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Use of Produced Water in Recirculating Cooling Systems at Power Generating Facilities

Deliverable Number 3
Treatment & Disposal Analysis

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Disclaimer

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Abstract

The purpose of this study is to evaluate produced water as a supplemental source of water for the San Juan Generating Station (SJGS). This study incorporates elements that identify produced water volume and quality, infrastructure to deliver it to SJGS, treatment requirements to use it at the plant, delivery and treatment economics, etc.

SJGS, which is operated by Public Service of New Mexico (PNM) is located about 15 miles northwest of Farmington, New Mexico. It has four units with a total generating capacity of about 1,800 MW. The plant uses 22,400 acre-feet of water per year from the San Juan River with most of its demand resulting from cooling tower make-up. The plant is a zero liquid discharge facility and, as such, is well practiced in efficient water use and reuse.

For the past few years, New Mexico has been suffering from a severe drought. Climate researchers are predicting the return of very dry weather over the next 30 to 40 years. Concern over the drought has spurred interest in evaluating the use of otherwise unusable saline waters.

Produced water use at SJGS is evaluated in this deliverable. Previous deliverables identified the produced water resource in the San Juan Basin and the infrastructure required to deliver it to SJGS.

Two approaches are employed to evaluate the use of produced water at SJGS:

- Use produced water “as is” by feeding it directly to major process area(s) in the plant, e.g. take advantage of significant dilution by blending produced water with plant freshwater and using it for make-up to the cooling towers.
- Treat produced water and use it with minimal restrictions in the plant.

Before evaluating these approaches, a simplified water balance is presented to show how water is used and reused at the plant. Water quality constraints are then established for each major water user and produced water chemistry is assessed against these constraints. It is shown in this evaluation that produced water must be treated to justify using it in any reasonable quantity at SJGS.

Produced water treatment alternatives are evaluated utilizing off-the-shelf technology. Water treating equipment at SJGS is also incorporated into the evaluation. The economics of produced water treatment is preliminarily assessed and a produced water treatment alternative is selected.

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Executive Summary

The purpose of this study is to evaluate produced water as a supplemental source of water for the San Juan Generating Station (SJGS). This study incorporates elements that identify produced water volume and quality, infrastructure to deliver it to SJGS, treatment requirements to use it at the plant, delivery and treatment economics, etc.

SJGS, which is operated by Public Service of New Mexico (PNM) is located about 15 miles northwest of Farmington, New Mexico. It has four units with a total generating capacity of about 1,800 MW. The plant uses 22,400 acre-feet of water per year from the San Juan River with most of its demand resulting from cooling tower make-up. The plant is a zero liquid discharge facility and, as such, is well practiced in efficient water use and reuse.

For the past few years, New Mexico has been suffering from a severe drought. Climate researchers are predicting the return of very dry weather over the next 30 to 40 years. Concern over the drought has spurred interest in evaluating the use of otherwise unusable saline waters.

Produced water is available to SJGS for reuse from three sources:

- Close-in CBM production including mine water from BHP Billiton (primary coal source for SJGS) and a small amount of industrial wastewater from Prax Air in Kirtland
- Conventional and CBM production gathered in the Tri-City area by the Hart Canyon Line
- CBM production gathered in the Fairway area by the CO₂ Line

Water gathered by the Hart Canyon Line and CO₂ Line, which are owned by Burlington Resources, would be sent to the Collection Center in Bloomfield where oil and grit would be removed.

Produced water, which has a TDS of approximately 14,000 mg/l, was first evaluated for use at SJGS without treatment. Its use was evaluated against plant operating criteria for certain key chemistry constituents (primarily chloride and TDS). Even small amounts of untreated produced water could not be used without generating significant quantities of wastewater. This approach was considered impractical.

Absorber Purge Water was also considered for treatment and reuse (blended with produced water) because it would free up 50 acres of evaporation pond capacity (66 percent of total). Currently, the plant must blowdown Purge Water from the absorbers to control chloride levels.

An assessment of off-the-shelf treatment technologies determined that reverse osmosis (RO) and brine concentration (BC) were the most feasible. Only off-the-shelf technologies were considered because PNM is currently evaluating supplemental water supplies for SJGS and proven technology is required to implement any plan. Two types of RO were evaluated:

- Conventional RO (CRO) – includes standard spiral-wound PA membranes operating at low pH. This is a traditional approach to operating RO systems.

- High-efficiency RO (HERO®) – includes standard spiral-wound PA membranes operating at high pH. This is a relatively new approach with inherent advantages to treating produced water.

Pretreatment was considered critical for produced water because it has a high potential for membrane fouling. Of the two RO types, HERO® appeared to be best suited because all the feedwater hardness is removed to minimize the potential for mineral scale and it operates at high pH so silica scale and oil/organic fouling are minimized as well.

Two idled BCs at SJGS (BC 2 and BC 3) were included in the evaluation. They were previously inspected for refurbishment and reuse at another PNM power plant. BC 3 was considered the best of the two.

Five treatment alternatives (CRO, HERO, BC 2/BC 3, CRO/BC 3 and HERO/BC 3) were evaluated for produced water and the same five for the produced water and Purge Water blend.

It was determined that Alternative 10, the HERO® and BC 3 combination, was the most economically feasible – it had the lowest evaluated capital cost (\$14.1 million) and operating cost (\$2.98 million per year), would recover the most produced water for reuse (1,255 gpm) and would require no additional evaporation ponds. These costs were developed to evaluate produced water treatment alternatives. Deliverable 6, Cost/Benefit Analysis, has a complete cost analysis, i.e. capital and operating costs for the Collection Center in Bloomfield, 28.5-mile pipeline from Bloomfield to SJGS and the treatment plant at SJGS.

Alternative 10 would require 1,915 kw of power. Alternatives 3 and 8, which employ both BC 2 and BC 3, would require the most power (4,830 kw) and were limited in the amount of water they could treat because of corrosion due to high chlorides.

SJGS determined that additional manpower needs for operating and maintenance coverage would be the same for all of the alternatives – full time operator coverage and one shift of a maintenance technician.

3.1 Introduction

Produced water use at San Juan Generating Station (SJGS) is evaluated in this deliverable. Previous deliverables identified the produced water resource in the San Juan Basin and the infrastructure required to deliver it to SJGS.

Two approaches are employed to evaluate the use of produced water at SJGS:

- Use produced water “as is” by feeding it directly to major process area(s) in the plant, e.g. take advantage of significant dilution by blending produced water with plant freshwater and using it for make-up to the cooling towers.
- Treat produced water and use it with minimal restrictions in the plant.

