groundwater, although the ASR program has been measured to generally offset the over-pumping and stabilize water levels in recent years (TMWA, 2016). Population growth has also challenged the quality of groundwater resources in some areas where wells have exhibited elevated nitrate levels due to septic tank density, depth to groundwater, and soil type among other factors (TMWA, 2016). Arsenic, tetrachloroethylene (PCE), sulfate, and TDS concentrations are also problematic in several wells due to geothermal waters, geology, and legacy contamination.

Table 1. Current water resource supply and demand for basins within TRA (TMWA, 2016a)

Description	Resource/ Demand (AFA)
Total water rights	**191,670**
Ground water-in basin	41,620
Ground water-importation [1]	8,000
Surface water [2]	119,800
Surface water-storage	22,250
Total water production [3]	**93,200**

1. Honey Lake water rights/resources are available to the North Valleys via the Vidler Pipeline
2. Converted agriculture and decree rights
3. Based on TMWA total water production in 2016

2.4 Reclaimed Water Management

Strategies to manage reclaimed water in the metropolitan area vary by basin. While much of the effluent in the city can be discharged to the Truckee River, which benefits from the additional flows but requires strict limits on nutrient loads, closed basins require more innovative strategies to manage reclaimed water. In the closed basins, strategies like non-potable reuse, evaporation, and discharge to playa environments, which can be managed to support wildlife and recreation opportunities. In the northwestern reach of Reno-Sparks, the North Valleys area comprises the communities of Cold Springs, Lemmon Valley, and Stead. This area is made up of several closed basins that fall within the Honey and Eagle Lakes watershed. While much of the watershed lies in California, several intermittent lakes lie within the boundaries of Nevada, including Swan Lake. Swan Lake plays numerous roles for the community by supporting habitat for migratory waterfowl, and the management of reclaimed water.

Within the North Valleys area, three water reclamation facilities are in operation, with the Reno-Stead Water Reclamation Facility (RSWRF) handling most of the wastewater flow, currently operating at 1.5 mgd (1,680 AFA) (NNWPC, 2017) and may increase to nearly 3 mgd by 2035. RSWRF effluent flows are presently conveyed to the Swan Lake Playa and seasonally to a reclaimed water distribution system for irrigating local parks, golf courses, and landscaping. Additionally, the Lemmon Valley Wastewater Treatment Plant (LVWWTP) produces 0.21 mgd of effluent that is evaporated from on-site ponds adjacent to the Swan Lake Playa (NNWPC, 2017).

The Swan Lake Playa is a wetland habitat that relies on effluent flows from RSWRF to maintain habitat crucial to birds and aquatic species. However, future effluent discharges to the Swan Lake Playa must be managed carefully and water manages may desire to limit annual total volumes discharged to Swan Lake. The Bureau of Land Management requires that RSWRF discharge reclaimed effluent to the Swan Lake Playa, permitting a minimum discharge of 490 AFA up to a maximum of 2,630 AFA. The use of reclaimed water for irrigation is limited by both customer demand and the lack of infrastructure including seasonal storage facilities. The North Valleys region is expected to increase in population, with plans for residential and commercial development already underway. Future wastewater flows from the region are expected to eventually reach 8,000 AFA (TMSA Facility Plan, 2010). Expansion of irrigation reuse may only increase demand by an additional 471 AFA due to limited user demand (NNWPC, 2017). Alternative effluent management options include discharge to other playas to enhance wildlife and wetlands, development of new wetlands, industrial uses, export of effluent, groundwater recharge, or development of a dual pipe water system for residential customers. Of these options, irrigation demands for agriculture and residential uses would not provide year-round demand, and discharge of effluent to other nearby playas (e.g. Silver Lake) may be detrimental to the community due to flood risks that have increased due to the impact of development on runoff into the drainage basin (NNWPC, 2017). While reuse of effluent for industrial applications may be beneficial and feasible, the scope of this demand is not yet known. Thus, groundwater recharge and the export of effluent may be the most feasible options to manage future flows that exceed current reuse needs.

2.5 Drivers for Potable Reuse

Reliance on groundwater and imported surface and groundwater resources in closed basins like those in the North Valleys, may make the area less resilient under the strains of climate change and population growth. For example, declining water levels are potentially resulting in aquifer compartmentalization that restricts groundwater recharge (TMWA, 2016). Declining water tables drive groundwater resources towards becoming prohibitively expensive by requiring increasing pumping power, declining well yields, and potentially worsening water quality. These challenges have been addressed through conjunctive resource management, including the ASR program. Other strategies include inter-basin transfers of surface water, extending the distribution system, utilizing imported water supplies. However, as climate change and population growth place greater stresses on the available water resources, water reuse strategies like potable reuse (PR) may address numerous risk factors in the current water and wastewater management systems.

Augmentation of water resources through PR in these closed basins may offer a sustainable solution with dual benefits that improve water supply while also providing a high value use for effluent water that may otherwise be costly to dispose of. In the North Valleys region, population growth was projected to increase water demand beyond the available supplies to the region by 2035 (NNWPC, 2035). Although water conservation may address this deficit, the water supplies will fall into the highest classification for water scarcity based on the available water supplies per capita (Falkenmark & Lundqvist, 1998; Haak et al., 2018). Higher water stress may make the region less resilient to droughts. Additionally, PR may enhance local management of reclaimed water. While most of the effluent produced in the region is diverted to irrigation or environmental systems, the water needs of these systems are seasonal and may also depend on annual precipitation patterns. Potable reuse provides a beneficial use that can include water banking, creating a management strategy that is less vulnerable to uncertainties in precipitation patterns.

2.6 SUSTAINABILITY OF WATER SUPPLIES

Uncertainty about the potential impacts of climate change on the region as well as increasing population have driven recent research to evaluate the sustainability of water resources. This research has been carried out by researchers at the University of Nevada, Reno (UNR), Desert Research Institute (DRI), TMWA, and others. Collaborative projects such as Water for the Seasons, led by UNR, are currently investigating how climate change may impact risk to regional water supplies in the Truckee River watershed. The following section reviews literature published by researchers participating in these projects and others that may have important implications regarding the potential impacts of climate change on uncertainty and sustainability of regional water resources.

Section 3

Review of Climate Change Literature

3.1 Purpose and Scope

The purpose of this section is to identify the potential effects of climate change on available water resources to the region through a review of literature on the topic. This comprehensive literature review highlights some global trends anticipated from climate change but largely focuses on the specific regional impacts to water resource resiliency that are relevant for long term planning.

Climate change refers to changes in long-term averages of daily weather; usually climate is measured as the average weather for a particular region over a time frame of about 30 years. Land surface air temperatures have been widely studied at global and regional scales as indicators of warming trends associated with climate change (e.g. (Hansen et al., 2010; IPCC, 2014). Multiple independent datasets have shown global warming of approximately 0.72°C occurring from 1951 to 2012 (Hartmann et al., 2013), with the northern hemisphere warming fastest (Ji et al, 2014). Human activities have accelerated emissions of greenhouse gases (GHG), which impact temperature, rainfall, glaciers, and sea ice among other factors due to their warming effect on surface and atmospheric warming. In addition to global and regional surface temperatures and GHG concentrations, extreme weather events are another important indicator to understand climate change. Rather than examining single extreme events, climate change science observes how occurrence of extreme events have changed. Observing changes to extreme patterns, like droughts, floods, wildfires, and heat waves, provides a statistical framework to understand how temperature and precipitation patterns associated with climate change can alter regional resilience.

The remainder of this section is organized in the following subsections:

- Future water supply reliability
- Water quality vulnerabilities
- Water supply system vulnerabilities
- Flood vulnerability

3.2 Future Water Supply Reliability

In the Reno-Sparks metropolitan area, Lemmon Valley and Stead make up closed sub-basins that lie in the Honey-Eagle Lakes watershed. Despite limited groundwater resources and marginal capacity for reclaimed water discharge, these sub-basins are among the fastest growing in the region. This area is expected to increasingly rely on imported water resources, which include surface water from the Truckee River and groundwater from Fish Springs to meet growing water demands and to recharge aquifers through ASR (TMWA, 2016). Under current water demands, water supplies to basins within the TRA are not utilized to capacity. Excess treated surface water from the Truckee River are utilized in the ASR program through injection into the Spanish Springs and Lemmon Valley basins, where groundwater levels have been depleted by over-extraction. However, the growing demand for water has also resulted in increased flows of reclaimed water treated at the local water reclamation facility (WRF). Reclaimed water is beneficially reused in the basin to support a wetland in Swan Lake and to provide irrigation with non-potable water. However, the volume of reclaimed water generated annually is expected to exceed local discharge capacity within a 20-year planning period (NNWPC, 2017).

3.2.1 Local Climate and Temperature

The high desert climate of the Reno-Sparks metropolitan area means the region has very low soil moisture, receiving an average rainfall of only 7.5 inches per year (NNWPC, 2017). Droughts affect the region frequently but are punctuated by years with larger precipitation than normal. To address droughts and compensate for uncertainty in precipitation patterns, surface water resources are stored in upstream reservoirs and injected into aquifers. Extreme precipitation events are particularly likely to take place during the winter, which is the season where the region generally accumulates most of its water supply (Das et al, 2013).

In the western United States temperatures have shown a warming trend over the last century. The Western Region Climate Center shows that the mean temperatures in Nevada and California have increased more than 1 degree above the historical mean in recent years. Both annual maximum and minimum temperatures in the states have also increased (Western Regional Climate Center, Climate Monitor). Temperature has a significant effect on water resources through many complex interactions with social and ecological systems including the type of precipitation, evapotranspiration rates, water demand characteristics, and the timing of snowmelt. Because the region is largely dependent on snowpack for water supplies, temperature changes may challenge the current water infrastructure. As temperatures rise an increase in flooding is expected to directly result as snowmelt-runoff peak flows increase (Das et al, 2013). This is expected to result in an increase in 50-year flood events. Although local weather patterns may not be as predictable as global trends, there is a consensus that the overall frequency of precipitation will decrease despite an increase in the intensity of precipitation events (Das et al, 2013). Warming temperatures also have been observed to cause a lengthening of frost-free seasons, with the greatest effects observed across the western U.S. (Walsh et al, 2014).

Heat islands describe a local phenomenon in which land use modifies temperature patterns in a way that causes an area to store heat. Land use or land cover changes associated with urbanization have been shown to greatly contribute to temperature measurements in urban areas (Hartman et al, 2014). These effects may have a strong effect on residential water consumption within urban areas, which are strongly influenced by temperature characteristics (Al-Zahrani & Abo-Monasar, 2015).

Air temperature is also among the most important climatic variables that drive evaporation rates throughout the region. In arid and semi-arid regions like Reno-Sparks, the largest driver of accelerated evaporation rates is likely to be an increase in the moisture-holding capacity of the atmosphere, with wind speed and surface temperature also playing key roles (Stone and Lopez, 2006). In addition to the effects evaporation rates may have on consumptive water use for agricultural and residential water use in the region, it is also likely to impact storage in reservoirs. Annual average air temperatures around the Lake Tahoe basin are expected to warm by 7 to 9°F by 2100, which may increase evaporation by 100% in some parts of the basin (TREC, 2018). While increased evaporation from the surface of the lake would impact water supplies available from storage, land evaporation rates in the basin will impact the risk of wildfires and resulting water quality risk.

