IMPLEMENTATION OF AN INLAND BRACKISH GROUNDWATER SUPPLY PROJECT FROM GROUNDWATER RECHARGE TO REVERSE OSMOSIS TREATMENT PLANT AND BRINE DISPOSAL

Dave Kaunisto, East Cherry Creek Valley Water and Sanitation District, Aurora, CO
Kelly DiNatale, DiNatale Water Consultants, Boulder, CO
Doug Brown, CDM, Denver, CO

Introduction

East Cherry Creek Valley Water and Sanitation District (ECCV) is constructing a 10-million-gallons-per-day (mgd) Reverse Osmosis (RO) Plant for treating brackish groundwater. The plan includes alluvial recharge, transient underground storage, withdrawal via shallow alluvial wells, RO treatment with brine minimization, and deep injection well disposal. State regulatory agencies for both water and wastewater were actively involved. Project implementation included active public participation regulatory and legal challenges concerning brine disposal, the RO treatment process, alluvial well filtration credit, and ultraviolet (UV) treatment of RO bypass blending water. Two different methods of brine disposal were permitted—deep well injection (U.S. Environmental Protection Agency [EPA]) and alluvial groundwater infiltration (Colorado Department of Public Health and Environment [CDPHE]).

ECCV serves approximately 60,000 customers in the Denver metro area. It also has entered into a contract with the Arapahoe County Water and Wastewater Authority (ACWWA) to treat additional water supplies. Both ECCV and ACWWA have been reliant on non-renewable deep groundwater with declining well yields increasing the urgency to develop renewable water supply sources. There are very limited high quality water supplies available for development along the arid front range of Colorado, and ECCV, working with United Water and Sanitation District, developed the Northern Water Supply Project. This project includes the following elements:

- Development of an alluvial well field in the Beebe Draw for withdrawal of brackish groundwater (completed and pumping water since 2006)
- Design and construction of a 32-mile, 48-inch pipeline and two pump stations with a total elevation lift of 1,000 feet (completed 2006)
- Design and regulatory approval of groundwater recharge facilities including detailed MODFLOW groundwater modeling and pilot testing of a recharge facility completed with construction of additional recharge ponds (in 2010)
- Water Court approval of the well pumping depletions replacement plan (decreed in 2009) and managed underground storage (in process)
- Development of water quality goals for finished water quality of 300 milligrams per liter (mg/L) total dissolved solids (TDS) and 100 mg/L total hardness (completed)
- Pilot testing of two brine minimization processes (completed 2008) and analysis of the capital and operations and maintenance (O&M) costs for various brine disposal options (2009)
- Design and construction of a 10-mgd (first phase) RO water treatment plant (WTP) consisting of 6.7 mgd of low TDS permeate production and 3.3 mgd of bypass blending water with UV disinfection, with construction commenced in June 2010
- State regulatory approval of disposal of brine to alluvial groundwater based on a non-degradation standard through recharge (accretion) basins after blending (approved 2009)

- EPA regulatory approval of Class 1 disposal wells for brine injection (approved May 2010)
- Construction and testing of first deep disposal well (fall 2010)

East Cherry Creek Valley Water Supply System Development

ECCV is located in unincorporated Arapahoe County and the City of Centennial approximately 11 miles southeast of downtown Denver, Colorado (Figure 1).

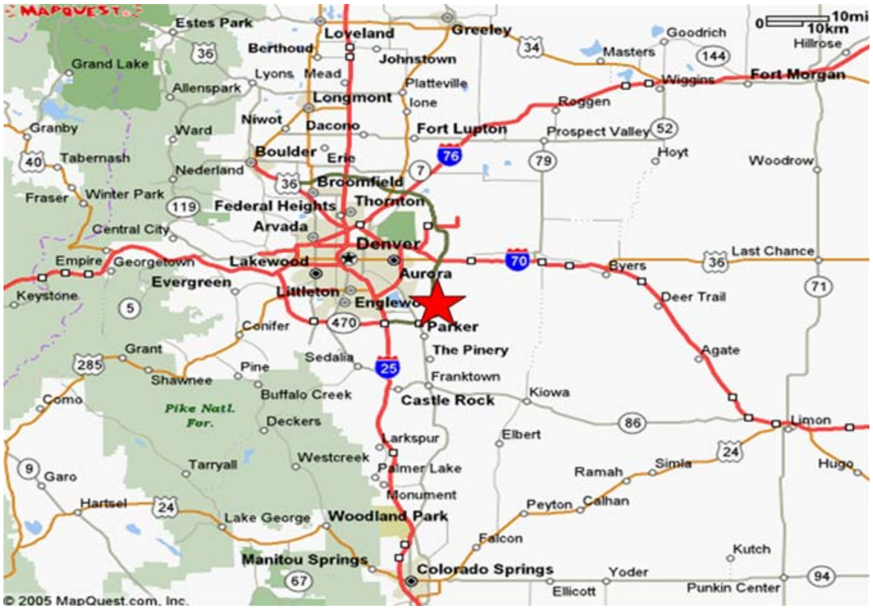

Figure 1. Vicinity Map

Major development commenced in 1977. Population in 1981 was approximately 3,100 and has steadily increased to a population of approximately 56,600 in 2008. Annual growth rates in the early 1980s were as high as 40%. Since 1981 growth has averaged 12% per year. With the recent downturn in the housing market, growth rates are now in the single digits. At buildout, water demand is projected at approximately 14,000 acre-feet per year (AFY).

