San Luis Project: Process Optimization

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Abstract

The San Luis Project in southern Colorado addresses the reclamation of a gold mine that closed in the 1990s. As groundwater filled the backfilled excavations, seeps into the Rito Seco were observed. These were deemed to be unpermitted discharges to surface water by the Colorado Department of Public Health and Environment (CDPHE).

A series of interceptor wells was installed to halt the movement of the presumed groundwater plume, and several extraction wells were installed in the backfilled material. Both the interceptor wells and the backfill wells feed into an equalization pond for the Rito Seco Water Treatment Plant (WTP). The original Rito Seco WTP included chemical precipitation and reverse osmosis (RO) to remove dissolved constituents from the groundwater, most notably manganese (Mn^{+2}), sulfate ($SO4^{-2}$), and fluoride (F^{-}). The faculty was conceived as a zero discharge facility, with chemical precipitation of the RO concentrate prior to recycling it back through the treatment process.

The original Rito Seco WTP suffered from numerous problems. Within the first six months of operation, the original RO membranes fouled with gypsum (calcium sulfate). The facility never achieved its design requirement of 350 gpm. Initial operations were plagued by changing water quality as a consequence of the concentrate recirculation, excessively high chloride concentrations that attacked the RO pressure vessels, and declining recovery as recirculating salts accumulated in the system.

The treatment process at Rito Seco was redesigned to a single pass lime/soda ash chemical precipitation process. RO system recovery was increased from 65 percent to 90 percent recovery. The mine implemented a concentrate disposal process to evaporate the concentrate along with tailings underflow. The RO influent was of such high quality that a significant sidestream could bypass the RO to be recombined prior to discharge, thus increasing WTP throughput to approximately 600 gpm and overall efficiency to 94 percent. This allowed the WTP to operate intermittently, reducing operating personnel, power requirements, and improved efficiency in chemical usage.

This paper describes the difficulties in operating the facility as designed, the process changes implemented to improve plant performance, and the successful WTP operations since the process optimization improvements were implemented. An example of the successful operations is the service life of the RO membranes: now fourteen years in service.

Key words: process optimization, mine reclamation, membranes, reverse osmosis

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Background

Battle Mountain Resources, Inc. (BMRI, *now* Newmont Mining Corporation) mined an oxidized gold deposit outside of San Luis, Colorado. The gold was hydrothermally deposited, and did not create acid rock drainage (ARD). The San Luis operation consisted of an open pit excavated adjacent to the Rito Seco, as well as high wall mining along the sides of the Rito Seco canyon. Ore was hauled out of the Rito Seco valley to a nearby mill and tailings impoundment. Figure 1 shows the site following mining operations.