Before evaluating these approaches, a simplified water balance is presented to show how water is used and reused at the plant. Water quality constraints are then established for each major water user and produced water chemistry is assessed against these constraints. It is shown in this evaluation that produced water must be treated to justify using it in any reasonable quantity at SJGS.

Produced water treatment alternatives are evaluated utilizing off-the-shelf technology. Water treating equipment at SJGS is also incorporated into the evaluation. The economics of produced water treatment is assessed and a produced water treatment alternative is selected¹.

3.2 Water Use at SJGS

High quality water from San Juan River is withdrawn and stored in a 30-day pond on the plant site. The plant uses 22,400 acre-feet of water per year (equivalent to 13,890 gpm) of San Juan River – the only source of water for the plant. The plant, which is operated by Public Service of New Mexico (PNM) is a zero liquid discharge facility and, as such, is well practiced in the efficient use and reuse of water. The plant recycles most of its wastewater and uses evaporation ponds for final disposal.

3.2.1 Plant Water Use

The plant uses, reuses and treats water for reuse, consumes water in the form of non-recoverable losses of water to process, and eventually disposes of wastewater. Five categories of plant water are identified in Table 3.1 including a summary of the major process streams. Each stream is designated with a number, description, category, annual average flow rate and applicable water quality constraint(s). Figure 3.1 presents a simplified schematic of the overall water balance at SJGS. Stream numbers found in Table 3.1 correspond to the stream numbers Figure 3.1.

¹ A full-project economic analysis for produced water collection, pipeline and treatment is developed in Deliverable 6, Cost/Benefit Analysis.

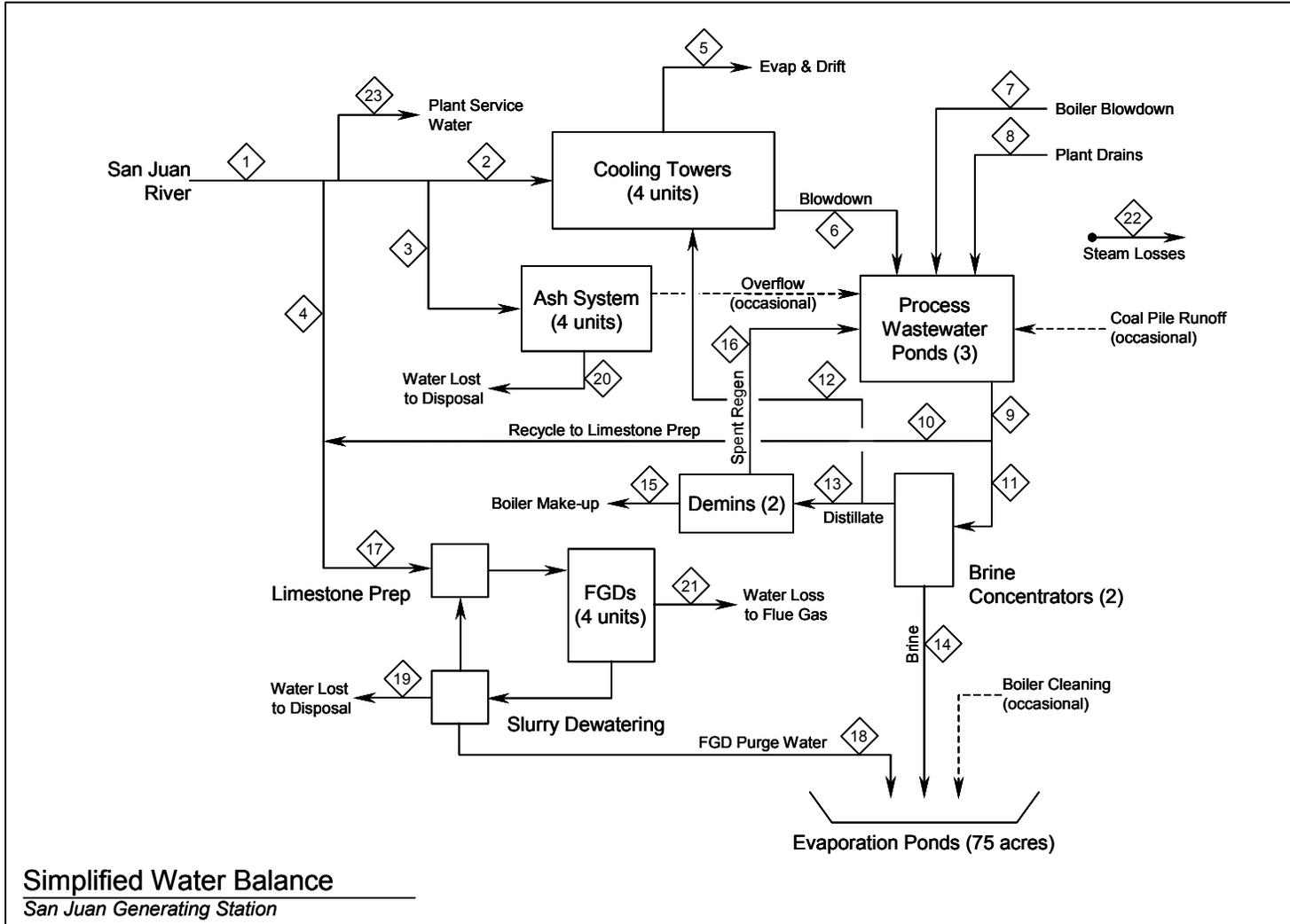
Table 3.1
Water Balance – Major Streams (4)
San Juan Generating Station

Stream	Description	Type (1)	Flow Rate gpm (2)	Major Water Quality Constraints (3)
1	Total Plant Feed	FW	13,890	
2	Cooling Tower Make-up	FW	12,480	chloride, calcium, sulfate, silica
3	Ash System Make-up	FW	100	TDS
4	Limestone Prep Fresh Make-up	FW	1,210	chloride, magnesium
5	CT Evaporation & Drift	Lost	11,640	
6	CT Blowdown	RW	1,000	
7	Boiler Blowdown	RW	430	
8	Plant Drains	RW	100	
9	Process Pond Recycle	RW	1,530	
10	Recycle to LS Prep	RW	730	chloride, magnesium
11	Brine Concentrator Feed	RW	800	chloride, boron
12	BC Distillate to CT	TRW	165	
13	BC Distillate to Demineralizers	TRW	620	
14	BC Brine to Evaporation Ponds	WW	15	
15	Boiler Feed Water	TRW	620	
16	Spent Regenerant (5)	RW	<2	
17	Limestone Prep Total Make-up	FW/RW	1,940	chloride, magnesium
18	Absorber Purge Water	WW	100	
19	Water Lost to Absorber Cake	Lost	140	
20	Water Lost to Ash System	Lost	100	
21	Water Lost to Flue Gas	Lost	1,700	
22	Steam Losses	Lost	190	
22	Plant Service Water	FW	100	TDS

Notes.....