ECCV is located in an area of limited and unreliable surface water supplies. The South Platte River is located many miles to the west and at the time of District formation, ECCV did not have the financial resources to develop the water rights and infrastructure necessary to divert, store, convey, and treat surface water supplies from the South Platte or major tributaries. Local streams in the vicinity of ECCV have intermittent flow and are unreliable for meeting the primary water supply needs of a water district such as ECCV. As a result, at the time of District formation, water supply development initially focused on non-tributary groundwater. Groundwater supplies in the Denver basin formation were readily available, drought resistant, could be developed incrementally at a relatively low cost, and needed minimal treatment. ECCV's goal was to eventually develop renewable water supplies to supplement the existing non-tributary groundwater supplies as the District developed and financial resources were sufficient to finance renewable water supply development.

ECCV is developing renewable surface water supplies through its Northern Water Supply Project. The Northern Water Supply Project is a multi-phase project to deliver surface water from the South Platte River to ECCV and reduce the reliance on Denver Basin non-tributary groundwater. ECCV initiated the planning of the Northern Water Supply Project in 2003. The Northern Water Supply Project provides a renewable surface water source that diversifies the resources of ECCV's water supply system and provides a reliable and sustainable water supply for ECCV's customers. This project was developed in cooperation with United Water and Sanitation District and the Farmers Reservoir and Irrigation Company. The initial phase of the Northern Water Supply Project, known as H2'06, was completed in 2006 and included the initial pumping of renewable water rights acquisitions that will eventually provide approximately 6,000 acre-feet (AF) of renewable surface water rights. The infrastructure constructed in the initial phase included six wells in the Beebe Draw alluvium approximately 2.5 miles downstream from Barr Lake, a 48-inch, 32-mile pipeline (Northern Pipeline), two pumping stations, and storage tanks to deliver potable water to ECCV, as shown in Figure 2. This initial infrastructure investment was over $75M. ECCV takes delivery of water pumped from the alluvial wells in the Beebe Draw and transports it to ECCV's storage tanks on the eastern edge of ECCV near Smoky Hill Road and E-470. At this location, water is blended with ECCV's other supplies and distributed to ECCV's customers.

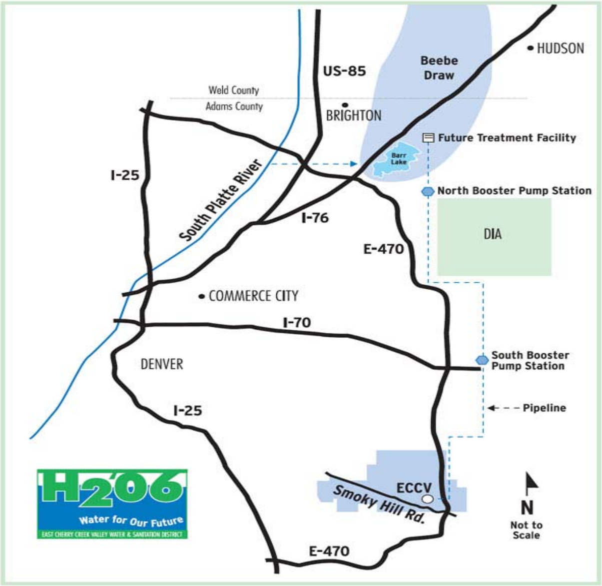

Figure 2. H2'06 Phase 1

Alluvial Groundwater Recharge and Storage

The Beebe Draw alluvium is a paleo-channel of the South Platte River. The alluvium is recharged by seepage from Barr Lake and the canals that deliver irrigation water out of Barr Lake. A MODFLOW groundwater model was constructed of the Beebe Draw. The model results indicated that as ECCV develops its Beebe Draw well field and increases annual pumping beyond 6,000 AFY, additional recharge of the aquifer may be necessary to sustain well pumping rates. In addition to supporting well pumping yields, it was important that the recharge be conducted in a manner that results in sufficient aquifer travel time to maintain alluvial filtration credits and improve water quality. A test recharge pond was constructed to evaluate recharge rates and to calibrate the groundwater model. The testing indicated that average recharge rates of approximately 1 foot per day were sustainable. This suggests that a 10-acre recharge pond could sustain infiltration rates of 10 AFY, or 5 cubic feet per second (cfs).