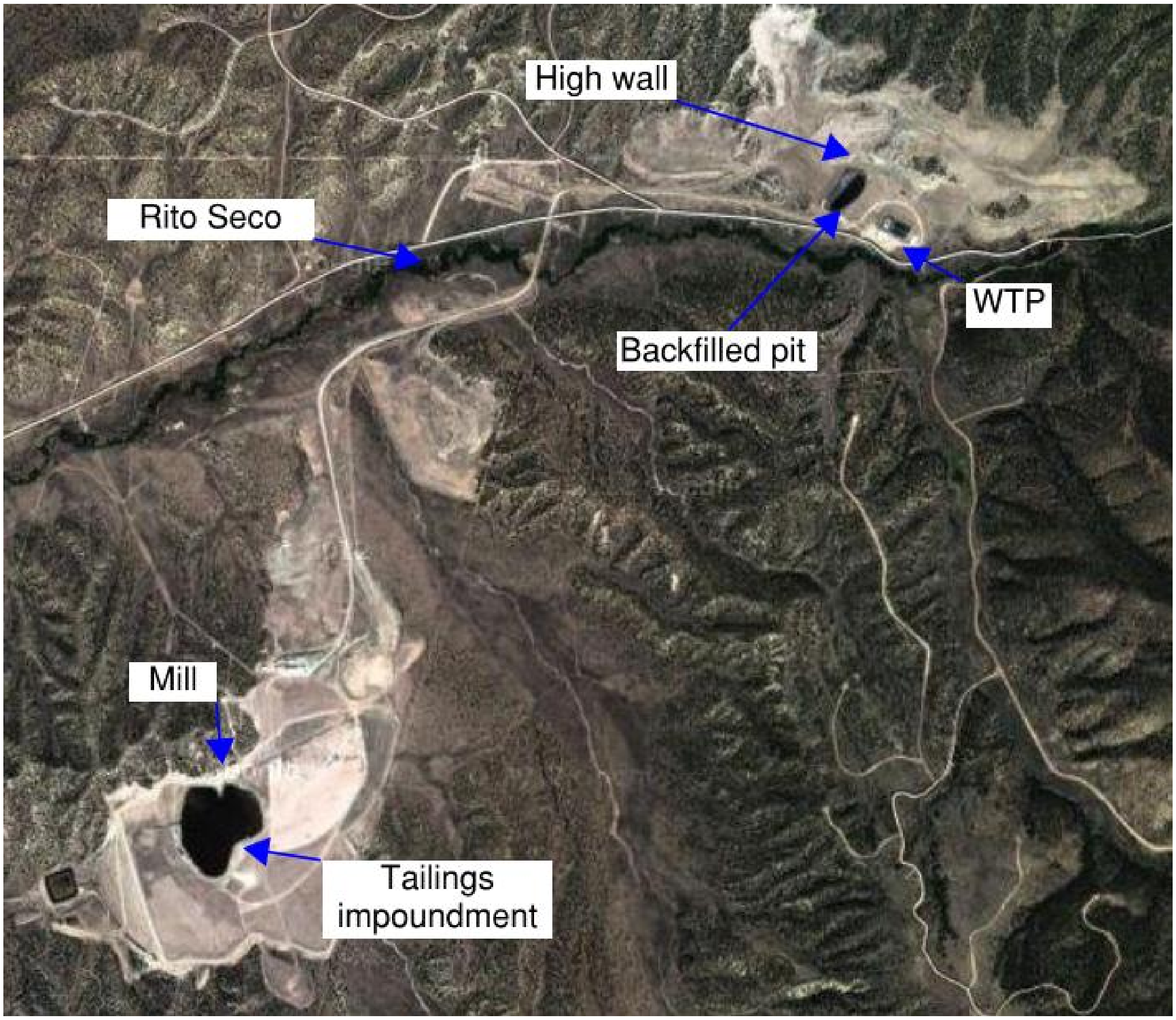

Figure 1 – San Luis Project site, post mining

As mining operations ceased, reclamation efforts began. Mine closure activities included backfilling streamside excavations with native backfill. As groundwater filled the backfilled excavations, groundwater seeps into the Rito Seco were observed. These were deemed to be unpermitted discharges to surface water by the Colorado Department of Public Health and Environment (CDPHE). In addition, the existence of a groundwater plume was hypothesized; this subsurface plume was under the jurisdiction of the state Division of Mines and Geology (DMG), now the state Division of Mined Land Reclamation and Safety (DMLRS). The unpermitted discharges resulted in a Notice of Violation/Cease and Desist Order (NOV/C&D).

To control the groundwater hydraulic gradient, a series of interceptor wells were installed to halt the movement of the presumed groundwater plume, and several extraction wells were installed in the backfilled material. The first attempt to address the accumulation of excess groundwater was by evaporation, a technique often employed in mine closure actions. Unfortunately, the evaporation system was commissioned during the wettest summer in San Luis in decades, and failed to address the accumulation of groundwater.

BMRI solicited proposals for the design/building/operation of an active treatment facility. Effluent limitations were stringent: the Rito Seco was subject to antidegradation protection as required by Colorado Regulation 31 – The Basic Standards for Surface Water. The constituents of concern were manganese (Mn^{+2}), sulfate ($SO4^{-2}$), and fluoride (F^{-}). The selected design was a chemical precipitation/reverse osmosis (RO) treatment process. The process was conceived as a zero discharge facility, with chemical precipitation of the RO concentrate prior to recycling it back through the treatment process. The flow diagram for the original treatment facility is shown in Figure 2.