3.2.2 SNOWPACK

Snowpack in the northern Sierra Nevada Mountains is critical to the Reno-Sparks metropolitan area as both a source of water storage and water supply. Recent monitoring of winter precipitation in this region has observed that from 2008 to 2017 snow level has increased but snow fractions have decreased (Hatchett et al, 2017). This phenomenon may be a regional characteristic associated with atmospheric rivers, which may often produce snow with less water content. The results indicate that future snowpack may continue to contain a declining amount of water content, reducing overall water storage as a response to rising surface temperatures and frequencies of atmospheric rivers (Hatchett et al., 2017; Neiman et al., 2008). The observations of research like (Hatchett et al., 2017) has resulted in defining snow droughts. Snow droughts describe the occurrence of precipitation with above or near average accumulations of snow but below average snow water equivalents (SWE), which are the units used to describe the water content of snowpack. The northern Sierra Nevada have experienced an increasing occurrence of snow droughts since 1951, often occurring in years with either extreme early season precipitation, years where rain events frequently follow snow events, and years with overall low precipitation (Hatchett & McEvoy, 2017).

Another key concern in how climate change may impact snowpack is the increasing trend towards earlier snowmelt and precipitation that is increasingly falling as rain rather than snow as a result of warming temperatures. This may alter the regions reliance on snowpack as future precipitation shifts towards a larger proportion of rain. In the northern Sierras SWE may decrease by 30% to 90% by 2035 (Walsh et al, 2014). Evidence indicates snowpack may increase at the highest peaks but decrease elsewhere (CDWR, 2014).

In addition to the projected decreases in snowpack described previously, further decreases may result from humidity increases anticipated as temperatures rise. In the dry climate of the northern Sierras the loss of snowpack is largely driven by direct losses to the atmosphere, known as winter sublimation, which are accelerating as a result of warming temperatures and humidity (Harpold & Brooks, 2018). However, the overall impacts of these changes on the region are not well understood; models do not consistently predict wetter or drier conditions in the Northern Sierras (NNWPC, 2017).

3.2.2 SURFACE WATER

The Truckee River Watershed (TRW) originates in the Sierra Nevada Mountains, crossing a portion of northeastern California, and eventually flows down into the northwestern part of Nevada. The Truckee River water is sourced from snowmelt that is captured in numerous lakes and reservoirs upstream. The Truckee River flows 120 miles from its source to its terminus at Pyramid Lake. Although the TRW's waters come from both snowmelt and other seasonal precipitation, most of the watershed's surface and groundwater supplies are sourced from post-winter snowmelt. These resources will largely be impacted by changes to evaporation from reservoirs and changes to water stored in snowpack, as described in preceding sub-sections. Refer to section 3.4 for a discussion on the potential impacts of changes to precipitation patterns on reservoir systems.

3.2.3 GROUNDWATER

Overall, there is great uncertainty about how groundwater recharge will be impacted by climate change, but several studies have examined this topic over the last decade. Although there is greater uncertainty in predicting future groundwater inflows compared to surface water, new hydrologic modelling approaches have been applied to understand the probability of different potential groundwater effects. A major concern in managing groundwater resources into the future is the large probability of increasing use of groundwater to supplement the global trend in declining surface water availability (IPCC, 2014).

A recent review by (Meixner et al., 2016) developed the body of knowledge about the potential impacts of temperature, precipitation amount, and precipitation type may impact aquifer recharge in the future. While no studies were found that simulated future aquifer recharge under climate projections in the Truckee Meadows watershed, Meixner et al (2016) did examine projections for several basins in the western U.S., identifying regional patterns in the anticipated changes to aquifer recharge that are expected to result in the northern region of the West experiencing small increases or modest declines resulting from uncertainty in future decreases in snowpack and snow-rain shifts. Several studies have also examined the sensitivity of recharge modelling, observing the variability of results obtained due to downscaling climate effects to regional levels and different modeling approaches used (Kurylyk & MacQuarrie, 2013; Moeck et al., 2016; Smerdon, 2017), (Crosbie et al, 2013).

3.3 WATER QUALITY VULNERABILITIES

As a result of uncharacteristically early rain and snow melts in the Truckee Meadows watershed, there is now the need for erosion control projects in areas that are naturally accustomed to gradual snowmelt, versus fast flowing rain waters and storm runoff (Elliot et al., 2015). Many repercussions can result from sustained changes of this sort in the area. Erosion often leads to hydrologic modifications that can increase pollutant loads from urban and agricultural activities (NNWPC, 2017). As runoff paths and drainage systems become compromised, they are more likely to carry runoff with excess temperature as well as forms of pollution such as septic seepage, and agricultural pollutants that are otherwise typically contained (NNWPC, 2017).

Efforts to protect the watershed have led to the creation of programs such as the State of Nevada's Integrated Source Water Protection Program (NNWPC, 2017). However, the implementation and enforcement of erosion control ordinances need to be strategized by local government management to ensure that storm-water runoff complies with National Pollutant Discharge Elimination System permits (NNWPC, 2017). The adoption of a storm water quality program could help to address other non-point sources as well

3.4 WATER SUPPLY SYSTEM IMPACTS

The water supplies in the Truckee Meadows are largely derived from snowmelt, which is likely to be impacted by climate change as precipitation is increasingly rain and as snowpack melts earlier in the spring. These considerations are likely to drive water management to adapt reservoir and conjunctive use of water resources as the region accounts for changing precipitation patterns. The balance between winter snows and spring rains has historically played a critical role in way that these natural aquifers and reservoirs absorb and accumulate this precipitation. Some of these factors not only include the form of precipitation (rain vs snow), but the rate of snowmelt, depth of snowpack, amount of precipitation, the timing of peak snowmelt-runoff, and streamflow volume and timing (CDWR, 2015; TMWA, 2016). Although annual precipitation in the Lake Tahoe and Truckee River hydrographic basins have been highly variable, the overall shift trends towards slightly reduced in winter precipitation especially at lower elevations that historically accumulated significant snowpack (Stone and Lopez, 2006).

Monitoring and forecasting of precipitation patterns as water systems reliant on reservoirs will be challenged to address the impacts of snow-rain shifts. Current natural and manmade systems are designed to capture a slow spring runoff. With peak runoff from snowmelt shifting to earlier in the spring there is a reduced ability for water managers to refill reservoirs after flood season (Western Region Climate Center; CDWR, 2015). Traditionally these waters would naturally release slowly throughout the spring. However, annual flow has increasingly shrunk in the late spring and early summer months, with snowmelt driven streamflow occurring earlier in the year (Stone and Lopez, 2006a). This elevates the risk of reservoir breaches and may result in reduced storage capacity in reservoirs to reduce flooding risks. In addition to the potential impacts on reservoir capacity, there are resulting challenges for the management of river flows. Water supply systems will have to adapt operations to prepare for longer peak season demands outside of the wet season as irrigation demands may shift earlier into the spring, overlapping with the flood protection season (CDWR, 2015).

Water demand management strategies will likely play an important role in helping adjust urban water systems to changes in supplies. In the Reno-Sparks metropolitan area outdoor irrigation and recreation demands account for approximately 60% of total annual demand (Truckee Meadows Water Authority (TMWA), 2016). Higher summer temperatures are expected to increase summer water demands across most sectors (CDWR, 2015). However, these increases can be offset through demand management strategies like watering restrictions, higher water pricing for outdoor use, and educational outreach about water conservation strategies.

Additionally, water supply improvements such as leak repair and water meter replacement can significantly reduce water use within an urban area.

Other research has shown that it is important for urban water systems to transform supplies so that they are not overly reliant on reservoirs to address water shortages; in fact this reliance can actually increase vulnerability to damage resulting from drought (Baldassarre et al., 2018). This vulnerability may result from socio-economic trends, such as a failure to implement long and short-term conservation strategies to improve the adaptive response of urban water demand during low flow years. Transformations such as non-potable and potable reuse in addition to water demand management may be better approaches to decrease drought vulnerability.

3.5 FLOOD VULNERABILITY

The national climate assessment highlighted the importance of addressing climate risk in land-use planning which can be linked to a state's hazard mitigation plans (Lempert et al, 2018). With population projected to increase significantly over the next two decades impervious surfaces will also increase, potentially resulting in decreased infiltration of stormwater and larger volumes of runoff. Increased runoff paired with the potential for more extreme precipitation events due to climate change may result in elevated flood risks. These risks may be most noticeable for communities built around playas that runoff drains to in the closed basins.

As severe storms become more prevalent, traditional notions of 100-year floods may need to be reconsidered. This consideration is driving regions to reevaluate flood risk to protect the inhabitants of these places. However, the understanding of how climate change and other anthropogenic changes may continue to alter flood risk is still being developed (Gersonius et al, 2013). Proper assessment strategies that account for uncertainty around flood risk due to climate change are necessary to ascertaining the appropriate long-term mitigation and adaptation solutions for a region. Flexible infrastructure to control flood risk is increasingly important as urbanization continues to push further into low lying valleys in closed basins, such as Lemmon Valley and Cold Springs.

After the 1997 flood, the Truckee River Flood Management Authority (TRFMA) was created to implement the Truckee River Flood Project, which assesses risks from the west side of Reno to the eastern city limits. However, this research does not currently include outlying neighborhoods and areas towards Pyramid Lake (FEMA, 2017). Existing efforts have already contributed towards the acquisition of multiple buildings and farmlands that have historically been subject to repeated flood loss over the years. In efforts to reduce flood costs in the future, long-term plans for the Truckee River Flood Project include the acquisition of all structures within project boundaries, impact assessments, building demolition, the removal of utilities prior to park conversions in these areas, as well as the addition of flood walls on the north side of the river (FEMA, 2017).

Failure in stormwater drainage canal infrastructure have resulted in localized flooding throughout Northern Nevada (NDWR, 2013). Previous efforts to channel flood waters have reduced nature's ability to control the containment and natural absorption of runoff waters, leading to decreased water quality at the lower reaches of the Truckee River (NDWR, 2013). However, efforts to mitigate these problems have only recently begun to have been put in place.

Section 4

Adaptations and Transformations to Address Climate Change Risks

4.1 Purpose and Scope

This section examines the historical adoption of strategies such as water conservation, drought restrictions, water pricing, and non-potable reuse. The remainder of this section is organized in following subsections:

- Trends in Water Demand
- Water Reuse
- Potential Transformation through IPR

4.2 Trends in Water Demand

Demand management strategies, such as outdoor watering restrictions and water pricing, can be useful tools that reshape how water is used in urban areas. These policies often complement water conservation goals and may result in long term changes in the water demand intensity exerted by households and businesses. Water users are grouped based on the customer identifications used by the water authority (e.g. single-family homes, multi-family homes, and commercial/industrial). These groups share similar characteristics in terms of seasonal water demand and indoor (non-seasonal) demands. For example, single family residences generally exert a higher per capita water demand than multi-family residences. Total water demand across TMWA water users was evaluated over the previous 14 years. To better see trends in the intensity of water demand, total annual water demand was normalized with the population of Washoe County (U.S. Census Bureau, Population Division, 2018). Figure 4 illustrates the historical trend in gallons of water demand per capita per day (GPCD), which has decreased by nearly 30% since 2004. The figure shows the trend measured the metered water use by utility customers yielded the annual average water demand per capita. The trend in demand per capita is driven downward by conservation strategies undertaken by customers of the water utility, such as changes to landscaping and irrigation methods. Additionally, water production per capita trend illustrates water conservation achieved through improvements in the water supply system such as reducing system losses due to leaks. This trend reflects both demand-side and supply-side improvements to enhance conservation, such as water leak repair and water meter replacement, among other efforts. During the severe drought occurring over 2013 to 2015, TMWA customers were asked to reduce water demand by 10% over the summer of 2015. The GPCD illustrates a strong customer response, which reduced demand to an average of 119, compared to the pre-drought average near 140 GPCD.