Up to 12 recharge ponds will be constructed in the Beebe Draw to provide for sustainable well pumping rates and to replace the pumping depletions from the wells as required under Colorado water law. Water will be routed to different recharge ponds depending on the need and timing of replacing well pumping depletions, sustain pumping rates, or manage recharge volumes to provide for transient groundwater storage for firming of water supplies.

The CDPHE designated the wells as Groundwater Under the Direct Influence (GUDI) of Surface Water based on small seasonal variation in nitrates and moderate microparticle analysis (MPA). CDPHE also recognized that the travel distance and time from potential recharge sources minimized the potential risk of surface water contamination and granted the wells 2-logs of natural filtration credits toward the required 3-logs of *giardia* inactivation credits required for surface water sources. CDPHE requires turbidity monitoring of the individual wells to confirm that wells are providing sufficient natural filtration, and during the 3 years of operation the turbidity of the well water is consistently below 0.1 NTU. The additional *giardia* removal credits are provided by the UV disinfection system for the bypass blending flow and free chlorine disinfection of the RO permeate.

Selection of Water Treatment Processes

In order to meet long-term water needs and water quality goals, additional water treatment and softening is necessary. Water quality objectives were established to provide drinking water that meets all current and anticipated drinking water standards, is acceptable to the District's customers, and is chemically stable in the distribution system. Table 1 presents the District's blended water quality goals along with secondary standards reflecting aesthetic water quality objectives such as taste, odor, and mineral content. ECCV will continue to comply with primary drinking water standards, i.e., maximum contaminant levels (MCLs) established by CDPHE and EPA.

Table 1. Finished Water Quality Goals

Parameter	**ECCV Goal**	**SMCL**[a]	**Minimizes Potential for:**
Hardness, mg/L	100 to 125	—	Hardness, deposits, mineral taste
Calcium, mg/L	< 30	—	Hardness, deposits, mineral taste
Magnesium, mg/L	< 10	—	Hardness, deposits, mineral taste
Sodium, mg/L	< 50	—	Salt ingestion from drinking water
Chloride, mg/L	< 50	250	Salty taste
TDS, mg/L	250 to 350	500	Hardness, deposits, colored water, staining, salty taste
CCPP, mg/L	4 to 10	"Noncorrosive"	Metallic taste, corrosion, fixture staining
Color	SMCL or lower	15 color units	Visible tint to the water
Fluoride, mg/L	SMCL or lower	2	Tooth discoloration
Iron, mg/L	SMCL or lower	0.3	Rusty color, sediment, metallic taste, reddish or orange staining of fixtures or clothes
Manganese, mg/L	SMCL or lower	0.05	Black to brown color, black staining, bitter metallic taste
Odor, TON[b]	SMCL or lower	3	"Rotten egg", musty, or chemical smell
Gross Alpha, pCi/L	SDWA or lower	15 [c]	

(a) Dash mark (—) denotes that an SMCL has not been established by EPA or CDPHE; not all constituents are listed here since District's NWS sources are well-below the recommended SMCL
(b) TON denotes threshold odor number
(c) Gross alpha is regulated by the Safe Drinking Water Act (SDWA)

ECCV has established 300 mg/L TDS and 100 mg/L hardness along with SMCL criteria or lower for other constituents. Blending analyses, therefore, focused on estimating blend ratios based on TDS and hardness values since the alluvial Beebe Draw groundwater supply exceeds SMCL values or the District's criteria for these parameters.

Source water quality data obtained by ECCV through well sampling collected from the existing six Beebe Draw wells operating since 2006 is summarized below. Source water quality parameters of concern include hardness, TDS, fluoride, and gross alpha as shown in Table 2.

Table 2. Source Water Quality Data for ECCV Membrane Facility

Parameter	**Average**	**Max**	**Min**
Alkalinity – Total, mg/L as $CaCO_3$	247	286	212
Calcium – Total, mg/L	82	98	72
Chloride, mg/L	94	103	78
Cyanide – Free, micrograms/liter (µg/L)	ND	ND	ND
Hardness – Total, mg/L as $CaCO_3$	346	400	300
Fluoride, mg/L	1.8	2.2	1.5
Nitrate, mg/L as Nitrogen (N)	2.1	13.1	0.5
Nitrite, mg/L as N	0.25	0.38	0.03
Ammonia Nitrogen, mg/L as N	<0.8	<0.8	<0.8
pH, s.u.	7.51	8.81	7.08
Phosphorus – Total, mg/L as P	0.30	1.0	< 0.05
Potassium – Total, mg/L	3.32	3.9	<0.1
TDS, mg/L	683	739	621
Silica, mg/L	15	19	7
Sulfate, mg/L	175	218	149
Temperature, degrees C	19	20	12
Metals			
Arsenic – , mg/L	<0.0074	<0.05	<0.002
Chromium Cr^{+3} – mg/L	0.0047	0.0089	0.0022
Chromium Cr^{+6} – mg/L	<0.01	<0.01	<0.01
Copper – mg/L	<0.01	<0.01	<0.01
Iron – , mg/L	0.18	0.62	<0.07
Magnesium – mg/L	35	42	25
Manganese – mg/L	0.006	0.015	<0.005
Nickel – mg/L	<0.0083	<0.01	<0.0005
Selenium – mg/L	0.0032	0.008	0.002
Zinc – mg/L	0.03	0.01	0.005
Other Parameters			
UV Absorbance at 254 nm – L/mg-m	2.75	3.60	2.00
UVT (Calculated) – %	94	95	92
Turbidity, NTU	0.36	2.61	0.1
TOC, mg/L	1.8	2.4	0.5
Gross alpha, pCi/L	16	23	8
MPA, count	2 - Low	16 – Mod	0 - Low