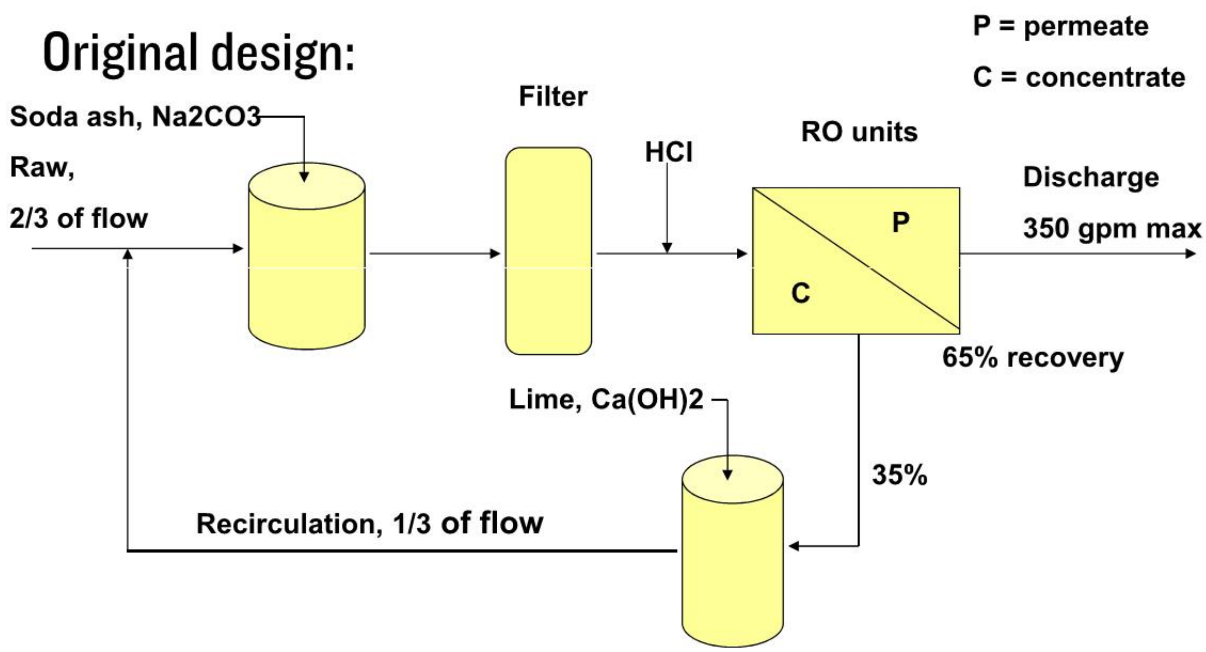

Figure 2 – Original process design

The original process included pumping the interceptor and backfill wells into the evaporation basin (Pond 1), which had been converted to function as forebay storage. From Pond 1, the groundwater was pumped (approximately 65 percent of the plant flow) to a soda ash precipitation process. The treated RO concentrate (approximately 35 percent of the plant) was also pumped to this reaction vessel. Precipitated solids were settled in a lagoon and were then pumped to a pressure filtration process. Following pressure filtration, the RO feed was acidified using sulfuric acid (later changed to hydrochloric acid). The RO machine was designed for 65 percent recovery. The *optimal* system recovery for the facility was 65 percent. RO concentrate was treated with hydrated lime ($Ca(OH_2)$) to remove calcium as gypsum (calcium sulfate), and following sedimentation, was recirculated to the soda ash reactor.

The original Rito Seco WTP suffered from numerous design and operational problems, an example of which was the fouling of the original RO membranes with gypsum within the first six months of operations. In addition, the facility never achieved its design requirement of 350 gpm. To resolve the facility problems, BMRI took adverse possession of the facility in May 2000 and began operating the facility itself. Initial operations were plagued by continuously changing water quality as a consequence of the concentrate recirculation, excessively high chloride concentrations that attacked the RO pressure vessels, and declining RO recovery as recirculating salts accumulated in the system.