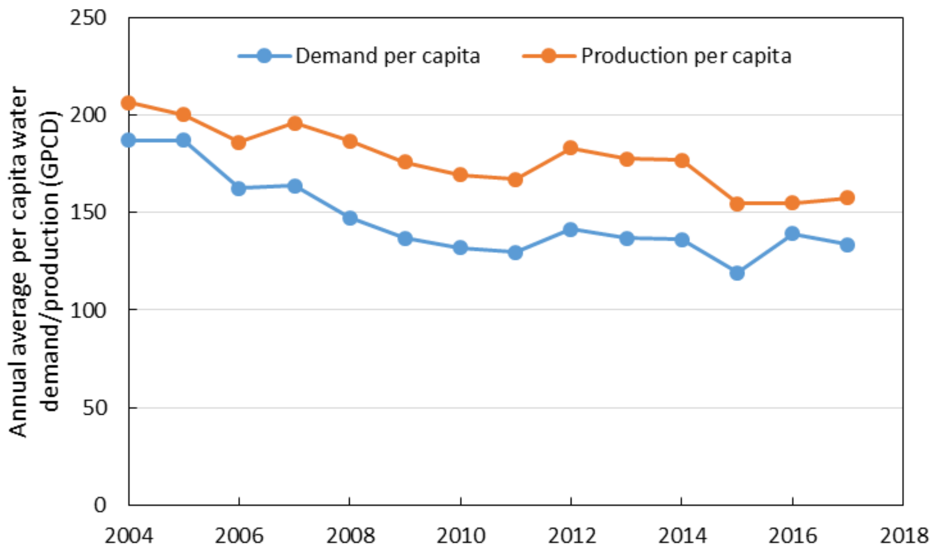


Figure 4. Average annual water production and water demand per capita

A closer examination of residential water demand reveals adaptations that have occurred in both single family and multifamily households. This calculation first determined the total annual water demand for each class of residential users based on the total monthly water demand billed. The billing data also included counts of households for each customer type every month, which was divided by the total annual water demand to determine the average annual demand per household. This value was then used to determine the average water demand per household per day for each year that billing data was available (2004 through 2017). Figure 5 presents the resulting summary of average water demand per household daily. Overall a downward trend in single-family water demand is apparent, resulting in 18% lower demand per household in 2017 compared to 2004. Multi-family household water demand was measured to be 7% lower in 2017 compared to 2004, but since 2010 this demand has been gradually increasing. Additionally, it is notable that during the 2015 drought year, in which TMWA requested a 10% water reduction, single family water demand dropped by as much as 12% (2015). This reduction appears to have resulted in a structural change to single family water use, such as changes to landscape irrigation practices, because water demand remained nearly 8% below pre-drought years in the post-drought years of 2016 and 2017. Multi-family water demand appeared to be much less sensitive to drought restrictions due to this class of customers largely exhibiting non-seasonal water demand for indoor uses.

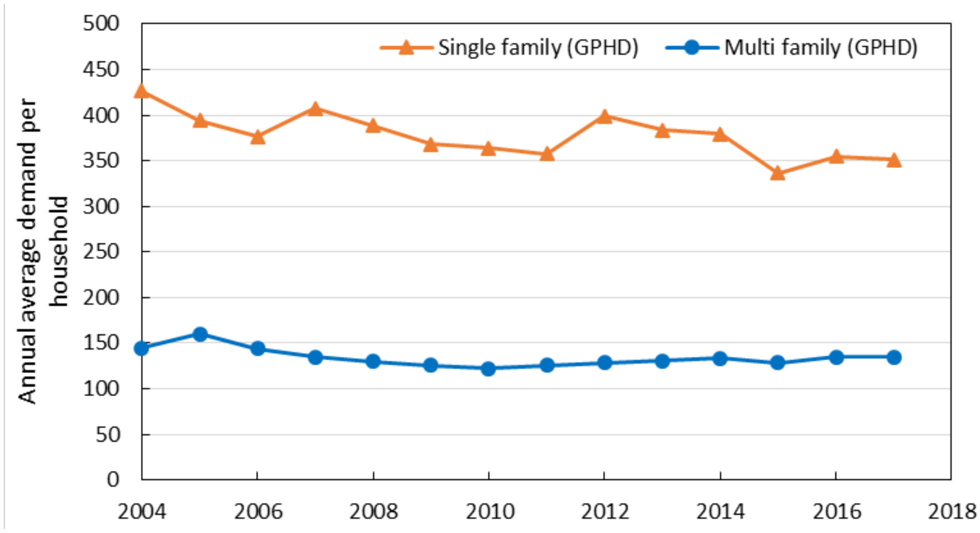


Figure 5. Trends in household water demand (average gallons of water demand per household daily)

The previous analysis has identified the total response observed across residential customers in response to drought cutback requests. The response can also be measured as water savings, the difference between monthly water demand under normal conditions and monthly water demand during the severe drought. Further discussion on this approach to analyze water savings during drought can be found in (Haque et al., 2014). The trends in water demand, normalized based on customer service counts (household or non-residential firm) in the TMWA billing data. Note that because billing data is used the peak summer demand is shown as occurring approximately half a month later than the actual peak demand. Figure 6 illustrates the monthly trend in water demand using average monthly water demand per customer connection (household or firm) from 2010 to 2013 for normal conditions and average monthly demand for 2014 and 2015 for drought conditions. Overall, both residential and non-residential customers were observed to have lower peak demand during the summer. No significant savings occurred in 2014 but more than 12,000 gallons per household were saved in 2015. Compared to an average of 152,000 gallons of water demand per household in 2013, the combined classes of residential households (both single- and multi-family together) saved over 9% of normal water demand despite the limited response by multi-family households.

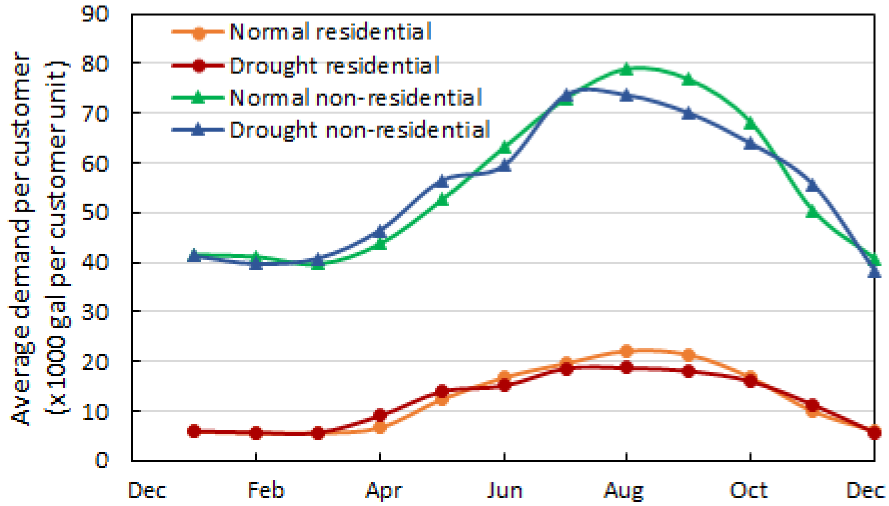


Figure 6. Water savings for residential and non-residential customers during drought

4.3 WATER REUSE

Non-potable water resources are primarily used for irrigation but are also sold at several regional wastewater treatment facilities for purposes such as construction water. Non-potable water demand is largely used seasonally for parks and golf courses (refer to NNWPC, 2018 for more information). Non-potable demand is also highly variable. During the economic recession total annual non-potable water demand declined by 20% of pre-recession levels, as illustrated in Figure 7. Recently, non-potable water demand has increased, as have the number of customers (or locations) receiving non-potable water. Although non-potable water demand is volatile and appears to be sensitive to economic conditions, this resource plays an important role in the urban area's ability to transform water demand during drought events.

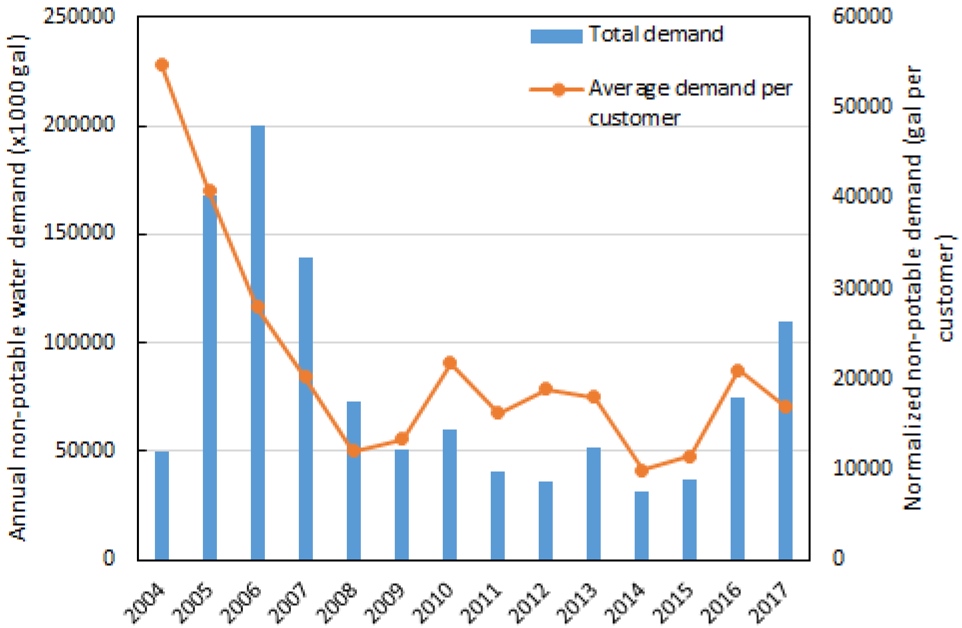


Figure 7. Adoption of non-potable water demand

4.4 POTENTIAL TRANSFORMATIONS THROUGH POTABLE REUSE

The purpose of this section is to evaluate the potential increases in available water resources that could be generated through potable reuse if Category A+ reclaimed water was developed in the region. The planned indirect reuse of water that meets or exceeds drinking water requirements has been demonstrated as a valuable strategy to enhance the resilience of urban water supplies, particularly in response to drought events. In closed basins like those throughout the Reno-Sparks metropolitan area potable reuse may reduce runoff into playa and wetland environments, which has increased due to land use change associated with population growth. Thus, this water management strategy may enhance resilience to both high-flow and low-flow risks associated with climate change in the region.

An ongoing feasibility study for potable reuse in the region has identified the potential to produce more than 1.5 mgd (or 1,120-acre feet per year) of category A+ water for groundwater replenishment by 2035. Note that this estimate is conceptual at this time and does not consider hydrologic limitations of injection or spreading basins that would govern the actual supply of potable reuse water to groundwater aquifers. Potable reuse may be a valuable resource for water banking or building up a resource that can supplement conventional water resources during a severe drought event.

Table 2 highlights risk scenarios that are likely to be elevated as a result of climate change (Section 3) and the potential impacts of these risks on water resources. While several systems are well adapted to the risks they may be exposed to (such as the resilience of surface water to drought risks), the vulnerability is not always well understood. Overall, potable reuse is a somewhat closed system, decoupled from these environmental risks.