Treatment Alternatives Considered

The softening and TDS reduction treatment technologies that were considered included three membrane processes—low pressure reverse osmosis (LPRO), nanofiltration (NF), and electrodialysis reversal (EDR); two chemical processes—lime softening and ion exchange (IX); and one thermal process—distillation. The advantages and disadvantages, residuals management issues (water quality and treatment technologies), and opinions of capital and operating cost were evaluated and compared. The low pressure RO process was determined to be the most cost-effective process meeting the water quality objectives.

Low Pressure Reverse Osmosis

LPRO process has broad applications worldwide for providing effective treatment of water sources high in TDS, hardness, nitrates, gross alpha, and other dissolved contaminants. LPRO can also be used for removal of a variety of synthetic organic chemicals, inorganic chemicals, and natural organic matter (NOM). The City of Brighton's LPRO WTP located approximately 3 miles from the project site has been treating source water from the South Platte alluvium since 1992 and the Town of Lochbuie's LPRO WTP located approximately 1 mile from the project site has been treating source water from the Beebe Draw alluvium approximately 1 mile from the ECCV Beebe Draw wells.

Usually a portion of the source water supply (20 to 40%) bypasses the membrane process to provide blended finished water consistent with desired water quality goals. Blending also reduces the amount of chemical addition needed for final pH adjustment and corrosion control as the LPRO process creates water with low TDS and low pH. For this application, the RO facility was designed a 33% blend. The low concentration of silica in the feedwater allowed the RO system to be design for 85%, resulting in 1.0-mgd concentrate stream for 6.7 mgd of low TDS permeate.

LPRO features compact equipment layout that requires a considerably smaller footprint than conventional granular media filtration or lime softening. A LPRO process treating clean groundwater is typically suitable for automatic and remote operation as the performance of the membrane remains stable for many months. Over time, the small amount of impurities in the water can accumulate on the membrane surface and it is necessary to increase the feedwater pressure slightly, or clean the membranes. Recently, the availability of new scale inhibitors has allowed many utilities to eliminate sulfuric acid addition. Process advantages and disadvantages are summarized below.

Advantages	**Disadvantages**
• Removes nitrates, NOM, and other dissolved organic compounds consistently to low levels	• Higher operating costs than media filtration due to power for feedwater pumps and membrane replacement
• Finished water quality can be achieved by blending of permeate and bypass water	• Additional pretreatment processes required for feedwater with measurable suspended solids
• Process amenable to automated operation; could run unattended	• 15 to 25% of the feedwater is discharged as a residual stream posing disposal issues
• Process is relatively compact, requires small building footprint; accommodates modular expansion	• Process potentially involves the use of strong mineral acid to lower pH of the feedwater

Description of Selected Treatment Process

The design capacity of the Phase I LPRO system is 6.7 mgd of permeate from 8.4 mgd of groundwater from the Beebe Draw aquifer downgradient of Barr Lake. The permeate will be blended with 3.3 mgd of UV treated groundwater to produce a non-corrosive water meeting the District's hardness and TDS water quality goals. The blending is possible because the permeate from the RO system will have less than 20 mg/L of hardness and 50 mg/L of TDS that offset the high hardness and TDS in the blend water. The total volume of raw water needed in Phase I to produce 10 mgd of blended product water is 11 mgd when the RO system is operated at 85% recovery.

The flow and proportions of water from each well are controlled by the use of variable speed drives at each well. Upon entering the RO Building, the groundwater is dosed with a scale inhibitor to prevent mineral compounds of calcium, magnesium, sulfates, and silica from forming on the surface of the RO membrane. The chemicals are mixed by a static in-line mixer as well as the mixing action imparted by the flow through the cartridge filters. The raw water piping material will allow 93% sulfuric acid to be injected in the future in the event that scaling cannot be controlled with scale inhibitor, the raw water quality hardness increases, or the recovery rate of the RO system is increased. Stainless steel piping also reduces the potential to generate soluble iron that can slowly foul the membranes.