Flow limitation

The inability of the original design to achieve the flow requirement was traced to the specification of the RO machines. The machines' output (permeate) was specified to be 400 gpm; however, the designer specified a minimum operating temperature of 45° Celsius. The standard RO design programs default to the "standard" conditions of 25° C, and correction factors are applied to derate performance at colder temperatures. The viscosity of water is greatly influenced by temperature; the viscosity of water profoundly affects the flow of water through a semi-permeable membrane, such as RO. The Fluid Systems FT30 membrane temperature correction factor equation approximates this viscosity effect. Thus, an RO system designed for 400-gpm permeate flow at 45 °F would produce significantly lower flow, at higher pressures, when operated at lower temperatures. Worst-case temperature, as determined by site instrumentation was 36° Fahrenheit. This decrease in output is shown graphically in Figure 3.

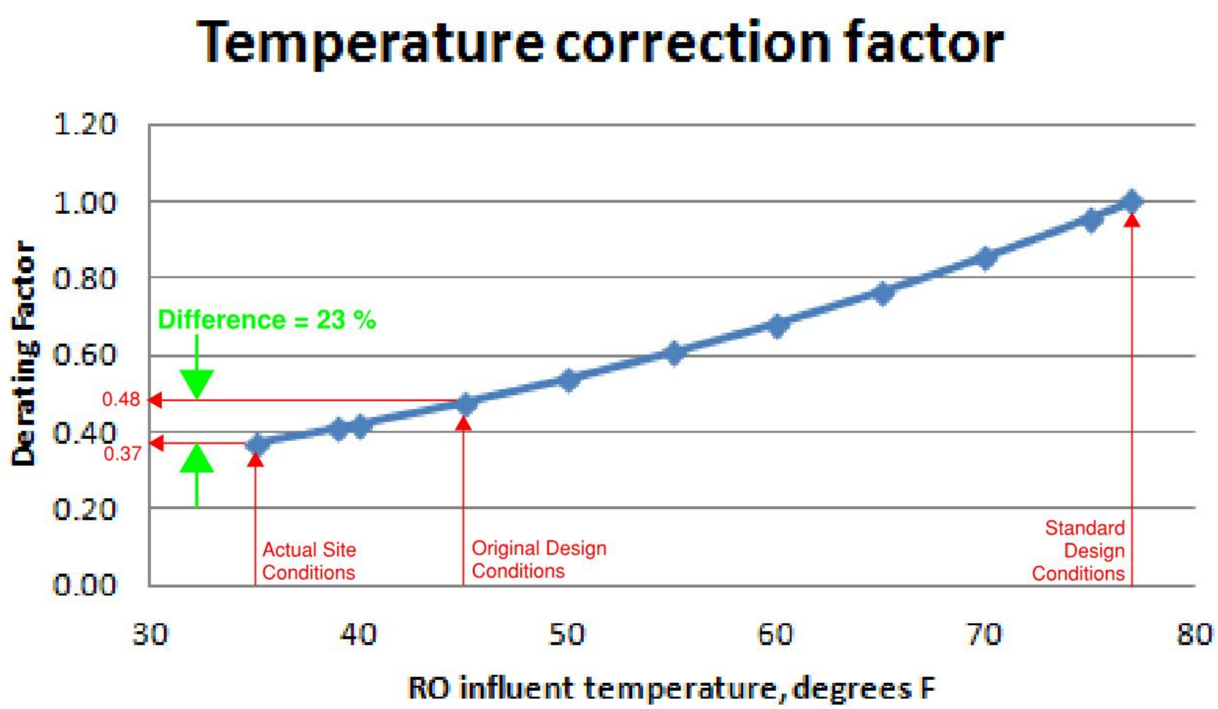

Figure 3 – Effect of temperature on RO performance

The permeate from an RO designed for a minimum temperature of 45 °F would be reduced by 23 percent when operated at an actual minimum temperature of 35 °F. Viewed from a different perspective, an RO designed to achieve a specific flow at 45 °F would have to be 30 percent larger to produce that same flow rate at 35 °F. Thus, the RO system was never capable of producing the required flow at the original feed chemistry at minimum temperature conditions. Further, the feed chemistry changed continuously, increasing in ionic strength and decreasing system recovery. The effect of ionic strength on system recovery is discussed below.