Table 2. Risk factors associated with water supplies

Climate Resilience Hazards	Surface Water	Groundwater	Potable Reuse
Severe drought	Risk factors: Severe droughts already occur and are likely to increase in frequency	Risk factors: Shortages of surface water can magnify demand on groundwater resources	Risk factors: Droughts were not observed to alter indoor water demand
	Vulnerabilities: Reservoir systems and conjunctive use are adapted for this risk	Vulnerabilities: Conjunctive use of surface water is adapted to decrease pressure on aquifers	Vulnerabilities: The availability of water for PR may be impacted by the abundance of surface water available for environmental needs
Snow drought	Risk factors: Historical observations of snowpack have observed an increasing frequency	Risk factors: Snow drought may alter aquifer replenishment	Risk factors: Snow drought may alter natural aquifer replenishment
	Vulnerabilities: Several reservoirs in the system are fully recharged even during drought years, but the potential effects of chronic snow drought on the region are not well understood	Vulnerabilities: Surface water availability for conjunctive use will impact artificial recharge of aquifers	Vulnerabilities: Storage of water may be impacted by deficits in adjacent water resources
Flooding	Risk factors: Localized flooding due to changes in precipitation patterns and intensity	Risk factors: Land use change, irrigation practices, and runoff can alter aquifer replenishment	Risk factors: Aquifer storage capacity may be impacted by elevated water tables during flooding
	Vulnerabilities: The risks are likely to be localized and may depend on the flexibility of reservoir management strategies	Vulnerabilities: Surface water availability for conjunctive use will impact artificial recharge of aquifers	Vulnerabilities: The ability to carry out groundwater augmentation may be limited if the aquifer storage is impacted

Section 5

Findings and Conclusions

5.1 WATER RESOURCES AND DEMANDS

The effects of climate change on the region are likely to impact water and reclaimed water management in the future, creating challenges that will be intensified by population growth. Climate change is likely to have dramatic impacts on the management of surface water resources by affecting snow/rain patterns; the frequency, duration, and severity of droughts; and, changes in surface water flow rates and seasonal flow patterns. Studies have observed decreases in the volume of water stored in snowpack, and a greater portion of precipitation is expected to fall as rain rather than snow into the future. Changes in precipitation are also likely to alter aquifer replenishment which can be facilitated through gradual snowmelt infiltration.

These alterations to water flow rates and seasonal flow patterns are likely to change the seasonal characteristics of water demand within the community as well as the water requirements of environmental systems. For example, the slow release of water from snowmelt plays a critical role in maintaining soil moisture and is likely to also impact natural aquifer replenishment throughout the region. Similarly, snowpack acts as an additional reservoir for local communities, providing water storage beyond the capacity of reservoirs. Thus, changes in precipitation may increase the water requirements of natural systems, potentially impacting the composition of vegetation, as well as the vulnerability of local communities to water supply shortages.

5.2 INFRASTRUCTURE AND POLICY IMPLICATIONS

To address how these changes may alter management of reservoirs and the conjunctive use of surface and groundwater, water planners will need to develop alternative strategies that enhance regional resilience to the impacts from climate change. The study area has embraced several strategies that have enhanced the flexibility of water management from the supply- and demand-side. These strategies include conjunctive use, outdoor water restrictions, block rate water pricing, and non-potable water reuse.

Conjunctive use of surface and groundwater resources is widely practiced and enhances local resilience to droughts by enhancing the volume of water stored in aquifers and allowing for water banking. Additionally, conjunctive use is used in the study area to carry out inter-basin transfers of water to decrease the stress of water demands on local aquifers. Table 2 highlighted the role of conjunctive use in addressing risks such as snow drought and severe hydrologic drought. However, this management strategy has vulnerability to the availability of surface water resources for ASR, which would be limited during drought years.

Water conservation has enhanced the regions ability to adapt to short- and long-term challenges. Figure 4 illustrated the scale of conservation in per capita water demand, reflecting both savings generated from infrastructure improvements like leak detection and from changes to water use by utility customers, resulting in a downward trend in average GPCD. Additionally, monthly water demand statistics illustrated the ability of residential and non-residential water users to reduce seasonal water demands in response to a severe drought.

5.3 PROSPECTS FOR POTABLE REUSE

Advantages of PR for addressing resiliency to climate change include enhancing the flexibility of both water and wastewater management. For example, PR could allow the region to increase its capacity for banking water resources, thereby reducing vulnerability to droughts. The long-term benefits of potable reuse may include greater flexibility in allocating water resources to support environmental systems and groundwater augmentation. For example, allocations of effluent for groundwater augmentation may decrease during a severe drought to compensate for shortages in surface water flows needed to support ecosystem maintenance. However, potable reuse could alleviate the strain on other water resources during a severe drought through water banking.

Climate change literature has highlighted several risk factors for water supplies in the study area. While strategies like conjunctive use and water conservation will continue to play an important role in addressing these risks, potable reuse offers a transformational path to address risk. By increasing the total potable water resources available to the study area and improving the flexibility of water and wastewater management, potable reuse may allow the region to adapt allocations of fresh and reclaimed water to address shifting environmental and community needs.

References

Al-Zahrani, M. A., & Abo-Monasar, A. (2015). Urban Residential Water Demand Prediction Based on Artificial Neural Networks and Time Series Models. *Water Resources Management*, *29*(10), 3651–3662. https://doi.org/10.1007/s11269-015-1021-z

Baldassarre, G. D., Wanders, N., AghaKouchak, A., Kuil, L., Rangecroft, S., Veldkamp, T. I. E., et al. (2018). Water shortages worsened by reservoir effects. *Nature Sustainability*, *1*(11), 617. https://doi.org/10.1038/s41893-018-0159-0

CDWR. (2015). *California Climate Science and Data for Water Resources Management*. California Department of Water Resources. Retrieved from http://www.water.ca.gov/climatechange/docs/CA_Climate_Science_and_Data_Final_Release_June_2015.pdf

FEMA. (2017). Nevada Loss Avoidance Study: Severe Storms and Flooding. U.S. Department of Homeland Security, Federal Emergency Management Agency. FEMA-4303-DR-NV. Retrieved from http://data.nbmg.unr.edu/Public/NEHMP/StateOfNevadaEnhancedHazardMitigationPlan2018.pdf

Gersonius, B., Ashley, R., Pathirana, A., & Zevenbergen, C. (2013). Climate change uncertainty: building flexibility into water and flood risk infrastructure. Climatic Change, 116(2), 411-423.

Hansen, J., Ruedy, R., Sato, M., & Lo, K. (2010). Global Surface Temperature Change. *Reviews of Geophysics*, *48*(4). https://doi.org/10.1029/2010RG000345

Haque, M. M., Rahman, A., Hagare, D., & Kibria, G. (2014). Probabilistic Water Demand Forecasting Using Projected Climatic Data for Blue Mountains Water Supply System in Australia. *Water Resources Management*, *28*(7), 1959–1971. https://doi.org/10.1007/s11269-014-0587-1

Harpold, A. A., & Brooks, P. D. (2018). Humidity determines snowpack ablation under a warming climate. *Proceedings of the National Academy of Sciences*, *115*(6), 1215–1220. https://doi.org/10.1073/pnas.1716789115

Hartmann, D. L., Tank, A. M. G. K., Rusticucci, M., Alexander, L. V., Brönnimann, S., Charabi, Y., et al. (2013). Observations: Atmosphere and surface. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al. (Eds.), *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 159–254). Cambridge, U.K. and New York, NY, USA: Cambridge University Press. Retrieved from https://miami.pure.elsevier.com/en/publications/observations-atmosphere-and-surface

Hatchett, B. J., & McEvoy, D. J. (2017). Exploring the Origins of Snow Drought in the Northern Sierra Nevada, California. *Earth Interactions*, *22*(2), 1–13. https://doi.org/10.1175/EI-D-17-0027.1

Hatchett, B. J., Daudert, B., Garner, C. B., Oakley, N. S., Putnam, A. E., & White, A. B. (2017). Winter Snow Level Rise in the Northern Sierra Nevada from 2008 to 2017. *Water*, *9*(11), 899. https://doi.org/10.3390/w9110899

IPCC. (2014). *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al., Eds.). Cambridge, U.K. and New York, NY, USA: Cambridge University Press. https://doi.org/10.1017/CBO9781107415324

Lempert, R., J. Arnold, R. Pulwarty, K. Gordon, K. Greig, C. Hawkins Hoffman, D. Sands, and C. Werrell, 2018: Reducing Risks Through Adaptation Actions. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. doi: 10.7930/NCA4.2018.CH28

Kurylyk, B. L., & MacQuarrie, K. T. B. (2013). The uncertainty associated with estimating future groundwater recharge: A summary of recent research and an example from a small unconfined aquifer in a northern humid-continental climate. *Journal of Hydrology*, *492*, 244–253. https://doi.org/10.1016/j.jhydrol.2013.03.043

Meixner, T., Manning, A. H., Stonestrom, D. A., Allen, D. M., Ajami, H., Blasch, K. W., et al. (2016). Implications of projected climate change for groundwater recharge in the western United States. *Journal of Hydrology*, *534*, 124–138. https://doi.org/10.1016/j.jhydrol.2015.12.027

Moeck, C., Brunner, P., & Hunkeler, D. (2016). The influence of model structure on groundwater recharge rates in climate-change impact studies. *Hydrogeology Journal*, *24*(5), 1171–1184. https://doi.org/10.1007/s10040-016-1367-1

Nevada Division of Environmental Protection (NDEP). (2014). *Nevada 2012 Water Quality Integrated Report with EPA Overlisting*. Carson City, NV: Nevada Departement of Environmental Protection. Retrieved from https://ndep.nv.gov/bwqp/file/IR2012_Report_Final.pdf

Nevada Division of Water Resources (NDWR). (2013). *Flood Hazards and Flood Risk in Nevada's Watersheds.* Carson City, NV: Nevada Division of Water Resources. Retrieved from http://water.nv.gov/floodrisk.aspx

Neiman, P. J., Ralph, F. M., Wick, G. A., Lundquist, J. D., & Dettinger, M. D. (2008). Meteorological Characteristics and Overland Precipitation Impacts of Atmospheric Rivers Affecting the West Coast of North America Based on Eight Years of SSM/I Satellite Observations. *Journal of Hydrometeorology*, *9*(1), 22–47. https://doi.org/10.1175/2007JHM855.1

NNWPC. (2017). *Comprehensive Regional Water Management Plan: 2016-2035*. Northern Nevada Water Planning Commission. Retrieved from http://www.wrwc.us/files/_Draft%20Chapters/PDF%20Web%20Draft%20Version.pdf

Smerdon, B. D. (2017). A synopsis of climate change effects on groundwater recharge. *Journal of Hydrology*, *555*, 125–128. https://doi.org/10.1016/j.jhydrol.2017.09.047

TREC. (2018). *Tahoe: State of the Lake Report 2018*. Davis, CA, USA: Tahoe Environmental Research Center, University of California, Davis. Retrieved from http://tahoe.ucdavis.edu/ stateofthelake/

Truckee Meadows Water Authority (TMWA). (2016). *2016-2035 Water Resource Plan, Volume II*. Reno, Nevada: Truckee Meadows Water Authority.