1. FW = freshwater (San Juan River), RW = recyclable wastewater, TRW = treated recycled wastewater, WW = non-recyclable wastewater, Lost = water lost to process (not recoverable).
2. Flow rates are best estimates based on a variety of plant data sources. Flow rates are based on an annual average plant operating capacity of 79.5% for a total consumption of 22,400 AF/year. Flows are rounded to the nearest 10 gpm except for BC brine and distillate recycled to cooling tower.
3. Some systems, such as the cooling tower, have numerous constraints. The constraints identified in the table are considered major water quality concerns relative to the use of produced water at SJGS.
4. Refer to Figure 3.1, Simplified Water Balance.
5. Demineralizers regenerate very infrequently because they receive low-TDS distillate.

Figure 3.1



Simplified Water Balance
San Juan Generating Station

Freshwater (FW). San Juan River water is primarily used for cooling tower make-up, absorber² make-up, ash system service (bottom ash sluicing, fly ash wetting, seal water, etc.) and plant service water. Some freshwater is required for the absorbers, because recycled wastewater can only supply a portion of their needs. Also, water quality limitations of the absorbers require some freshwater (discussed later).

Recyclable Wastewater (RW). This water is collected in the three Process Wastewater Ponds at SJGS and consists of cooling tower blowdown, boiler blowdown, spent regenerant (from the boiler feedwater demineralizers) and plant drains (primarily service water used for housekeeping and maintenance). A portion of it is used for Absorber make-up and the rest is treated by brine concentrators³ (BCs) for reuse as boiler feedwater and cooling tower make-up. There is significant flexibility in the wastewater recycle system. Wastewater destined for recycle can be transported from/between any of three Process Wastewater Ponds for reuse or treatment.

Treated Recycled Wastewater (TRW). Approximately half of the water from the Process Wastewater Ponds is treated with BCs. High-quality distillate (TDS < 10 mg/l) from the BCs is further treated by two sets of demineralizers (one for each unit pair) for boiler feedwater. Excess distillate is sent to the cooling towers for reuse.

Non-Recyclable Wastewater (WW). These streams are not useable. They cannot be treated by the BCs (because of water quality limitations) and are sent to the evaporation ponds for final disposal. Of the 13,890 gpm of water used by SJGS on an annual average basis, less than one percent is sent to final disposal in the evaporation ponds (~110 gpm).

Water Lost to Process (Lost). These process streams are not recoverable and consist of cooling tower evaporation and drift loss, absorber water lost to flue gas, steam losses from the power block and waters of moisture and hydration lost to bottom and fly ash and absorber sludge cake. The cooling towers consume the most water (84 percent lost to the atmosphere) followed by the absorbers (12 percent).

3.2.2 Water Quality Constraints in the Process Areas

Major plant process areas – cooling towers, absorbers, ash systems and boilers – all have operating controls and limitations that are related to water quality⁴. Operating constraints for each system are discussed next. Refer to Table 3.1 and Figure 3.1.

Cooling Towers

The allowable cycles of concentration for the cooling towers are controlled by water quality criteria, i.e. levels of calcium (Ca), sulfate (SO₄), silica (SiO₂) and chloride (Cl) among other criteria. The criteria were developed for San Juan River which is

² SJGS refers to flue gas de-sulfurizers (FGDs) as absorbers. Another term for this equipment is SO₂ scrubbers.

³ Brine concentrators are also known as VCEs (vapor compression evaporators) or just evaporators. SJGS refers to this equipment as BCs.

⁴ Operating constraints are put into place to prevent corrosion and mineral scale formation, maintain equipment performance and reliability, establish a safe work environment, etc.

characterized by relatively low levels of TDS. Refer to the following general mineral analysis⁵.

Na	29 mg/l
K	3 mg/l
Ca	54 mg/l
Mg	11 mg/l
HCO ₃	125 mg/l
Cl	22 mg/l
SO ₄	107 mg/l
SiO ₂	12 mg/l
TDS	360 mg/l
pH	8.0

The cooling towers for Units 1, 2 and 4 are operated at 10 cycles of concentration with the limiting factor being calcium sulfate (CaSO₄). Therefore, calcium is kept at or below 1,600 mg/l_{CaCO₃}. Silica (SiO₂) is kept at or under 150 mg/l. The Unit 3 cooling tower⁶ is operated at seven cycles of concentration and its blowdown is sent to the cooling tower at Unit 4 for reuse.

Another area of sensitivity in the cooling system is the metallurgy of the cooling tower hardware. Packing hangers, bolts, etc. are stainless steel, and as such, are susceptible to stress-corrosion cracking at circulating water chloride (Cl) concentrations in excess of 1,000 mg/l. This is not a problem with San Juan River water, but it would be a concern with high-chloride produced water (if it were fed to the cooling towers untreated).

Absorbers

SO₂ is removed from the flue gas in the limestone-based absorbers and converted to gypsum (CaSO₄•2H₂O). Water is used to slurry and convey limestone to the absorbers (from the limestone preparation area) and compensate for water lost to the flue gas (by way of evaporation).

Make-up for the absorbers is satisfied with recycled water from the Process Wastewater Ponds and water from the San Juan River. Gypsum sludge is dewatered and the filtrate is recycled back to limestone preparation. A portion of the filtrate – Purge Water – is disposed of to the evaporation ponds. Purge Water is bled from the absorbers to control chloride levels to less than 5,000 mg/l to minimize internal corrosion. Most of the chloride entering the absorbers is organically bound in the fuel, and after combustion, it is released as HCl (hydrochloric acid) in the flue gas. As the HCl is scrubbed in the absorbers, the chloride concentration rises⁷.

⁵ Average daily chemistry (2002) for the San Juan River provided by SJGS.

⁶ The Unit 3 cooling tower is a hybrid design that carries 70 percent of the heat load in an air-cooled dry section and 30 percent in a wet section.

⁷ 85 to 90 percent of the chloride entering the absorbers comes from scrubbed HCl and this is equivalent to 6.6 tons of HCl per day.

A secondary concern for the absorbers is magnesium (Mg). Magnesium sulfate (MgSO_4) is very soluble and if magnesium levels are elevated in the absorbers, converted SO_2 would remain in the soluble sulfate form. Purge Water also helps to avoid elevated concentrations of MgSO_4 . In a recent chemical analysis (data presented later), the Mg concentration in one of the absorbers was 4,200 mg/l⁸ (this sample was taken during normal operating conditions). There are currently no operating standards for Mg, however, it is monitored closely by the plant.