Concentrate recirculation

To create a zero discharge facility, the designer relied on the precipitation of RO concentrate sulfate by its precipitation by lime. Following sedimentation of gypsum solids, the precipitated concentrate (one-third of plant flow) was introduced to the soda ash precipitation reactor. The soda ash was dosed to precipitate excess calcium as calcium carbonate. However, the concentration of monovalent ions (most importantly, sodium and chloride) inexorably increased as these ions were not as well rejected as were the divalent ions (most notably sulfate). This increased concentration resulted in an increased ionic strength, which resulted in requiring ever higher doses of lime to precipitate sulfate in the RO concentrate. This effect cascaded, so that higher doses of soda ash were required to precipitate calcium carbonate (resulting in increased sodium concentrations). Further, increased doses of acid were required to address the higher pH required for precipitation, increasing chloride concentration. Thus, this feedback cycle repeated and ionic strength continued to increase across the facility.

To address the build-up of monovalent ions, the designer relied on two barriers to the accumulation of salts which accumulate in a recirculating system: ion exchange and reverse osmosis rejection. The pressure filters upstream of pH adjustment and reverse osmosis were loaded with spent ion exchange resin beads, on the assumption that the media would exchange sodium, thus decreasing the ionic strength of the RO feed. However, the designer had not included regeneration facilities for the ion exchange media, and the operating life of the filter media was calculated to be in the range of hours to days. Further, the use of uniformly-sized spherical media creates a *strainer*, not a deep bed filter. Gypsum and calcium carbonate solids accumulated on the surface of the filters, eventually sheeting down the sides of the vessels. This increased acid demand and the concentration of chloride challenging the RO membranes and pressure vessels.

RO rejection is the amount of water rejected (as concentrate or brine) as a proportion of the feed. As ionic strength increases, the solution osmotic pressure likewise increases. As osmotic pressure increases, feed pressure must increase to continue driving the process in a reverse direction. Increased osmotic pressure also means that the RO membrane will reject ions less efficiently, resulting in degraded performance: an increase in concentrate flow and an increase in the Total Dissolved Solids (TDS) of the permeate.

The design premise was that as salt concentration increased RO rejection would decrease, allowing the passage of salts into the RO permeate. As the concentrate ionic strength increased during recirculation, chloride concentrations in excess of 8,000 mg/L were observed, as well as feed pressures approaching 600 psig. Pinhole (chloride) corrosion of the stainless steel RO pressure vessels was observed. Further, as the RO feed pressures and ionic strength increased, the membrane rejection decreased so that RO recovery decreased (producing less permeate), exacerbating the inability of the RO system to achieve the required discharge flow rate. When the RO recovery decreased to below 50 percent, the facility would shut down and the concentrate sedimentation basin was pumped to the tailing impoundment, to be blended with water disposed by evapotranspiration.

Interim operations

Since the San Luis Project water treatment facility was adversely possessed by BMRI, it was important to demonstrate that the system, as originally designed, could be successfully operated by BMRI ***prior*** to conducting any significant modifications. Therefore, for a six-month period, the facility was operated as designed while process optimization projects were formulated.

Training of operations and maintenance personnel was the first requirement. Personnel from the decommissioned mill were rehired, and included individuals with experience with heavy equipment operation, an electrician, and one individual with some college (one introductory chemistry course) – he became the plant supervisor. Two days of intense training in process chemistry, mathematics and hydraulics were conducted immediately prior to the adverse possession.

Unsatisfactory equipment items were immediately replaced or abandoned:

- The pressure filter media was replaced with standard granular media
- ODP motors were replaced with TEFC motors for safety
- An eductor-based hydrated lime feeder was fabricated to replace the grain auger/slurry tank lime feed arrangement that was unreliable.
- Manually-primed centrifugal pumps (operating in suction lift conditions with insufficient NPSHa) were replaced with submersible pumps.
- Gypsum sludge could not be effectively removed from the flat-bottomed sedimentation tanks without "ratholing," which produced an inconsistent feed to the dewatering centrifuge. The centrifuge was removed from the facility.

To address the constantly changing chemistry of the RO feed, it was necessary to predict future chemical concentrations to properly calculate the required dosage of antiscalant. Fortunately, the analytical laboratory provided results in a one-week turnaround. These results were used as a check on the predicted chemistry from the week before. Since the increasing concentrations were a function of RO throughput, it became a relatively straight forward exercise to predict future concentrations and make proactive changes to antiscalant dosage.