U.S. Census Bureau, Population Division. (2018). *Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2017. [Database]*. Retrieved from https://www.census.gov/data/tables/2017/demo/popest/counties-total.html

Report 4

Low Energy Treatment Technologies for Potable Reuse

This report summarizes the evaluation and selection of low energy water treatment technologies suitable for potable reuse projects in inland locations without readily available and economically viable means of managing brine from higher energy reverse osmosis systems, and other treatment residuals. The treatment technology evaluations are being conducting as a project element referred to as Advanced Water Treatment Technology Demonstration Project (hereafter referred to as the "demonstration project") in northern Nevada. Treatment technologies were assessed for addressing pathogens, regulated contaminants, and unregulated constituents. Evaluation criteria included effectiveness, track record, and energy intensity. Based on evaluation findings, advanced water treatment (AWT) process trains were developed. Determination of low energy water treatment technologies for potable reuse applications is based on a comprehensive energy use analysis of three AWT trains (full-stream RO, Ozone-Biofiltration with side-stream RO, and Ozone-Biofiltration without RO).

Northern Nevada Indirect Potable Reuse Feasibility Study

Low Energy Advanced Water Treatment Technologies for Reuse

Final Report

Prepared by:

Krishna Pagilla, PhD, PE, Professor
Vijay Sundaram, PE, PhD Candidate

University of Nevada, Reno

March 2019

Submitted to:

Lydia Peri, P.E., Environmental Engineer
Washoe County CSD

Low Energy Treatment Technologies

Tables

Figures

Section 1

Introduction

1.1 PURPOSE

This report summarizes the evaluation and selection of low energy water treatment technologies suitable for potable reuse projects in inland locations without readily available and economically viable means of managing brine from higher energy reverse osmosis systems, and other treatment residuals. The evaluation was performed in conjunction with the OneWater Nevada, which is northern Nevada's regional feasibility study level effort examining the economic, social, and environment impacts of indirect potable reuse (IPR). The treatment technology evaluations are being conducting as a project element referred to as Advanced Water Treatment Technology Demonstration Project (hereafter referred to as the "demonstration project") in northern Nevada.

1.2 REPORT ORGANIZATION

The report consists of the following sections:

- **Section 1 - Introduction:** This section describes the background, goals, and objectives.
- **Section 2 – Regulatory Contaminant Removal Requirements:** This section summarizes regulatory pathogens, regulated contaminants, and unregulated constituents removal requirements for injection well IPR projects.
- **Section 3 – Treatment Technologies:** This section describes available treatment technologies for each contaminant group in IPR regulations.
- **Section 4 – Selection of Advanced Water Treatment Trains:** This section summarizes the selection of advanced water treatment (AWT) trains suitable for injection well IPR projects.
- **Section 5 – Energy Use Analysis:** Described in this section are the findings of energy use analysis of AWT trains.
- **Section 6 – Summary and Conclusions**
- **Section 7 – References**

1.3 WATER REUSE DRIVERS

Water crisis is one the highest risks for urban development, industrial growth, and food security. In recent years, water stress was being experienced by communities from Cape Cod, South Africa to the State of Arizona, USA. As the world population grows, there are often competing interests for the water resources. A clear plan is needed for managing various elements of the hydrosphere (i.e., wastewater, stormwater, industrial water use, agricultural/irrigation water consumption, etc.) to meet forecast future water needs. Reuse of treated wastewater has been shown to provide a new potable water supply alternative. Storing advanced treated reclaimed water in aquifers establishes locally controlled water reserves that are relatively secure during protracted droughts.

Climate change impacts water availability, management, and infrastructure. To mitigate this impact, considerable amounts of energy are being utilized for water and wastewater conveyance and treatment. Energy use related to water infrastructure can be a considerable portion of the overall energy demand of an economy. Regulations governing water reuse must be protective of public health. However, over regulation can result in implementation of energy and resource intensive treatment and management solutions that, then, exacerbate greenhouse gas emissions and climate change. Therefore, energy consumption related to water must be minimized to the extent feasible. An understanding of low energy treatment options that can be applied to water reuse projects is essential for sustainable water resource management and therefore sustainable development.

1.4 POTABLE REUSE

Reuse of municipal effluent is not new. Well-known reuse projects have been in practice since the 1980s. However, the methods for providing advanced treatment to wastewater and the realistic options for reuse water have changed significantly as new technologies are developed and increased public education occurs. The new water planning paradigm considers all water in the hydrosphere as “one water”. When considering advanced treated reclaimed water as a reliable source for augmenting a community’s water supply, there are two basic options: “dual pipe” and “single pipe” systems.

1.4.1 Dual Pipe Systems

Dual pipe water systems use two separate water distribution systems (potable water and reclaimed water for non-potable reuse such as landscape irrigation) to meet the community’s water supply needs. Generally, “dual pipe” systems require less money on wastewater treatment but more on the water conveyance and distribution systems. Additional operation and maintenance costs are associated with “dual pipe” systems for long-term maintenance, back flow prevention, pipe flushing and biofilm control, and control of “cross connection” risks.

1.4.2 Single Pipe Systems

Single pipe systems only use the potable water distribution system. Municipal wastewater effluent is highly treated to generate exceptional quality treated water that meets all regulatory requirements for potable reuse (including Federal and State drinking water standards). The “single pipe” approach allocates more money on advanced wastewater treatment but less on distribution piping and has no cross-connection concerns. Improvements in advanced wastewater treatment technologies are tilting the economics in favor of the “single pipe” approach. Consequently, numerous cities and towns are currently planning and implementing potable reuse projects as the more economical alternative.

In implementing the single pipe approach, both regulators and the public are concerned about pathogens, potential carcinogens (such as disinfection byproducts [DBPs], pesticides, heavy metals, etc.), and chemicals of emerging concern (CECs, which include hormones, pharmaceuticals, personal care products, etc.). Within the single pipe approach, there are three methods of potable water augmentation: 1) groundwater recharge, 2) surface water augmentation, and 3) treated water utilized as an approved potable water supply. The first two methods are generally grouped under “indirect potable reuse” (IPR), and the last method is referred to as “direct potable reuse” (DPR).

1.5 POTABLE REUSE IN NORTHERN NEVADA

Groundwater recharge is being considered as the potential IPR methodology in greater Reno area in Northern Nevada. Groundwater recharge can be achieved via 1) surface spreading and 2) injection wells, as shown in Figures 1 and 2, respectively. Surface spreading utilizing spreading basins may not be feasible in areas where underlying clay layers are found in the groundwater formation. Several locations within the greater Reno area have underlying clay layers. Therefore, injection well IPR is considered to be the more widely applicable groundwater recharge methodology in Reno. However, there are a few locations conducive for surface spreading, and groundwater recharge via surface spreading IPR will be investigated in those areas. This report is focused on advanced water treatment (AWT) technologies for injection well IPR.

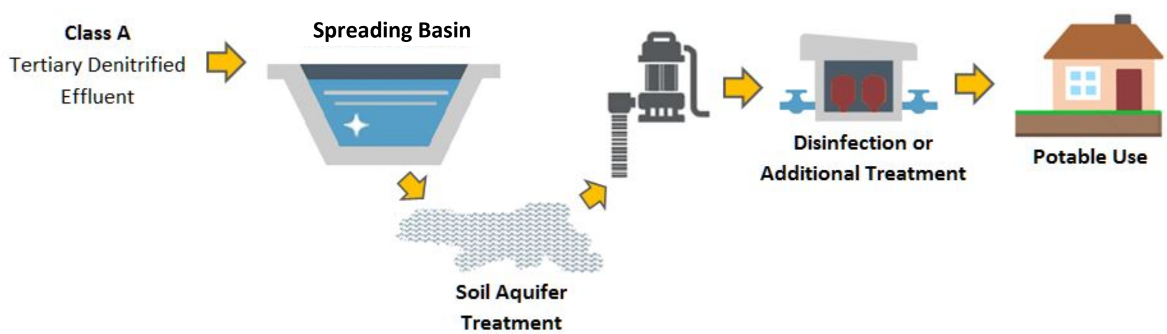


Figure 1. Indirect Potable Reuse through Spreading Basins

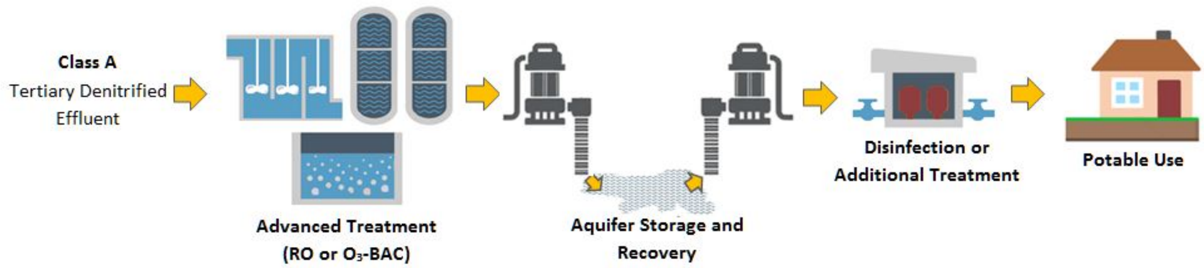


Figure 2. Indirect Potable Reuse through Injection Wells

1.6 OBJECTIVES

The objective of this study and report is to evaluate low energy AWT technologies for injection well IPR projects utilizing the approach described below:

- Summarize regulatory contaminant removal requirements for injection well IPR,
- Evaluate treatment technologies for achieving the regulatory requirements,
- Develop AWT trains based on the evaluation findings,
- Perform energy use analysis of each AWT train, and
- Determine low energy AWT train for injection well IPR projects

Section 2

Regulatory Contaminant Removal Requirements

Nevada Administrative Code (NAC) 445A.425 regulations define a Category A+ (exceptional quality) reclaimed water as suitable for groundwater recharge IPR projects (State of Nevada, 2016). Category A+ requirements include control of 1) Pathogens, 2) Regulated Contaminants, and 3) Unregulated Constituents.

2.1 PATHOGENS

Pathogens are the foremost concern with every reuse project, particularly potable reuse projects. *Giardia lamblia*, *Cryptosporidium parvum*, enteric viruses, and coliforms are often utilized as indicator pathogens. Regulatory requirements include target log removals for indicator pathogens. Nevada Category A+ requirements include 12-log enteric virus reduction, 10-log *Giardia* cyst reduction, and 10-log *Cryptosporidium* oocyst reduction prior to injection well IPR. Pathogen inactivation requirements of Nevada IPR regulations are based on total log reduction achieved from the influent wastewater (i.e., raw sewage) to the water resource recovery facility (WRRF) to the point of compliance (i.e., downstream of either the environmental buffer or the last treatment process in the AWT train). Injection well IPR pathogen inactivation requirements in Nevada are summarized in Table 1.

Table 1
State of Nevada Injection Well IPR Project Pathogen Inactivation Requirements

Pathogen	Log Reduction Requirements	Maximum Log Reduction Per Treatment Step	Minimum Log Reduction Per Treatment Step	Minimum No. of Pathogen Removal Steps Required	Comments
Virus	12	6	1	3	1 log virus reduction is allowed for each month of underground storage of treated water.
Giardia	10	6	1	3	Log reduction for saturated zone travel time is not allowed.
Crypto	10	6	1	3	Log reduction for saturated zone travel time is not allowed.

2.2 REGULATED CONTAMINANTS

Regulated contaminants requirements include contaminants listed in the National Primary drinking water regulations (USEPA, 2009) and the Nevada Secondary drinking water contaminants.

NATIONAL PRIMARY DRINKING WATER MCLS

National Primary drinking water MCLs are summarized in Tables 2 through 6 (NAC 445A.4525).