For other constituents, the absorbers operate at roughly eight cycles of concentration (based on the water balance around the absorbers). The flow from the Process Wastewater Pond could be increased to the scrubbers (with commensurately less freshwater) if one of the BCs was down for maintenance and the chloride concentration in the absorbers was within limits. Also, if high-chloride produced water is fed to the absorbers untreated it could exacerbate corrosion and/or require an increase in the Purge Water rate.

Ash System

The ash system requires water for sluicing bottom ash and wetting fly ash. San Juan River water is used for this service. The sluice system educts bottom ash from collection bins under the furnace. Sluice water is also used to seal the ash bins beneath the furnace and to wash the ash from the bin walls. The sluiced ash is sent to decanters and clarifiers where the ash is allowed to separate and settle. After clarification, the sluice water is returned for further service. Bottom ash water occasionally overflows from one of the two sluice system sumps into the plant drain system.

Sulfuric acid is added to the sluice water to maintain a pH of 7 to 9 (otherwise it rises to over 11 and causes significant scaling). The TDS of the sluice water system is 3 to 6 times⁹ (1,000 to 2,000 mg/l) that of fresh water as a result of acid addition (for pH control) and evaporative losses in the furnace bins and ash clarifiers. Sluice system corrosion is monitored and inhibitors are added to minimize corrosion and scale formation. For the purpose of this analysis, sluice water TDS should be maintained at or less than 2,000 mg/l to minimize corrosion in sluicing equipment (uncoated return piping, sluice pumps, seal water piping, etc).

Water is also used to wet fly ash as it unloaded into hauling trucks. This is done manually, and therefore, is not implemented consistently. At times there is excessive over-spraying which flows to the plant drain system.

Bottom ash and fly ash water uncontrolled releases eventually reach the Process Wastewater Ponds. High-TDS produced water used in the ash system could contaminate water to be recycled to other plant areas that are sensitive to high-salt levels.

⁸ 90 to 95 percent of the Mg in the absorbers comes from the limestone. The limestone used at SJGS is dolomitic and is comprised of 95% CaCO_3 (limestone) and 2.5% MgCaCO_3 .

⁹ This is based on anecdotal information provided by SJGS plant staff. There is no control limit for TDS – 1,000 to 2,000 mg/l appears to be the operating level for the system as it is operated.

Boiler Water

Boiler feedwater is supplied to the plant by make-up demineralizers originally designed to treat water from the San Juan River. After reconfiguring the plant to zero liquid discharge, the demineralizers now receive high-quality distillate from the BCs (fed by the Process Wastewater Ponds). Regeneration frequency has been dramatically reduced because distillate TDS is <10 mg/l (typically around 1 to 2 mg/l).

The BCs “pass” trace levels of boron in the form of boric acid to the distillate. This has been found to cause deposition problems on steam turbine blades even though distillate is further treated with the plant demineralizers. Boron levels should be less than 1 mg/l in the feedwater to the BCs (current levels) to minimize passage to the distillate. Produced water is a concern because it consistently has high levels of boron.

Summary

Compared to San Juan River water, produced water has very high levels of TDS and chloride, high levels of boron and moderate levels of silica. Table 3.2 summarizes water quality constraints for the process areas discussed above. These criteria are general and are meant to be guidelines for assessing produced water use at SJGS. The constraints are used as guidelines in the remainder of this section to evaluate untreated and treated produced water as a supplemental water supply at SJGS.

Table 3.2
Summary of Water Quality Constraints by Process Area
San Juan Generating Station

Process Area	Water Quality Constraint		Notes
Cooling Towers	Ca	1,600 mg/l _{CaCO3}	Circulating water
	SiO ₂	150 mg/l	Circulating water
	Cl	1,000 mg/l	Circulating water
Absorbers	Cl	5,000 mg/l	Purge water
Ash System	TDS	2,000 mg/l	Sluice water TDS after pH adjustment
Brine Concentrators	B	<1 mg/l	BC feedwater (to prevent boron carryover)
	Cl	9,000 mg/l	BC recirculation water (Footnote 11)

3.2.3 Recycled Wastewater

SJGS collects the following wastewater streams for reuse (refer back to Figure 3.1):

- Cooling tower blowdown¹⁰ from Units 1, 2 and 4
- Boiler blowdown (four units)
- Plant drains – mostly service water used for housekeeping and maintenance
- Spent regenerant (intermittent flow) from the boiler feedwater demineralizers

¹⁰ Cooling tower blowdown from Unit 3 is sent to the Unit 4 cooling tower. The Unit 3 cooling tower is less efficient (thermally) and routinely operates at higher circulating water temperatures. Therefore, it is more prone to certain types of scale formation and operates at a lower cycles of concentration (seven rather than ten). At seven cycles of concentration, its blowdown was considered recyclable (at commissioning) and has always been fed to the Unit 4 cooling tower.

- Ash system – overflow from the bottom ash system sumps and spillage from excessive spraying in fly ash unloading area.
- Coal pile run off (occasional flow during the rainy months)

The above streams are sent to the Process Wastewater Ponds for recycle to the absorbers and the BCs. Recycled water constitutes about 40 percent of the absorbers water demand. The BCs treat the remainder of the water from the Process Wastewater Ponds. BC distillate is sent to the demineralizers to be further treated for boiler feedwater. Excess distillate is sent to the cooling towers as supplemental make-up. BC brine is sent to final disposal in the evaporation ponds.

A limit of 9,000 mg/l of chloride¹¹ has been established for BC recirculation water. The wetted stainless steel (316L) components of the BCs experience corrosion above this limit in the form of pitting. Untreated produced water with high levels of chloride could cause a problem for the BCs.

3.2.4 Final Disposal of Wastewater at SJGS

Final disposal of wastewater at SJGS is to the evaporation ponds. The evaporation ponds consist of three 25-acre cells for a total of 75 acres. The evaporation ponds receive wastewater that cannot be recycled or treated for reuse. Of the 1,530 gpm of wastewater that is generated at SJGS, only 110 gpm (BC brine and absorber purge water) is considered unusable and disposed of in the evaporation ponds.

Plant staff have determined that every acre of pond evaporates the equivalent of 2 gpm of continuous wastewater inflow. Refer to Table 3.3 for a summary of wastewater streams and their volume requirement in the evaporation ponds.