Following chemical addition, the feedwater flows through three parallel cartridge filters to remove sand, chemical residue, and dirt. The cartridge elements have a rating of 5 microns, which remove silt, bacteria, and colloidal material that could become trapped in the annular spaces of the spiral-wound membranes. The pressure drop across the cartridge filters is monitored by a differential pressure (delta P) indicating transmitter. A clean delta P is normally 1- to 2-pounds-per-square-inch (psi) and cartridges should be replaced whenever the delta P reaches 20 psi to avoid reducing the pump suction pressure below the design point. A 3- to 6-month life is expected from each set of cartridges based on pilot test data.

Following cartridge filtration, the feedwater flows to each RO unit where a vertical turbine booster pump raises the pressure to 140 to 170 psi depending on RO unit flow rate, degree of short-term and long-term membrane fouling, recovery ratio, and membrane manufacture. The booster pumps are vertical turbine centrifugal variable speed pumps dedicated to a single RO unit. The variable frequency drives (VFDs) will be used to adjust long-term variations in pressure resulting from the following:

- Variations in cartridge filter differential pressure (delta P) from clean to dirty conditions
- Variations in the RO membrane driving pressure requirements resulting from membrane fouling, scaling, or changes in feedwater quality
- Variations in raw water pipeline pressure resulting from different combinations of wells in service.

The RO feedwater pump discharge pressure is controlled based on operator setpoint at the RO process control system supervisory control and data acquisition (SCADA) workstation. An active control loop based on train flow rates or discharge pressure is not necessary because the RO process is inherently very stable. Flow rates and calculated values such as recovery rates are continuously monitored and alarmed if out-of-range values occur.

The feedwater then enters the first stage of membranes comprised of 48 pressure vessels, each with seven membrane elements. The elements are standard 8-inch diameter by 40-inch long – a size manufactured by all membrane manufacturers. The feed water differential pressure drop through the first stage is approximately 30 psi and is referred to as delta P. The difference in pressure from the feedwater side of the membrane to the permeate side is referred to as the driving pressure, and it is a function of the osmotic pressure of the feedwater, the desired water diffusion rate, and the resistance of the RO membrane to the diffusion of water molecules at a given temperature. The net driving pressure is the pressure difference from the feedwater to the permeate stream minus the osmotic pressure, and averages 100 psi in the 1st stage and 75 psi in the second stage without the interstage booster.

An energy recovery booster pump between the first and second stages of the RO system increases the net driving pressure in the second stage by recovering the energy from the final concentrate stream. As it flows along the face of the RO membranes, water permeates through the membrane so at the end of the pressure vessel the volume of the water on the feedwater side of the membranes is reduced by approximately 50 percent. The second stage of membranes contains 24 pressure vessels with seven standard sized elements each. The differential pressure drop in the second stage will be approximately 20 psi. The ERT also reduces the noise associated with dissipating the residual pressure in the concentrate before routing the flow to the brine minimization system and final deep well injection.

Permeate from the RO trains or skids flows to a standpipe in the above grade 2.5-million-gallon reservoir that creates a 15 psi backpressure on the RO permeate discharge. A small portion of the permeate will be diverted to the clean-in-place (CIP) mixing and storage tank for storage. The water will be used to flush the membranes in the event that power failure prevents the normal flushing of the membranes with well water prior to shutdown.

Provisions are included to route the permeate to a forced draft decarbonator in the future if an acid feed system is installed, and it is necessary to reduce the resulting carbon dioxide in the permeate prior to stabilization with sodium hydroxide. The inlet to the decarbonator would be the same height as the inlet standpipe.

RO Trains

Table 3 shows the RO Train design criteria. It is based on a standard 2:1 cascading array using a standard 8-inch diameter by 40-inch long thin film polyamide element available from four reputable and experienced membrane manufacturers. The 2:1 array is standard for RO systems designed for an 80 to 85 percent recovery ratio.

The number of RO pressure vessels and elements has been established by the design team to achieve an average flux rate of 15 to 16 gallons per day per square foot. This average flux rate is typical of membrane manufacturers suggested range for clean brackish groundwater, and has resulted in reliable operation at numerous brackish water RO facilities throughout the country. It is also consistent with the flux rate utilized during the pilot testing at the Lochbuie WTP in 2004. Specifying the number of pressure vessels, RO elements, and membrane square footage eliminates the potential for bidders to adopt optimistic membrane performance projections and saddle the District with an overly sensitive RO design.