Table 2
Organic Contaminant MCLs

Contaminant	MCL (mg/L) (NAC 445A.4525)
Vinyl chloride	0.002
Benzene	0.005
Carbon tetrachloride	0.005
1,2-Dichloroethane	0.005
Trichloroethylene	0.005
para-Dichlorobenzene	0.075
1,1-Dichloroethylene	0.007
1,1,1-Trichloroethane	0.2
cis-1,2-Dichloroethylene	0.07
1,2-Dichloropropane	0.005
Ethylbenzene	0.7
Monochlorobenzene	0.1
o-Dichlorobenzene	0.6
Styrene	0.1
Tetrachloroethylene	0.005
Toluene	1
trans-1,2-Dichloroethylene	0.1
Xylenes (total)	10
Dichloromethane	0.005
1,2,4-Trichloro- benzene	0.07
1,1,2-Trichloro- ethane	0.005

Table 3
Synthetic Organic Contaminant MCLs

Contaminant	MCL (mg/L) (NAC 445A.4525)
Arachlor	0.002
Aldicarb	0.003
Aldicarb sulfoxide	0.004
Aldicarb sulfone	0.002
Atrazine	0.003
Carbofuran	0.04
Chlordane	0.002
Dibromochloropropane	0.0002
2,4-D	0.07
Ethylene dibromide	0.00005
Heptachlor	0.0004
Heptachlor epoxide	0.0002
Lindane	0.0002
Methoxychlor	0.04
Polychlorinated biphenyls	0.0005
Pentachlorophenol	0.001
Toxaphene	0.003
2,4,5-TP	0.05
Benzo[a]pyrene	0.0002
Dalapon	0.2
Di(2-ethylhexyl) adipate	0.4
Di(2-ethylhexyl) phthalate	0.006
Dinoseb	0.007
Diquat	0.02
Endothall	0.1
Endrin	0.002
Glyphosate	0.7
Hexacholorbenzene	0.001
Hexachlorocyclopentadiene	0.05
Oxamyl (Vydate)	0.2
Picloram	0.5
Simazine	0.004
2,3,7,8-TCDD (Dioxin)	3 × 10−8

Primary MCLs - Inorganic Contaminants

Table 4
Inorganic Contaminant MCLs

Contaminant	MCL (mg/L) (NAC 445A.4525)
Fluoride	4
Asbestos	7 Million Fibers/liter (longer than 10 µm).
Barium	2
Cadmium	0.005
Chromium	0.1
Mercury	0.002
Nitrate	10 (as Nitrogen)
Nitrite	1 (as Nitrogen)
Total Nitrate and Nitrite	10 (as Nitrogen)
Selenium	0.05
Antimony	0.006
Beryllium	0.004
Cyanide (as free Cyanide)	0.2
Thallium	0.002
Arsenic	0.01

Primary MCLs - Disinfection Byproducts

Table 5
Disinfection Byproduct MCLs

Disinfection Byproducts	MCL (mg/L) (NAC 445A.4525)
Bromate	0.01
Chlorite	1
Total Trihalomethanes (TTHM)	0.08
Haloacetic acids (five) (HAA5)	0.06

Primary MCLs – Radionuclides

Table 6
Radionuclides

Contaminant	MCL (NAC 445A.4525)
Alpha particles	15 picocuries per Liter (pCi/L)
Beta particles and photon emitters	4 millirems per year
Radium 226 and Radium 228 (combined)	5 pCi/L
Uranium	30 ug/L

NEVADA SECONDARY DRINKING WATER MCLS

Nevada Secondary drinking water contaminant MCLs are summarized in Table 7.

Table 7
Nevada Secondary Contaminants MCLs

Contaminant	MCL (mg/L) (NAC 445A.450, NAC 445A.455)
Aluminum	0.2
Chloride	400
Color	15 color units
Copper	1.0
Corrosivity	Non-corrosive
Fluoride	2.0
Foaming agents	0.5
Iron	0.6
Manganese	0.1
Odor	3 TON (threshold odor number)
pH	6.5 - 8.5
Silver	0.1
Sulfate	500
Total Dissolved Solids (TDS)	1,000
Zinc	5
Magnesium	150

2.3 UNREGULATED CONSTITUENTS

Unregulated constituents include chemicals of emerging concern (CECs), which are considered the “fingerprints” that the water has been impacted by human activity. CECs include hormones, pharmaceuticals, and personal care products. As part of an IPR project in Nevada, a monitoring plan must be established for unregulated constituents (NAC 445A.4525). A list of unregulated constituents is shown in Table 8. The list was developed by reviewing recommended indicator constituents for unregulated constituents monitoring, and includes hormones, pharmaceuticals, flame retardants, recalcitrant organics, and emerging disinfection byproducts (Anderson et al., 2018; Drewes et al., 2018; Minnesota Department of Health, 2018; Southern California Coastal Water Research Project, 2012; Tchobanoglous; 2015).

Table 8
Unregulated Constituents

CEC Name	Published Criterion/ Guidance Level	DPR Framework, 2015	CA DDW CEC Panel, 2018	CEC Ecosystems Panel, 2012	Min. Dept. Health, 2016
Perfluorooctanoic acid (PFOA)	0.4 ppb	√			√
Perfluorooctane sulfonate (PFOS)	0.2 ppb	√		√	√
Perchlorate	15 ppb (USEPA) 6 ppb (CA MCL)	√			
1,4 Dioxane	1 ppb	√	√		√
Ethinyl estradiol	0.2 ppt	√			√
17-β-estradiol	580	√		√	
Estrone	320 ppt	√		√	
Cotinine	1 ppb	√			
Primidone	10 ppb	√			
Phenyltoin	2 ppb	√			
Meprobamate	200 ppb	√			
Atenolol	4 ppb	√			
Carbamazepine	10 ppb	√			√
Sucralose	150 mg/L	√			
Caffeine	50 ppt				
N,N-diethyl-meta-toluamide (DEET)	200 ppb	√			√
Triclosan	2100 ppb	√	√	√	√
Tris (2-Chloroethyl) phosphate (TCEP; flame retardant)	5 ppb				√
NDMA	10 ppt		√		
NMOR	10 ppt		√		

Section 3

Treatment Technologies

3.1 PURPOSE

Evaluate available AWT technologies for achieving Category A+ requirements.

3.2 CONTAMINANT CATEGORIES

The broader contaminant categories listed in Nevada injection well IPR regulations (i.e., pathogens, regulated contaminants, and unregulated constituents) are further subdivided into the following categories for this evaluation:

- Organics and Nutrients
- Suspended Solids and Turbidity
- Pathogens
- DBPs
- Heavy Metals
- CECs
- Salinity

The abovementioned seven categories are developed based on methodologies utilized in water resource recovery facility (WRRF) design. For example, wastewater organics, nutrients, and suspended solids must be removed prior to employing disinfection technologies for effective performance of the disinfection technology.

3.3 ORGANICS AND NUTRIENTS

Secondary biological wastewater treatment plants are an important component in producing reliable water for potable reuse. Preliminary treatment physically removes large materials and grit from the raw waste influent. Primary sedimentation, if included, removes less bioavailable constituents in wastewater prior to secondary treatment. Secondary treatment provides biological removal of carbon, nitrogen, and some incidental portion of phosphorus and other contaminants.

AWT trains rely on the efficiency of secondary treatment processes, which are responsible for considerable pathogen inactivation as well as removal of organics and nitrogen (Rose et al., 2004). Pathogen removal during secondary treatment has been well documented. Chang et al. (2014), reported 2 log removal for virus; 1 log removal for *Cryptosporidium*; and 2 log removal for *Giardia* in secondary treatment.

Conventional activated sludge (CAS) process with secondary clarifiers, and membrane bioreactors (MBRs) are the two main technologies utilized for secondary biological treatment today. The difference in these two technologies is the solids separation methodology. CAS plants utilize secondary clarifiers for gravity-based separation of solids from the water. In MBR processes, membrane (e.g., ultrafiltration [pore size around 0.01 μM] or microfiltration [pore size around 0.1 μM]) modules are installed inside activated sludge process tanks and vacuum is utilized to pull the water through the membranes. A side-by-side evaluation of these two technologies is summarized in Table 9.

Table 9
Organics and Nutrient Removal Technologies

System Type	Strengths	Weaknesses	Secondary Benefits
CAS	Widely utilized secondary treatment with longest track record	Requires clarifiers and filters	May provide up to 1-2 log removal of Crypto and Giardia
MBR	Eliminates the need for clarifiers and filters; Lower space requirements; Substantial turbidity/ particulate removal	Proprietary technology; Requires maintenance and cleaning steps	May provide up to 4 log removal of Crypto and Giardia

3.4 SUSPENDED SOLIDS AND TURBIDITY

Under the multi-barrier approach of IPR projects, achieving required log removals of protozoans, Cryptosporidium parvum (Crypto) and Giardia lamblia (Giardia), during filtration is extremely important. In drinking water systems, Crypto and Giardia log reductions during filtration are credited only when filtration systems are designed and operated per EPA requirements and when combined filter effluent turbidity is less than 0.3 NTU 95% of time (EPA 2010).

For IPR projects, the critical issue is receiving at least 3 log removal credits for Giardia and Crypto during filtration. Three log removal of Giardia and Crypto has been demonstrated to occur in drinking water systems when combined filter effluent turbidity is less than 0.3 NTU 95% of time (EPA 2006; EPA 2010).

Based on the industry experience, wastewater filtration technologies with performance records achieving a less than 0.3 NTU effluent turbidity reliably are believed to include:

- Granular media filters with coagulation, flocculation, and clarification pretreatment.
- Microfiltration/ultrafiltration/Membrane Bioreactor (MBR) with micro- or ultrafiltration membranes.

In MBR systems, membranes are utilized as an integrated unit within the secondary biological treatment process thereby eliminating the need for secondary clarifiers and downstream tertiary filters. Therefore, for wastewater applications, MBRs are generally more cost effective than standalone microfiltration or ultrafiltration systems.

Based on the industry experience, wastewater filtration technologies with performance records not achieving less than 0.3 NTU effluent turbidity reliably are believed to include:

- Granular media filters, alone.
- Continuous backwash media filters.
- Disk filters.

Therefore, for IPR projects that already have an existing CAS process with nitrogen removal, addition of granular media filters with coagulation, flocculation, and clarification pretreatment is recommended. For IPR projects with new secondary biological treatment, use of MBR for wastewater treatment and particle removal to less than 0.3 NTU is recommended.

An evaluation of filtration technologies is summarized in Table 10.

Table 10
Filtration Technologies

Filtration System Type	Strengths	Weaknesses	Secondary Benefits
Granular Media Filter including coagulation, flocculation, and clarification	Less than 0.3 NTU effluent turbidity with adequate pretreatment	Requires pretreatment during high NTU events	Versatile: Provides pathogen removal. Useful as a polishing step for phosphorus and CEC removal, as needed.
Continuous Backwash Media Filter	Smaller footprint and lower capital cost	Moderately effective in producing low turbidity water	None
Disk Filter	Low capital cost	Turbidity: 1-2 NTU Requires pretreatment during high NTU	None

		events	
MBR	High quality effluent (less than 0.3 NTU) even during upsets	High cost	Provides pathogen removal

3.5 PATHOGENS

Regarding pathogen disinfection processes, the track record of chlorination is the best in terms of the number of operational years. However, the chlorination process generates disinfection byproducts such as trihalomethanes and haloacetic acids that have National Primary MCLs. Therefore, chlorination is not suitable as primary disinfectant in IPR applications. Ozone has a proven track record of providing virus inactivation and has been utilized in the drinking water industry for Cryptosporidium parvum and Giardia lamblia inactivation. Ozonation also oxidizes refractory organics and converts them to readily biodegradable organics. Therefore, ozonation followed by biofiltration is being considered for as an industry trend for potable reuse applications. Ultraviolet (UV) disinfection and advanced oxidation systems are widely utilized for potable reuse projects. Depending on the energy applied, UV systems are utilized for disinfection only or for disinfection and advanced oxidation of organics. UV systems offer excellent Cryptosporidium, Giardia, and virus inactivation. UV advanced oxidation process offers removal of CECs and disinfection byproducts such as NDMA. An evaluation of disinfection technologies is summarized in Table 11.