Table 3.3
Wastewater to Evaporation Ponds
San Juan Generating Station

Wastewater Stream	Flow	Reserve Volume
Brine Concentrator Brine (1)	10 to 20 gpm	5 to 10 acres
Absorber Purge Water	100 gpm	50 acres
Boiler Cleanings (2)	Occasional	15 acres
Total		70 to 75 acres
Excess Capacity		0 to 5 acres

Notes.....

1. As a safety margin, the plant assumes a BC brine rate of 10 to 20 gpm to the evaporation ponds.
2. This volume is reserved for occasional boiler cleanings.

¹¹ This operating constraint was established by the brine concentrator manufacturer, Ionics-RCC. A higher grade of stainless steel (316 LM, 5+% Mo) would be required to operate at higher chloride concentrations for internal circulating water at a design pH of 4.0 to 5.0.

Absorber Purge Water requires 66 percent of the available evaporation pond capacity, i.e. 50 of 75 acres. Because of this, Purge Water is assessed along with produced water when evaluating treatment alternatives (later in this deliverable). Freeing up 50 acres of evaporation ponds would make that volume available for waste streams generated by produced water treatment.

3.3 Produced Water Resources in the Study Area

Three areas of produced water – Close-in, Tri-City and Fairway – are presented in Deliverable 2, Infrastructure Availability and Transportation Requirements, Figure 2.4. Collection would be accomplished by gathering produced water from the Tri-City and Fairway areas using the Hart Canyon Line and CO₂ Gas Line, respectively. A new Collection Center would be built in Bloomfield to store and pre-treat the water (oil removal). A 28.5-mile pipeline originating at the Collection Center would be installed to convey the water to the plant. Close-in water from the Kirtland area would be filtered and injected directly into the pipeline just prior to delivery at SJGS. Refer to Figure 3.2 for a schematic of produced water sources, gathering and conveyance.

3.3.1 Produced Water Chemistry and Volume

The produced water chemistry in Table 3.4 is for a number of sources in the Study Area. Table 3.4 introduces more chemistry data than found in Deliverable 1, Produced Water Assessment, Tables 1.4 and 1.5 – additional Close-in sources as well as coal bed methane (CBM) wells in the Fairway¹². The table includes chemistries and flow information for:

- Three Close-in CBM wells – Salty Dog 2/3, Turk’s Toast and Taber Locke
- BHP Billiton mine water (primary source of coal for SJGS) – two samples (similar to CBM water) of like concentration were averaged
- Prax Air – cooling tower blowdown from a nitrogen plant in Kirtland
- Tri-City – average values of 30 samples
- Fairway – average values of three CBM well samples

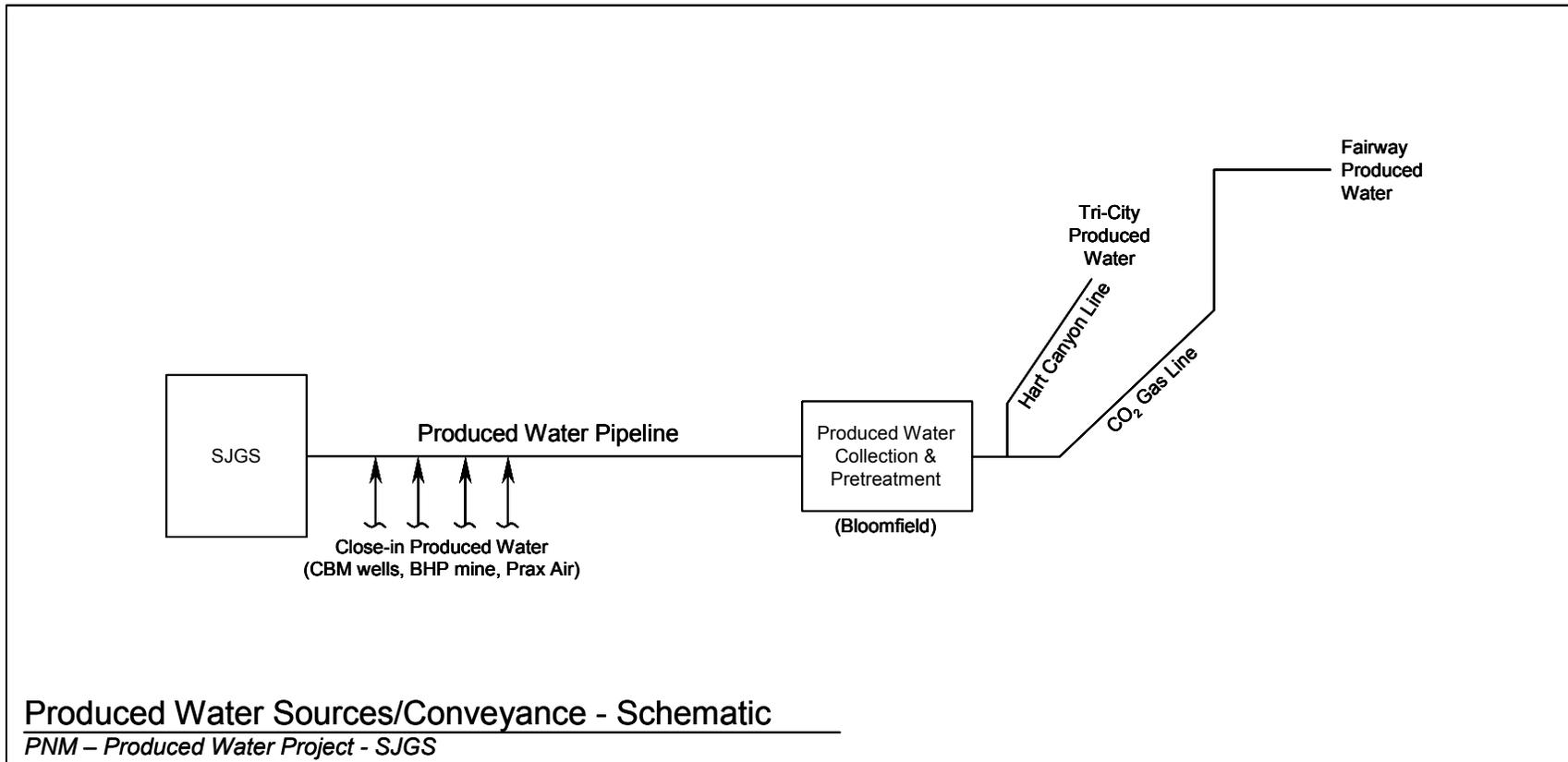
Also an effort was made to calculate maximum probable concentrations of heavy metals by using PQL¹³ values (practical quantitation level) as the minimum non-detectable values. This type of analysis is meaningful when conducting blend calculations for constituents that are near their detection levels, because PQLs are used rather than a zero value for a non-detectable concentration. One aspect of this type of analysis, is that it provides higher values for trace-level constituents. Metals concentrations are also included in Table 3.4.