As stated above, once RO recovery declined to 50 percent, the facility was shut down and the RO concentrate was pumped to the land application area where it mixed with water within the tailings impoundment (Figure 1). Then, the treatment facility was restarted with fresh groundwater. Given an initial RO system recovery of 65 percent and a final RO system recovery of 50 percent, the facility averaged **57.5** percent recovery.

After demonstrating that BMRI could successfully operate the facility according to its designer's intent, the next phase was the reconfiguration of the treatment process.

Revised process

The first task aimed at optimizing the process was to construct a permanent pipeline to convey RO concentrate to the tailings impoundment and to institute regular, periodic concentrate wasting to address increasing ionic strength.

RO concentrate precipitation was abandoned. It was an inefficient chemical precipitation process, and gypsum residuals were difficult to remove from the interior sedimentation tanks.

The entire chemical precipitation process was converted to a single-pass lime/soda ash precipitation process. Lime dosage was controlled by reaction pH, and soda ash dosage was manually set to produce a dissolved calcium concentration of approximately 20 mg/L as Ca. Since the water chemistry was relatively unchanging (a rinsing down of the backfill material by groundwater pumping gradually reduced the concentration of sulfate and other ions), manual control of soda ash feed was not difficult.

The RO units were replumbed to isolate the pair of ROs installed on a single skid, with a single set of controls for each skid. As originally configured, the performance of each individual RO could not be measured or controlled independently. Four separate concentrate recirculation pipelines, complete with flow instrumentation, were installed. This allowed the individual RO units to be separately controlled, and it allowed for taking a single RO unit out of service (25 percent reduction in treatment capacity) rather than taking a two-RO skid out of service (50 percent reduction in treatment capacity).

RO recovery was set at 65 percent by the design of the units. However, ***system*** recovery was increased by the recirculation of a portion of the RO concentrate to the RO feed. A diagram depicting system recovery is shown in Figure 4.

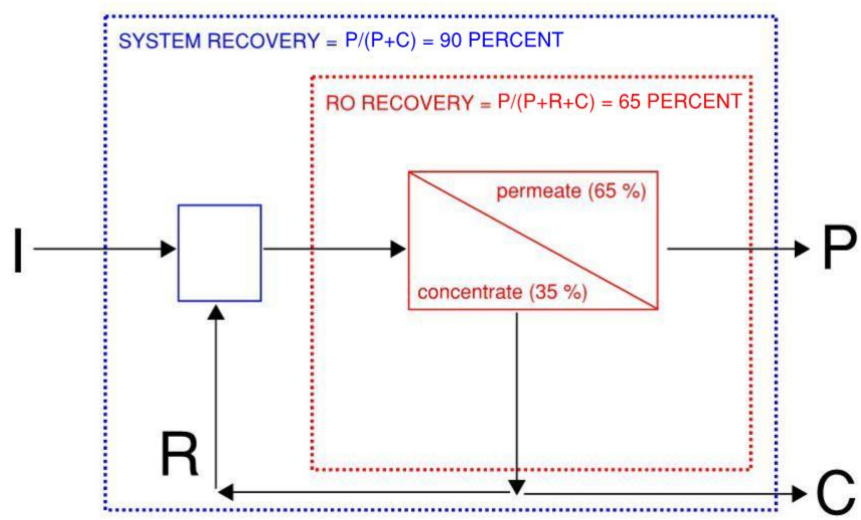

Figure 4 – System recovery vs. RO recovery

RO recovery was gradually increased to 90 percent by increasing the flow of concentrate recirculated (R, above) to the RO feed tanks. During a testing period, system recovery was pushed to 95 percent. While the membranes tolerated this high recovery, the labor and chemical (cleaning) costs to maintain the membranes was not considered to be worth the cost. With stable upstream chemistry and stable chemistry of the concentrate, the system became an easily operated and maintained advanced treatment process.