Table 11
Disinfection Technologies

Disinfection Process Type	Strengths	Weaknesses	Secondary Benefits
Chlorine	Has longest track record; Provides disinfectant residual	Generates disinfection byproducts such as THMs and HAAs; Adds salt or TDS	Provides oxidation of some CECs
UV	Provides excellent Cryptosporidium and Giardia log removal; Does not generate any disinfection byproducts	Requires maintenance and cleaning steps; Energy requirements are influenced by water quality	None
Ozone	Provides excellent virus inactivation	High cost if utilized only for disinfection; Generates disinfection byproducts such as bromate and NDMA	Provides substantial CEC removal; Improves color, taste, and odor

3.6 DISINFECTION BYPRODUCTS

Disinfection byproducts (DBPs) are commonly detected in potable water supplies, regardless of whether water reuse is involved. Common DBPs include total trihalomethanes (TTHMs), haloacetic acids (HAAs), bromate, and NDMA (N-Nitrosodimethlyamine). Control of DBPs during water treatment and distribution requires a deep understanding of DBP precursors and formation pathways. As examples, total organic carbon (TOC) is a good indicator of the presence of TTHM precursors. TTHMs can be formed during chlorine-based disinfection processes. Formation of bromate during ozonation is a concern if relatively high levels of bromide are present in the influent. NDMA is an emerging DBP formed during chloramination and, to a lesser extent, during ozonation. The key to IPR projects, as with conventional projects to a lesser extent, is controlling DBP concentrations to acceptable levels. Potential technologies for controlling DBPs by removing DBP precursors and/or removing DBPs include granular activated carbon (GAC) and reverse osmosis (RO). GAC requires regular media change outs upon exhaustion. RO generates a continuous reject stream. For inland IPR project locations, replacing GAC media is simpler and cost effective when compared to specialized disposal needed for RO reject. An evaluation of DBP mitigation and control technologies is summarized in Table 12.

Table 12
Candidate Technologies for DBP Mitigation and Control

Process Type	Strengths	Weaknesses	Secondary Benefits
Granular Activated Carbon (GAC)	Removes most of the flame retardants and PFCs; Reduces bulk TOC	Media replacement frequency is a function of contaminant and bulk TOC removal	Increased UVT, which reduces the downstream UV system requirement
Reverse Osmosis (RO)	Removes bulk organics and most of the organic chemicals	Generates a continuous reject stream	Salinity reduction; Heavy metal reduction

3.7 HEAVY METALS

Heavy metals removal is necessary in relatively few IPR projects. When necessary, conventional filters with coagulation, flocculation, and clarification can be utilized for heavy metals removal if conditions facilitating heavy metal removal are created in the system (e.g., maintenance of pH optimal for metal precipitation). Ion exchange (IX) offers effective removal of heavy metals by employing ion-selective resins. However, IX requires regular resin replacement or regeneration. These IX waste streams from regeneration must be managed. Reverse osmosis provides removal of a wide-range of heavy metals. However, RO generates a continuous reject stream that contains the heavy metals and this reject stream requires specialized disposal. Evaluation of candidate treatment processes for removal of heavy metals is summarized in Table 13.

Table 13
Candidate Technologies for Heavy Metal Removal

Process Type	Strengths	Weaknesses	Secondary Benefits
Ion Exchange (IX)	Removes boron and heavy metals	Resin replacement frequency is a function of contaminant removal	May provide incidental removal of other anions and cations
Coagulation/ Flocculation/ Clarification	Removes a wide range of heavy metals	Generates chemical sludge	Pathogen reduction; Bulk organics reduction
Reverse Osmosis	Removes a wide range of heavy metals	Generates reject stream requiring specialized disposal	RO provides salinity and CEC control

3.8 CHEMICALS OF EMERGING CONCERN (CECS)

CEC removal has been expensive until recent advances in technology. Historically, RO was used to remove CECs. RO is expensive, particularly for inland IPR projects where discharge of RO reject to the ocean is not feasible. Recent research of the treatment performance of the Ozone-Biofiltration process train has demonstrated that it is cost-effective for CEC control (Sundaram, et al., 2014). A side-by-side comparison of RO and Ozone-Biofiltration technologies is summarized in Table 14.

Table 14
Comparison of Technologies for CEC Removal

Category	RO	Ozone-Biofiltration
Refractory Organics (e.g., CECs)	Concentrated in brine stream	Degraded and/or adsorbed
Reject/Side Streams	Some	None
Total Dissolved Solids (TDS)	Concentrated in brine stream	Unchanged
Corrosivity	Increased	Unchanged
Net TOC Removal	Limit of Technology ≤0.5 mg/L	Function of carbon change out frequency.
Energy, Maintenance, & Capital Cost	Highest on all accounts	Substantial Advantage

3.9 SALINITY

RO and electrodialysis reversal (EDR) are two technologies available for salinity control. RO systems are widely used, have a proven track record in potable reuse projects in providing multiple other benefits (e.g., CEC, heavy metal, and pathogen removal), and require smaller footprint when compared to EDR. A side-by-side comparison of salinity removal technologies is summarized in Table 15.

Table 15
Comparison of Technologies for Salinity Control

Category	RO	Electrodialysis Reversal (EDR)
Effectiveness	Highly effective in reject wide-range of salts	Moderately effective in rejecting salts
Reject/Side Streams	Some	Some
Footprint	Smaller footprint	Relatively large footprint
Pretreatment Requirements	UF/MF	UF/MF/GMF
Energy, Maintenance, & Capital Cost	Moderate	High

Selection of Advanced Water Treatment (AWT) Trains

4.1 PURPOSE

Based on the evaluation summarized in Section 3, develop AWT Trains for injection well IPR projects.

4.2 AWT TRAIN #1 – OZONE-BIOFILTRATION WITH NO REVERSE OSMOSIS

Treatment technologies included in AWT Train #1 (and the purpose of each) are summarized in Table 16. AWT Train #1 is suitable for injection well IPR projects where salinity control is not required in the near-term future.

Table 16
AWT Train #1 Summary of Treatment Technologies and Purpose

Treatment Technology	Purpose
Secondary Treatment	Removes organics and nutrients. Provides some refractory organics removal and pathogen inactivation.
Granular media filtration (GMF) with coagulation/flocculation/clarification pretreatment	Removes suspended solids and turbidity. Provides considerable log removal of Crypto and Giardia.
Ozonation	Removes CECs and provides pathogen inactivation.
Biofiltration	Removes CECs and ozonation byproducts
Granular Activated Carbon (GAC)	Removes refractory organics and provides polishing treatment for a wide range of organics
UV Disinfection/AOP	Provides pathogen inactivation and advanced oxidation of organics

Proposed AWT Train #1 pathogen log reduction credit summary for meeting Category A+ requirements is provided in Table 17.

Table 17
AWT Train #1 Pathogen Log Reduction Credit Summary for Injection Well IPR

Injection Well IPR (Ozone-BAC AWTF)			
Process	**Virus**	**Giardia**	**Crypto**
Secondary Treatment	2	2	1
Coagulation/Flocculation/Clarification/Granular Media Filtration		3	3
Ozonation	6	TBD	TBD
Biological Activated Carbon Filtration	TBD	TBD	TBD
Granular Activated Carbon	TBD	TBD	TBD
UV Disinfection/AOP	5	6	6
Effluent Polishing (if needed)		1+	1+
Injection - Saturated Zone Travel Time	6		
Total Log Reduction	**19**	**12+**	**11+**
Required Log Reduction	**12**	**10**	**10**

TBD – To be determined.

A multiple barrier approach utilized in AWT Train #1 for addressing Category A+ requirements is summarized in Table 18.

Table 18
AWT Train #1 Multiple Barrier Approach for Injection Well IPR

	Suspended Solids Removal	Pathogen Removal	Regulated Contaminants Removal	Unregulated Constituents Removal	Bulk Organics Removal
Secondary Treatment	√	√	√	√	√
Coag-Floc-Clar GMF (see Note 1)	√	√	√	-	√
Ozone	-	√	√	√	-
Biofiltration	√		√	√	√
GAC	√		√	√	√
UV AOP	-	√	-	√	-
Conveyance System Biological Growth Control (as needed)	-	-	-	-	-
Injection Well	-	-	-	-	-
Saturated Zone	-	√	-	-	-
Number of Barriers	**4**	**5**	**5**	**5**	**4**

4.3 AWT TRAIN #2 - OZONE-BIOFILTRATION WITH SIDE-STREAM RO

AWT #2 consists of an AWT Train #1 with side-stream RO treatment for a portion of the water being treated to trim salinity from the injection well IPR water when required. AWT Train #2 treatment technologies (and purpose of each) are summarized in Table 19.

Table 19
AWT Train #2 Summary of Treatment Technologies and Purpose

Treatment Technology	Purpose
Secondary Treatment	Removes organics and nutrients. Provides some refractory organics removal and pathogen inactivation.
Granular media filtration with coagulation/flocculation/clarification pretreatment	Removes suspended solids and turbidity. Provides considerable log removal of Crypto and Giardia.
Ozonation	Removes CECs and provides pathogen inactivation.
Biofiltration	Removes CECs and ozonation byproducts
Granular Activated Carbon (GAC)	Removes refractory organics and provides polishing treatment for a wide range of organics
Side-Stream Reverse Osmosis	Removes salts, heavy metals, and refractor organics
RO Reject Management	Reduces RO Reject volume prior to disposal
UV AOP	Provides pathogen inactivation and advanced oxidation of organics

A multiple barrier approach utilized in AWT Train #2 for addressing Category A+ requirements is summarized in Table 20.

Table 20
AWT Train #2 Multiple Barrier Approach for Injection Well IPR

	Suspended Solids Removal	Pathogen Removal	Regulated Contaminants Removal	Unregulated Constituents Removal	Bulk Organics Removal
Secondary Treatment	√	√	√	√	√
Coag-Floc-Clar GMF (see Note 1)	√	√	√	-	√
Ozone	-	√	√	√	-
Biofiltration	√		√	√	√
GAC	√		√	√	√
Side-Stream RO	√		√	√	√
UV AOP	-	√	-	√	-
Conveyance System Biological Growth Control (as needed)	-	-	-	-	-
Injection Well	-	-	-	-	-
Saturated Zone	-	√	-	-	-
Number of Barriers	**5**	**5**	**6**	**5**	**5**

4.4 AWT TRAIN #3 – FULL-STREAM RO (NO OZONE-BIOFILTRATION)

Treatment technologies included in AWT Train # 3 (and purpose of each) are summarized in Table 21. AWT Train #3 is suitable for injection well IPR projects where substantial salinity control is required.