Daily volume estimates are also shown in Table 3.4 along with the relative contribution from each site (expressed as a percent of total). It should be stressed that these are volume estimates and are highly dependent on the participation of individual oil and gas producers.

¹² Fairway chemistry was within the reported ranges for the McGrath SWD. McGrath receives water from a variety of sources including the Fairway area.

¹³ The practical quantitation level is the minimum concentration value a laboratory is willing to report with confidence for a specific analyte. Concentrations less than their PQL are considered non-detectable.

Figure 3.2



3.3.2 SJGS Reuse Opportunities for Untreated Produced Water

The following analysis shows how much untreated produced water could be used at SJGS, while still meeting all of the water quality constraints outlined previously. Refer to Table 3.4 for an estimate of produced water blend chemistry (all sources delivered to SJGS). Two scenarios were developed to evaluate this concept – one using the cooling towers as receivers of untreated produced water, and the other, the SO₂ absorbers. These areas of the plant were chosen because they are the largest users of water, and therefore, can theoretically accept relatively large quantities of saline produced water before their water quality limits are affected.

No assessment was done for the ash system, because the TDS of produced water chemistry, which exceeds 13,600 mg/l, is significantly greater than the 2,000 mg/l TDS constraint of the ash system. Also the water requirement for the ash system is only 100 gpm.

Produced water delivered to SJGS would contain estimated concentrations for target constituents as follows:

Target Constituent	Delivered Produced Water (1)
Ca	79.0 mg/l
SiO ₂	18.5 mg/l
Cl	5,043 mg/l
TDS	13,670 mg/l
B	2.51 mg/l

Notes.....

1. Extracted from Table 3.4.

The water balance shown in Figure 3.1 was used to develop a flow- and mass-calculation spreadsheet to evaluate produced water addition to the cooling towers and absorbers for a variety of produced water flow rates. Key streams in the spreadsheet could be varied, such as brine flow rate from the BCs and purge water from the absorbers, to keep the processes within their operating constraints. As can be seen in Table 3.5, all the water quality limits set for target constituents could be met, but only if certain wastewater stream flows were increased. Both scenarios are discussed next.

Scenario 1 – Cooling Towers

155 gpm of produced water could be added to the cooling towers without increasing blowdown (operating at the current cycles of concentration). Chloride levels in the cooling tower would rise from 260 mg/l to 1,000 mg/l. Because the chloride concentration of the blowdown is significantly higher to the Process Wastewater Ponds, the waste brine rate from the BCs would have to be increased from 14.8 gpm to 58.1 gpm to maintain the 9,000 mg/l chloride operating limit in the BCs. Likewise, the absorber purge water rate would have to be increased from 100 gpm to 171.9 gpm to

Table 3.4

Produced Water Chemistry - All Sources (page 1 of 2)

PNM - Produced Water Project - SJGS

		Salty Dog 2/3	Turk's Toast	Taber Locke	BHP Mine Water	Prax Air Blowdown	Tri-City (McGrath)	Fairway	All Sources
Flow Rate	BPD	5,000	2,500	2,200	1,700	300	10,000	20,000	41,700
	gpm	146	73	64	50	9	292	583	1,216
Flow Fraction		11.99%	6.00%	5.28%	4.08%	0.72%	23.98%	47.96%	100.00%
Na (1)	mg/l	9,563	2,119	6,848	2,936	364	4,201	3,620	4,501
K	mg/l	149	6.45	25.0	18.8	16.8	177	26.5	75.7
Calc'd NH ₄	mg/l	12.4	2.16	121	56.7	3.72	16.3	16.1	21.9
Ca	mg/l	128	6.27	66.6	40.3	693	143	31.0	75.1
Mg	mg/l	87.4	4.34	32.1	41.0	105	34.1	15.1	30.3
Ba	mg/l	20.8	1.86	13.6	1.10	0.94	3.08	25.1	16.2
Sr	mg/l	20.6	1.73	18.3	3.61	9.36	19.4	14.6	15.4
Dissolved Fe	mg/l	0.84	ND	ND	ND	3.50	33.1	4.87	10.4
Cu	mg/l	ND	ND	ND	ND	0.200	ND	ND	0.131
Zn	mg/l	0.298	ND	ND	ND	ND	0.230	ND	0.180
As	mg/l	ND	ND	ND	ND	ND	ND	ND	<0.180
Cr	mg/l	ND	0.005	ND	0.009	0.090	ND	0.003	0.004
Pb	mg/l	0.036	ND	ND	ND	1.550	ND	0.040	0.037
Se	mg/l	0.017	ND	ND	ND	ND	ND	0.015	0.013
Hg	mg/l	ND	ND	ND	ND	ND	ND	ND	<0.002
Ag	mg/l	NA	ND	ND	ND	0.250	NA	ND	0.022
U	mg/l	NA	ND	ND	ND	ND	NA	ND	<0.003
TC	mg/l _{CaCO3}	21,697	4,649	15,557	6,827	3,004	9,970	8,117	10,285

Table 3.4

Produced Water Chemistry - All Sources (page 2 of 2)

PNM - Produced Water Project - SJGS

		Salty Dog 2/3	Turk's Toast	Taber Locke	BHP Mine Water	Prax Air Blowdown	Tri-City (McGrath)	Fairway (4)	All Sources
HCO ₃	mg/l	1,440	1,952	1,050	853	139	764	6,377	3,622
CO ₃	mg/l	5.51	34.2	0.68	5.04	0.61	0.64	21.8	13.6
Cl (1)	mg/l	14,518	2,089	10,418	3,536	352	6,219	2,018	5,021
Br	mg/l	15.6	2.74	3.17	8.72	NA	14.5	18.9	15.1
F	mg/l	ND	2.30	1.47	1.04	NA	ND	0.74	0.61
NO ₃	mg/l	2.55	ND	ND	0.32	NA	ND	3.49	1.99
NO ₂	mg/l	ND	ND	ND	ND	NA	ND	ND	ND
SO ₄	mg/l	24.9	37.4	ND	1,082	2,300	544	4.32	198
TA	mg/l _{CaCO3}	21,697	4,649	15,557	6,827	3,004	9,970	8,130	10,291
SiO ₂	mg/l	9.7	12.2	32.5	15.9	1.82	18.5	21.44	19.0
Total Fe	mg/l	0.78	4.05	9.08	4.08	NA	41.3	4.58	13.1
Total Alkalinity	mg/l _{CaCO3}	1,180	1,910	1,050	790	119	697	5,398	3,101
Total NH ₃	mg/l _N	10.6	1.90	94.0	45.2	3.20	12.8	13.25	17.6
B	mg/l _B	2.87	1.60	2.40	0.81	29.0	2.05	2.31	2.41
O-PO ₄	mg/l _P	ND	ND	ND	ND	ND	ND	ND	ND
Total Sulfide	mg/l _S	ND	17.0	NA	NA	NA	ND	4.45	NC
pH		8.23	8.82	7.40	8.37	8.27	7.05	8.00	7.83
EC	μS/cm	40,300	9,160	29,900	13,200	NA	19,880	14,556	19,246
TDS (Calc'd)	mg/l	26,010	6,300	18,660	8,610	4,160	12,210	12,236	13,658
TSS	mg/l	42	16	18	814	NA	108	26	79
TPH	mg/l	ND	17	2.3	75	NA	163	71	77

Notes.....