Table 3. RO Trains w/ Interstage Boost – Basis of Design

Phase 1 Train Configuration	
Number of Trains	2
Permeate Capacity each train (mgd)	3.35
Total Capacity (mgd)	6.7
Membrane Surface Area per element (square foot)	380-440
Number of RO Element per Pressure Vessel	7
Number of Stages	2
Number of Pressure Vessels in First Stage	48
Number of Pressure Vessels in Second Stage	24
Membrane Operating Conditions	
Average Flux Rate (gfd)	15
Average Permeate Recovery (%)	80-85%
Average Osmotic Pressure	20 psi
Manifold Piping Loss (psi)	6.0
Permeate Backpressure (psi)	15
Feed Pressure (psi) (clean)	145
Feed Pressure with Fouling Allowance (psi)	170
Stage 1 longitudinal pressure loss delta P (clean)	30
Stage 2 longitudinal pressure loss delta P	10

RO Concentrate Disposal

Cost-effective disposal of the concentrated residual stream from a RO system is one of the primary factors affecting the feasibility of RO projects in inland areas where ultimate discharge to a saline water body is not feasible. A wide range of traditional and innovative concentrate disposal alternatives are being investigated for existing and future facilities. One of the concerns with the current approach of surface water discharge has been the potential impact on receiving water from the large quantity of dissolved salts that are concentrated in the residual stream. A concern with evaporation basins and the standard thermal mechanical evaporation processes used by industries is the resulting loss in up to 15% of the usable water in the brackish supply. These concerns were used as a guide for developing RO concentrate disposal alternatives, and ultimately to a pilot testing study to demonstrate the feasibility of brine minimization and zero liquid discharge (ZLD) technologies.

The primary objective of the pilot study was to test two technologies that could recover a large percentage of the high quality water associated with the concentrate stream of a standard municipal brackish RO system. For many municipalities in the arid west being able to recover a significant percentage of the high quality water in the concentrate from a brackish water RO system using a brine minimization or ZLD process helps makes the best use of the original brackish water right. After the usable water is extracted, the ZLD operation can continue until the dissolved solids are reduced to a dry salt that can be landfilled, thereby permanently removing the salt from the water cycle, and the downstream users.

Very few commercial ZLD operations are at the scale most municipal WTPs would require, and they do not operate at a cost consistent with municipal residential water rates. ECCV focused on non-thermal processes using less mechanically intensive membrane based processes that would be consistent with municipal water treatment operational complexity, costs, and treatment capacity. The brine minimization pilot testing focused on determining the following for a standard high pressure brackish and seawater RO system, and flat sheet membrane process called VSEP that used high speed vibrations to control concentration polarization and solids build-up at the face of the membranes.

- Practical permeate flux rates
- Factors limiting the maximum recovery rate
- Fouling tendencies
- Specific dissolved solids concentration in the brine
- Operational stability and sensitivity

Brine Minimization Process

The level of recovery for the brine minimization systems generally ranged from 70 to 85%, which results in an overall recovery of 94 to 97% of low TDS permeate for every gallon of the raw brackish groundwater ECCV pumps from its wells.

The High Recovery RO system provided stable operation for overall recoveries up to 94 to 95% at brackish water pressures. Increasing recovery to 97% required more extensive pretreatment, seawater pressures, and resulted in less stable operation and required more frequent chemical cleaning.

The VSEP system operation displayed gradual flux declines at the expected recovery range of 94 to 97%. The system exhibited the need for continual permeate flushing and/or frequent chemical cleaning.

Acidification of the concentrate was a key to improving process performance. The highly buffered nature of this (and most) concentrate makes this a significant economical consideration for this process. High pH chemical cleaning of the early onset silica fouling was determined to be consistently effective. It is theorized that perhaps one of the catalyzing mechanisms (total organic carbon [TOC] or sodium) that led to early onset silica fouling is also responsible for allowing the amorphous silica scale to be more easily removed.

Subsequent research and pilot testing by universities, scale inhibitor manufacturers, and utilities confirmed the ability to reduce the volume of the concentrate by 70 to 80% using a high pressure RO system. ECCV decided to proceed with the design of a brine minimization system to reduce the volume of the RO concentrate to 200 to 300 gpm, and to inject the highly concentrated brine into sandstone and shale formation approximately 10,000 feet below ground. The preliminary design indicates that the system will initially operate at approximately 200 psi. The feedwater will not be softened to avoid the production of large quantities of precipitated solids from a pre-treatment, but this approach is expected to result in the need for frequent chemical cleanings to maintain production. The concentrated brine will probably need to be stabilized prior to deep well injection to avoid the formation of precipitates in the sandstone and shale underground formations. This will be evaluated after the injection well is completed and the formation water analyzed.

Brine Disposal

The initial phase of brine disposal was based on alluvial groundwater accretion disposal, as shown in Figure 3. Brine is to be blended with canal releases from Barr Lake to a concentration that matches existing groundwater quality. This permit was contested by local agricultural users that believed the groundwater accretion disposal would contaminate their irrigation groundwater supplies. After extensive public comment, a discharge permit was issued by CDPHE in December 2009. The final permit is very restrictive and may require up to an 11:1 blending of canal water to brine to meet the permit requirements. The capital and operating costs of this brine disposal method are low, but ECCV decided to pursue the deep injection well alternative first and use the alluvial groundwater accretion disposal permit as a secondary alternative if the deep well disposal costs were excessive.