A benefit of the increased system recovery, plus the high quality of the lime/soda ash-treated RO influent stream, allowed a portion of that stream to bypass the RO process. This stream was treated via bag filtration and pH adjustment prior to blending with RO permeate before discharge. The limiting constituent was fluoride. To address this situation, the bypass flow rate was controlled by a variable-speed centrifugal pump paced off the output signal of an on-line fluoride analyzer.

Including the RO bypass stream, the Rito Seco WTP system recovery improved to **94** percent.

The revised process is depicted below in Figure 5:

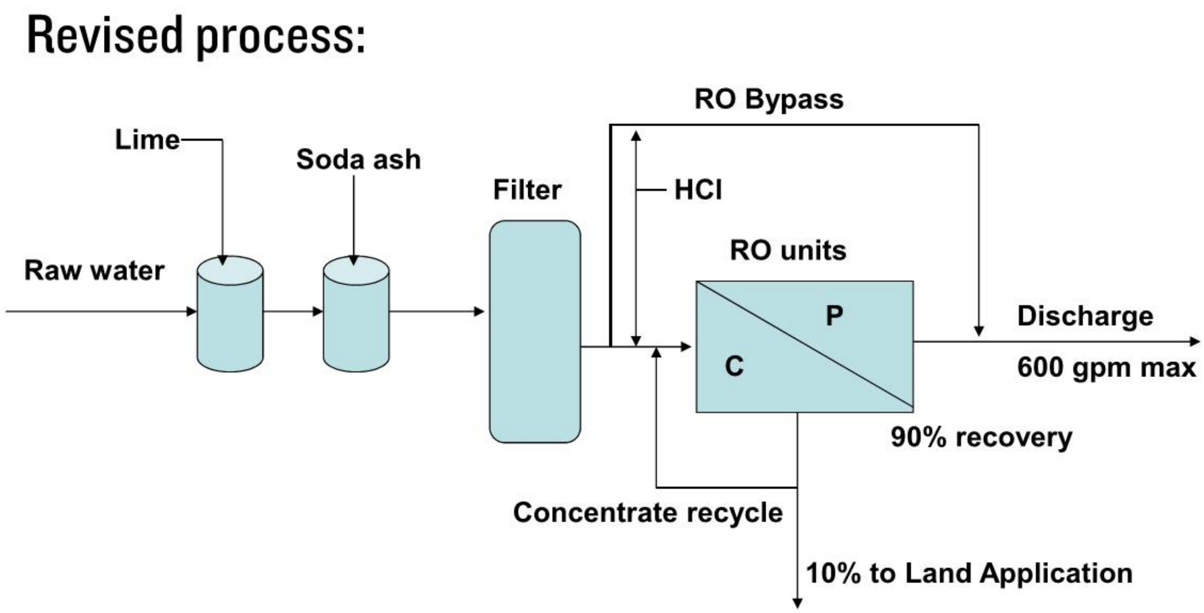

Figure 5 – Revised process

Optimization benefits

The San Luis Project optimization program began with a poorly operating, unreliable treatment facility that did not meet the requirements of consistently producing a high-quality effluent while maintaining a local water table that would not migrate off site or into Rito Seco. The outcome of the optimization program was a smoothly operating treatment facility at increased flow rates, improved water quality, and enhanced reliability.

The optimization program achieved nine major benefits for BMRI:

- The treatment facility could lower the local water level so effectively, that the existing wells and treatment plant could be operated part time. This increased system efficiency and reliability.
- The lowered water table provided an additional measure of reserve storage. This increased system reliability.
- The treatment facility experienced a capacity increase of approximately 30 percent (600 gpm vs. 350 gpm), repurposing all required tankage and mixers (actually four fewer tanks were used). This increased the efficiency of the installed equipment and enhanced system reliability
- The treatment facility produced a higher-quality precipitation process effluent, a portion of which did not require demineralization by reverse osmosis.
- Electrical costs were lowered by more than 40 percent as a consequence of reduced operational time and the lower osmotic pressure of the RO influent stream
- Water treatment facility operations labor costs were reduced by 40 percent.
- Chemical costs were reduced by approximately 75 percent
- The facility concentrate stream was reduced by more than 50 percent.
- Membrane life was extended, now going on 14 years.

Figure 6 – Rito Seco Water Treatment Facility

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