1. Na and Cl values adjusted (as required) to achieve ionic balance.
2. NA = not analyzed, ND = not detectable, NC = not calculable.
3. PQL = practical quantitation limit.
4. Fairway TPH is an average of three sources - two sources had TPH concentrations typical of CBM production, i.e. at or less than 5 mg/l. One source (or the sample) was likely contaminated.

Table 3.5
Operating Adjustments to Meet Target Constraints
PNM – Produced Water Project – SJGS

Mass Balance - Target Constituents		Current Operation	Scenario 1 Produced H₂O to Cooling Towers (1)	Scenario 2 Produced H₂O to Absorbers (1)
Cooling Towers	Ca	1599 mg/l _{CaCO₃}	1594 mg/l _{CaCO₃}	1594 mg/l _{CaCO₃}
	SiO ₂	140 mg/l	145 mg/l	140 mg/l
	Cl	260 mg/l	1,000 mg/l	260 mg/l
Absorbers	Cl	5,000 mg/l	5,000 mg/l	5,000 mg/l
BC Feedwater	B	0.8 mg/l	1.0 mg/l	0.8 mg/l
BC Brine	Cl	9,000 mg/l	9,000 mg/l	9,000 mg/l

Key Water Balance Stream Adjustments to Meet Target Constraints (1)

Produced Water	0 gpm	155 gpm	100 gpm
BC Brine to Evap ponds	14.8 gpm	58.1 gpm	14.7 gpm
Absorber Purge Water to Evap Ponds	100.0 gpm	171.9 gpm	200.3 gpm
Total Wastewater to Evap Ponds	114.8 gpm	230.0 gpm	215.0 gpm
Additional Wastewater to Evap Ponds	0 gpm	115.2 gpm	100.3 gpm
Net Water Savings, gpm	0 gpm	39.8 gpm	(-0.3 gpm)
Annual Plant Demand	22,400 AF	22,336 AF	22,401 AG
Annual Freshwater Savings	0 AF	64 AF	(-1 AF)

maintain the 5,000 mg/l chloride limit. Under these conditions, chemistry constraints would be met for all process systems. However, the total-plant wastewater flow to the evaporation ponds would increase from 114.8 to 230.0 gpm. This would require the addition of at least 58 acres¹⁴ (equivalent to 116 gpm) of new evaporation ponds to receive the additional wastewater.

The amount of produced water could be increased above 155 gpm, but there would be a commensurate increase in cooling tower blowdown to maintain a chloride content of 1,000 mg/l. The cooling tower blowdown would double from 1,000 to 2,000 gpm, if 356 gpm of produced water were added to the cooling tower stream (maintaining 1,000 mg/l of chlorides in the cooling tower blowdown). Note that produced water has a relatively high chloride concentration, so increased amounts to the cooling tower accelerate the amount of additional blowdown. The blowdown would go to the Process Wastewater Ponds where a balance is maintained between the BCs and the absorbers. The BC receives 800 gpm (BC capacity) and the balance is sent to the absorbers. Therefore as the blowdown increases, the recycle flow of wastewater increases to the absorbers. With more cooling tower blowdown (at 1,000 mg/l of chlorides), Process Wastewater Pond water would be higher in chlorides. This in turn would require an increase in the purge water flow to maintain absorber chlorides. If the produced water rate to the

¹⁴ Logistically, SJGS can install an additional 20 to 30 acres of evaporation ponds on relatively flat terrain within the plant proper. Additional ponds would have to be installed at the edge of plant property by Highway 64 (about 3 to 4 miles from the existing ponds).

cooling towers exceeded 466 gpm, the Process Wastewater Ponds would generate more water than is recyclable to the absorbers and BCs. At this point, excess Process Wastewater Pond water would be sent directly to the evaporation ponds.

Scenario 2 - Absorbers

The absorbers have an operating limit of 5,000 mg/l of chlorides. Coincidentally, the produced water blend has a concentration of 5,040 mg/l of chlorides. If produced water were added to the absorbers it would create a wastewater stream of slightly larger magnitude. For example, if 100 gpm of produced water were added to the absorbers, purge water would increase by 100.3 gpm, i.e. 100 gpm to 200.3 gpm. Given this water chemistry, there are no direct-addition scenarios that are feasible for untreated produced water.

3.3.3 Summary

The use of untreated produced water is not practical at SJGS. Small amounts of high-TDS produced water (a fraction of what is available on a continuous basis) generate excess wastewater that cannot be handled by the plant.

The next part of this deliverable identifies technologies capable of treating produced water, develops treatment configurations and preliminarily assesses the economics of each treatment configuration.

3.4 Produced Water Treatment

Three sources of produced water – Close-in, Tri-City and Fairway – along with water from the BHP Billiton coal mine and a small amount of industrial wastewater are evaluated for treatment. Treating absorber Purge Water¹⁵ is also assessed, because it would free up 50 acres of evaporation pond capacity to accommodate wastewater generated by produced water treatment.

Off-the-shelf commercially available technology is evaluated in this section of the deliverable. PNM is currently looking at supplemental sources of water for SJGS, so proven technology is needed to implement any project. Water treating equipment at the plant is also included in the evaluation.

3.4.1 Water to be Treated

Chemistry for produced water is found in Table 3.4 along with BHP Billiton coal mine water and Prax Air cooling tower blowdown. Flow assumptions (provided by the oil and gas producers) are used to calculate an estimated blend chemistry. Refer to Table 3.6 for produced water blend chemistry, Purge Water chemistry and a hypothetical blend of produced water and Purge Water (PW/PW).

¹⁵ Purge Water generates a continuous flow of 100 gpm and uses 50 of the 75 acres of evaporation ponds at SJGS.