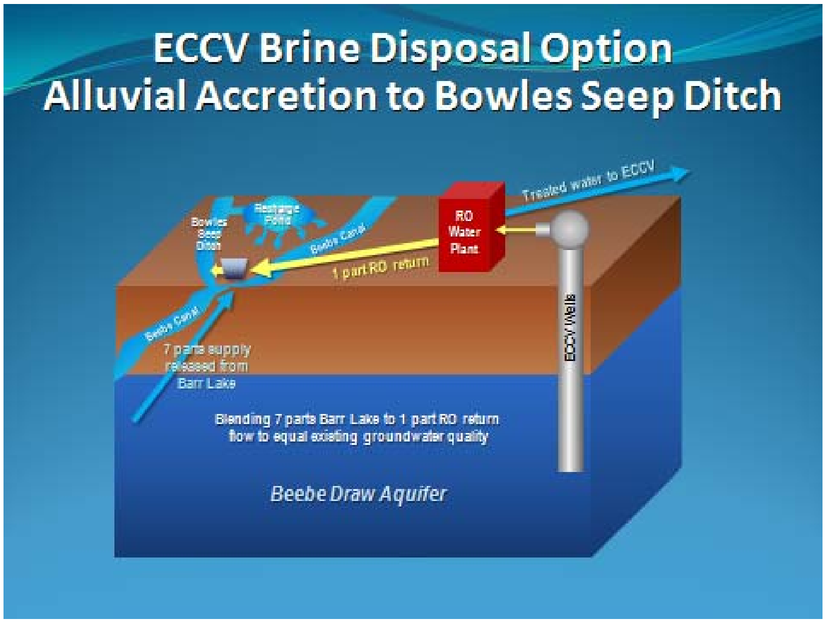
ECCV Brine Disposal Option
Alluvial Accretion to Bowles Seep Ditch

Figure 3. Canal Discharge

ECCV also applied for a permit to construct one to three Class I, deep injection wells; two located on the RO WTP site. The wells will be drilled to a depth of about 2 miles, which is about 1.5 miles deeper than any drinking water source. These wells are proposed to be constructed over the next several years.

The purpose of these wells is to dispose of non-hazardous RO brine via injection into deep underground formations. The process water contains the minerals and compounds that are naturally found already in this region's water; however, they are concentrated because of the water treatment process. This water will contain a TDS level that may range from about 4,700 to 24,000 mg/L.

ECCV's local water wells currently draw water from depths of around 70 feet. Comparatively, the saline water will be injected to far deeper levels, into underground formations that lie about 9,300 to 10,400 feet below ground level, kept safely from any drinking water sources in the area. The geologic injection zones include, in descending order, the Lyons, Wolfcamp, Amazon, Council Grove, Admire, Virgil, and Missourian Formations. These are all non-drinking water formations in the area. TDS levels in these formations are typically between 12,400 and 38,600 mg/L. Records from the Colorado Oil and Gas Conservation Commission indicate there are approximately 47 deep injection wells that have been injecting and/or are currently injecting salty oil well-related production water into these and other deep formations in Adams and Weld Counties.

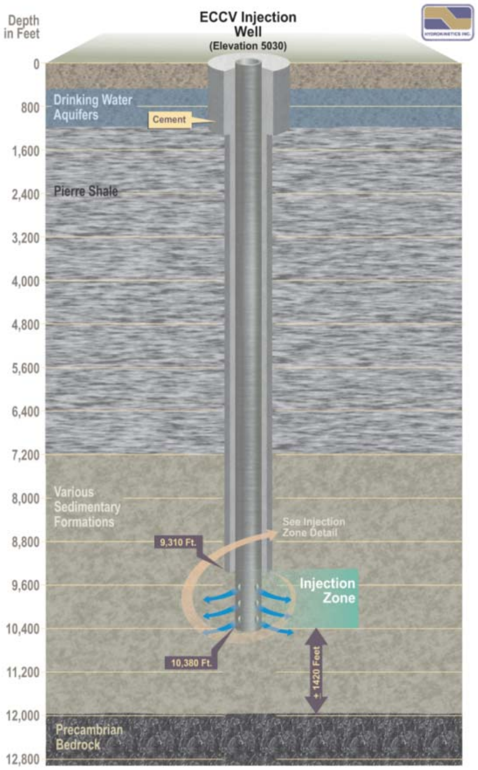

Figure 4. ECCV Injection Well

There are three drinking water aquifers in the area including the stream-deposited sand/gravel with depths of 30 to 90 feet and the Arapahoe and Laramie-Fox Hills at depths of 400 to 1,200 feet. There are two barriers that will prevent the injected water from migrating toward the drinking water aquifers. The first is a natural barrier, the Pierre Shale, which is approximately 6,000 feet thick. This shale is of very low permeability and will prevent upward flow to the drinking water aquifers. Also, each injection well will be cemented off from ground level to a depth of about 9,300 feet. This cement will provide further protection to prevent the injected water from being able to seep into the drinking water aquifers.