Table 21
AWT Train #3 Summary of Treatment Technologies and Purpose

Treatment Technology	Purpose
Secondary Treatment	Removes organics and nutrients. Provides some refractory organics removal and pathogen inactivation.
UF/MF	Removes suspended solids and turbidity. Provides substantial log removal of Crypto and Giardia.
RO	Removes CECs, heavy metals, bulk organics, and pathogens.
UV AOP	Provides pathogen inactivation and advanced oxidation of organics
RO Reject Management	Reduces RO Reject volume prior to disposal

A multiple barrier approach utilized in AWT Train #3 for addressing Category A+ requirements is summarized in Table 22.

Table 22
AWT Train #3 Multiple Barrier Approach for Injection Well IPR

	Suspended Solids Removal	Pathogen Removal	Regulated Contaminants Removal	Unregulated Constituents Removal	Bulk Organics Removal
Secondary Treatment	√	√	√	√	√
MF/UF	√	√	√	-	√
RO	√	√	√	√	√
UV AOP	-	√	-	√	-
Conveyance System Biological Growth Control (as needed)	-	-	-	-	-
Injection Well	-	-	-	-	-
Saturated Zone	-	√	-	-	-
Number of Barriers	**3**	**5**	**3**	**3**	**3**

Energy Use Analysis

5.1 PURPOSE

The purpose of this section is to summarize the findings of the energy use analysis of the three treatment trains analyzed in Section 4.

5.2 ENERGY USE ANALYSIS

An energy use analysis for AWT Trains (#1, #2, and #3 as described in Section 4) was performed. Findings of the energy use analysis are shown in Figure 3.

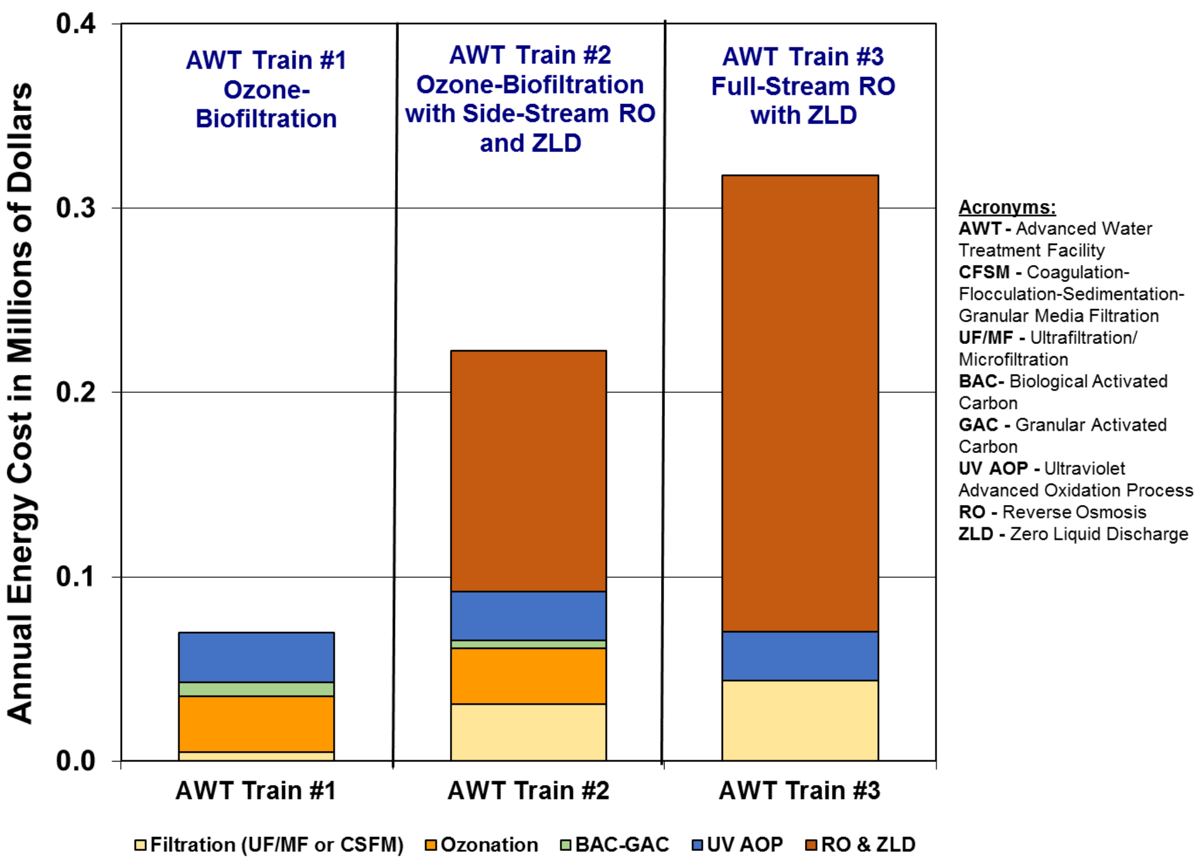


Figure 3. Energy Use Analysis Summary

As shown, AWT Train #1 uses substantially less energy than either of the other AWT Trains in inland projects like those in Northern Nevada where 1) oceanic disposal of RO reject is not feasible, and 2) RO reject management requires zero liquid discharge (ZLD) solutions. AWT Train #1 appears to be the best apparent alternative for injection well IPR projects where salinity reduction is not a necessity immediately, or in the near-term future. When some salinity reduction is needed, AWT Train #2 appears to be the best apparent alternative. AWT #3 is the best apparent alternative only when major salinity reduction is needed. In the Northern Nevada setting, it appears that AWT Train #1 is the best alternative for implementation.

5.3 BASIS OF ENERGY USE ANALYSIS

Annual energy costs per Mgal/d of feed are estimated for AWT Trains #1, #2, and #3 (as shown in Figure 3) are based on the energy data available from previous studies (EPR and WRF, 2013; EPA 1999) and the following assumptions:

Applicable to all three AWT Trains:

1. Unit power cost is $0.105/kWh
2. Influent to the AWT would be fully nitrified and denitrified secondary effluent.
3. Energy uses related to RO membrane, biofilter media, and GAC carbon replacement are not included.

Applicable to AWT Trains with RO (#2 and #3):

4. Influent to the RO membrane would receive microfiltration or ultrafiltration pretreatment.
5. As a mitigation measure for NDMA, RO Permeate would be treated by UV AOP.
6. RO recovery would be 85% and RO TDS removal efficiency would be 95%
7. The Zero Liquid Discharge (ZLD) process train would include (in the order of use): concentrate treatment process, brine concentrator, and crystallizer.

Applicable to AWT Trains with Ozone-Biofiltration (#1 and #2):

8. Ozone dose would be about 0.9 Ozone:TOC ratio
9. GAC effluent would be treated/disinfected utilizing UV AOP

Applicable to AWT Train #2:

10. For AWT Train #2 consisting of Ozone-Biofiltration and side-stream RO, the GAC effluent will be split into two streams. Part of the GAC effluent (roughly 50%) would be further treated by RO for salinity reduction. Influent to UV AOP would be a blend between RO permeate and GAC effluent.
11. For scenarios consisting of side-stream RO for salinity reduction, the salinity of secondary effluent would be reduced from 1000 mg/L to 500 mg/L.
12. When the side-stream RO is installed downstream of Ozone-Biofiltration treatment, the power requirement of RO will decrease by 15% and concentrate management will be decrease by 10% because of the higher quality of RO feed water in these scenarios.

Section 6

Summary and Conclusions

An evaluation of treatment technologies suitable for producing Nevada Reuse Category A+ (Exceptional Quality) water for injection well indirect potable reuse was completed. Treatment technologies were assessed for addressing pathogens, regulated contaminants, and unregulated constituents. Evaluation criteria included effectiveness, track record, and energy intensity. Based on evaluation findings, three advanced water treatment (AWT) process trains were developed: AWT Train #1 (Ozone-Biofiltration without RO), AWT Train #2 (Ozone-Biofiltration with side-stream RO) and AWT Train #3 (Full-stream RO with zero liquid discharge for brine management).

AWT Train #1 is the best apparent alternative for injection well IPR projects in Northern Nevada when salinity reduction is not needed in the near-term future. AWT Train #2 is the best apparent alternative for injection well IPR projects when minor to moderate salinity reduction is needed immediately. AWT Train #3 is the best apparent alternative when major salinity reduction is needed.

Findings from comparative energy use analysis show that the AWT Train #3 has substantially higher energy use when implemented in inland injection well IPR projects. Due to high energy use and cost that AWT Train #3 is likely infeasible in most inland locations except in very specific situations.

AWT Train #1 offers a conceptualized approach for IPR in the Reno area. Further demonstration and validation are being provided by pilot testing and demonstration trials.

Section 7

References

Anderson, P., Denslow, N., Drewes, J.E., Olivieri, A., Schlenk, D., Snyder, S. (2018). Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water. California Environmental Protection Agency (CalEPA)

Electric Power Research Institute (EPRI) and Water Research Foundation (WRF) (2013), Electricity Use and Management in the Municipal Water Supply and Wastewater Industries, 3002001433, Final Report, November 2013.

Chang C. H. C.; Fu, P.L.K.; Nellor, M.H. (2014) A Case Study of Multi Barrier Treatment Based on the Expanded Alamitos Barrier Recycled Water Project in Los Angeles County, California, Proceedings of WEFTEC 2014

Drewes, J. E., Anderson, P., Denslow, N., Jakubowski, W., Olivieri, A. W., Schlenk, D., & Snyder, S. A. (2018). *Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water: Recommendations of a Science Advisory Panel Convened by the State Water Resources Control Board*.

Minnesota Department of Health Contaminants of Emerging Concern Program. (2018, September 30). Nominated Contaminants Status Table. Retrieved from http://www.health.state.mn.us/divs/eh/risk/guidance/dwec/chemstatus.pdf

Rose, J.B., Nowlin, H., Farrah, S.R., Harwood, V., Levine, A., Lukasik, J. Menendez, P. & Scott, T.M., (2004) Reduction of Pathogens, Indicator Bacteria, and Alternative Indicators by Wastewater Treatment and Reclamation Processes. Water Environment Research Foundation Report 00-PUM-2T, Alexandria, VA.

Southern California Coastal Water Research Project, Costa Mesa, CA (2012), Monitoring Strategies for Chemicals of Emerging Concern (CECs) in California's Aquatic Ecosystems.

State of Nevada, Nevada IPR Regulations, 2016 https://www.leg.state.nv.us/nac/nac-445a.html#NAC445ASec27612

Sundaram, V. Emerick, R.W., and Shumaker S.E. (2014) *Advanced treatment process for pharmaceuticals, endocrine disruptors, and flame retardants removal*. Water Environment Research 86 (2), 111-22.

Tchobanoglous, G., Cotruvo, J., Crook, J., McDonald, E., Olivieri, A., Salveson, A., & Trussell, S. R. (2015). Framework for Direct Potable Reuse. *WateReuse Research Foundation*.

USEPA. (1999) Alternative Disinfectants and Oxidants Guidance Manual, Chapter 3 – Ozone, EPA 815-R-99-014, Office of Water, April 1999.

USEPA (2006), National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule. https://www.federalregister.gov/documents/2006/01/05/06-4/national-primary-drinking-water-regulations-long-term-2-enhanced-surface-water-treatment-rule#h-54

United States Environmental Protection Agency (2009), National Primary Drinking Water Regulations, EPA Office of Ground Water and Drinking Water. https://www.epa.gov/ground-water-and-drinking-water

USEPA (2010) Comprehensive Surface Water Treatment Rules Quick Reference Guide: Systems Using Conventional or Direct Filtration, EPA816-F-10-074, Office of Water, August 2010 https://nepis.epa.gov/Exe/ZyPDF.cgi/P100N2UO.PDF?Dockey=P100N2UO.PDF