The injection rates for each well will range up to 150 to 400 gallons per minute at certain times of the year. Injection pressures will likely range from 2,000 to 3,000 psi.

The Class 1 deep injection wells were permitted in May, 2010. Only one set of comments were submitted to EPA on the permit, regarding the potential for creating earthquakes. There are numerous injection wells currently operating in the area without creating earthquakes. The final EPA permit requires temporary cessation and investigation of any detectable earthquakes.

Projected Capital and O&M Costs

The capital cost for the RO treatment system, site improvements for the ultimate 40-mgd facilities, high service pump stations, and treated water storage is based on the 2008 bid prices developed by the general contractor providing construction management services. The Phase 1 capital cost was $28 million in September 2008 dollars not including the brine minimization system and deep injection well. The estimated cost for the high pressure brine minimization system and ancillary facilities is $2.1 million, and the cost for the deep injection well and high pressure brine injection pump is $2.8 million.

Annual O&M costs for water treatment, brine minimization, and deep well disposal (Table 4) were estimated at $1,300,000 (2008 dollars). This equates to about $1,300 per million gallons or $1.30 per 1,000 gallons of treated water. The breakdown of annual costs is shown below.

Table 4. LPRO Annual Costs

Cost Component	**Sept. 2008 Annual Costs**(1)
Power	$200,000
Labor	$125,000
LPRO Chemicals	$462,000
Finished Water Chemicals	$94,000
Membrane Replacement	$92,000
Cartridge Filter Replacement	$37,000
Miscellaneous Repairs/Replacement	$60,000
Lab Fees	$25,000
Brine Minimization High Pressure Injection Well Pumping	$120,000 $80,000
Total Annual Costs	**$1,295,000**
Unit Costs	
Unit Cost ($/MG)	$1,300
Unit Cost ($/1,000 gallons)	$1.30

(1) O&M calculated for a WTP design flowrate of 10 mgd

(2) Assumed 3,000 AFY averaged over the entire year

In addition to deep well disposal with and without brine minimization, brine minimization and evaporation were analyzed and compared. An important consideration in Colorado is the value of the water rights and inclusion of the value of water lost through the various brine disposal options. Including this cost changes the bottom line comparison of the options. As shown in Figure 5, brine minimization is an important consideration when evaluating options. At 85% recovery the lost 15% brine, if not partially recovered for use through brine minimization or other means, represent a significant capital cost. Comparing estimated capital costs for a 12,000 AFY, 10-mgd water production, ZLD with landfill of solids has an estimated cost of $45 million compared to $40 million for deep well injection without brine minimization. Approximately $35 million of that cost is the value of the lost water.

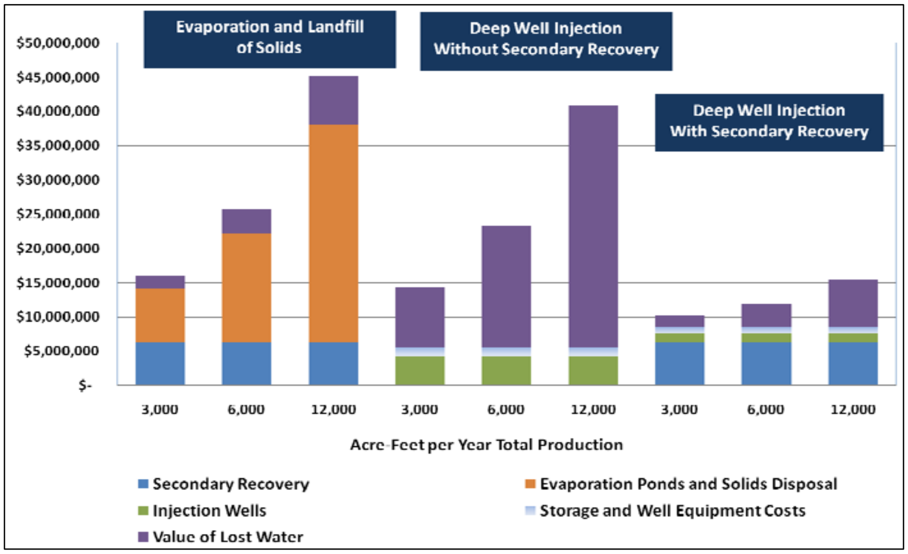

Figure 5. Comparison of RO Concentrate Disposal Capital Costs for 10-mgd ECCV RO Plant