If it is feasible, blending purge water with produced water produces two benefits:

- Frees up 50 of the 75 acres of evaporation ponds at the plant. 50 acres are equivalent to \$8.6 million in new evaporation pond costs.
- Provides an additional 100 gpm of water that, if treatable, can be reused at the plant.

Produced water sources are characterized as follows:

- Relatively high TDS – 13,700 mg/l – comprised mostly of sodium bicarbonate and sodium chloride salts.
- Ammonia in the form of ammonium (NH_4^{+1}) is moderately high.
- Low level of calcium and magnesium hardness¹⁶ at 325 mg/l_{CaCO3}.
- Iron concentration is typical for produced water¹⁷ and can range as high as 20 to 30 mg/l at times.
- Heavy metals concentrations are low - near the detection limit for most constituents and non-detectable for the remaining.
- Silica is relatively low. Some produced waters in California have SiO_2 concentrations as high as 180 mg/l.
- Boron levels are high – consistent with oil and gas production.
- pH is slightly above neutral – probably lower (6.8 to 7.2) before it is released at the wellhead.

Total suspended solids (TSS) and total petroleum hydrocarbons (TPH) presented in Tables 3.4 and 3.6 are not representative of produced water “just out of the ground”. Samples taken at McGrath SWD (salt water disposal injection facility in the Tri-City area) were grabbed prior to injection, i.e. pretreated for oil separation and filtration. CBM produced water from Close-in and Fairway production was taken from storage prior to pretreatment¹⁸ (unfiltered). Also, the McGrath SWD receives conventional produced water with high levels of TPH. Close-in produced water is consistently low in TPH but high in TSS (mostly coal fines). Of note is the Fairway TPH concentration in Table 3.4. It is an average of three sources - two sources had TPH concentrations typical of CBM production, i.e. at or less than 5 mg/l. One source (or the sample) was likely contaminated.

Purge water¹⁹ is characterized as follows:

- Higher TDS – 20,500 mg/l – than the produced water blend and mostly comprised of sodium chloride and magnesium sulfate salts.
- Ammonium is twice that of produced water.
- Much higher levels of calcium as compared to produced water.

¹⁶ Calcium and magnesium hardness is calculated as follows: Ca-Mg Hardness, mg/l_{CaCO3} = Ca, mg/l_{ion} x 2.50 + Mg, mg/l_{ion} x 4.12.

¹⁷ Piping and tankage in oil and gas production are usually bare carbon steel, so iron levels from corrosion are typically high.

¹⁸ CBM water pretreatment prior to produced water injection consists of filtration to remove coal fines. Unlike conventionally produced water, CBM does not contain floatable hydrocarbons, and thus does not require oil separation.

¹⁹ It is assumed that the significantly high concentrations of ammonium, strontium, selenium, fluoride and boron in the absorber Purge Water derive from the plant coal. The nitrate concentration is from scrubbed NO_2 in the flue gas.

Table 3.6

Produced Water & Purge Water Chemistry

PNM - Produced Water Project - SJGS

		Produced	Purge	Blend	
		Water	Water		
Flow Rate	BPD	41,700	3,429	45,129	
	gpm	1,216	100	1,316	
Flow Fraction		92.40%	7.60%	100.00%	
Na (1)	mg/l	4,491	2,785	4,362	
K	mg/l	76.4	178	84.1	
Calc'd NH ₄	mg/l	19.7	31.4	20.6	
Ca	mg/l	79.0	493	110	
Mg	mg/l	30.5	4,160	344	
Ba	mg/l	13.8	0.374	12.8	
Sr	mg/l	13.6	207	28.3	
Dissolved Fe	mg/l	11.3	<0.01	10.5	PQL (3)
Cu	mg/l	0.131	0.134	0.131	0.13
Zn	mg/l	0.180	0.667	0.217	0.14
As	mg/l	<0.180	0.042	0.020	0.018
Cr	mg/l	0.004	0.035	0.006	0.003
Pb	mg/l	0.037	<0.005	0.034	0.005
Se	mg/l	0.013	6.180	0.482	0.011
Hg	mg/l	<0.002	<0.002	<0.002	0.002
Ag	mg/l	0.022	<0.02	0.022	0.02
U	mg/l	<0.003	0.078	0.009	0.003
TC	mg/l _{CaCO3}	10,268	24,966	11,384	
HCO ₃	mg/l	3,619	87.3	3,351	
CO ₃	mg/l	14.3	0.01	13.2	
Cl (1)	mg/l	5,043	3,976	4,962	
Br	mg/l	14.3	12.6	14.1	
F	mg/l	0.93	120	10.0	
NO ₃	mg/l	1.99	305	25.0	
NO ₂	mg/l	ND	ND	ND	
SO ₄	mg/l	198	18,000	1,550	
TA	mg/l _{CaCO3}	10,320	24,966	11,432	
SiO ₂	mg/l	18.5	32.5	19.6	
Total Fe	mg/l	14.0	3.01	13.2	
Total Alkalinity	mg/l _{CaCO3}	3,105	110	2,877	
Total NH ₃	mg/l _N	15.8	27.0	16.6	
B	mg/l _B	2.51	129	12.1	
O-PO ₄	mg/l _P	ND	ND	ND	
Total Sulfide	mg/l _S	NC	NA	NC	
pH		7.84	7.86	7.84	
EC	μS/cm	18,931	24,050	19,320	
TDS (Calc'd)	mg/l	13,666	20,460	14,182	
TSS	mg/l	83	269	97	
TPH	mg/l	99	64	96	

Notes.....

1. Na and Cl values adjusted (as required) to achieve ionic balance.
2. NA = not analyzed, ND = not detectable, NC = not calculable.
3. PQL = practical quantitation limit.

- Significantly high levels of magnesium at 4,160 mg/l – the magnesium comes from the dolomitic limestone used in the SO₂ absorbers.
- Strontium levels are significantly high at 207 mg/l.
- Very low levels of iron – the absorber vessels are lined to minimize corrosion.
- Relatively low concentration of heavy metals (except for selenium), although they are consistently higher than produced water.
- Selenium levels are very high at 6.18 mg/l.
- Fluoride and nitrate concentrations are very high – both likely originate from the coal. Also, NO_x is likely being scrubbed as well.
- Sulfate levels are very high at 18,000 mg/l as a result of scrubbing SO₂ from flue gas.
- Silica is moderately low.
- Boron levels are very high at 129 mg/l.
- pH was slightly above neutral in this sample (it usually is controlled between 5.0 and 6.0)²⁰.

Since there is twelve times as much produced water (92.4 percent of total) as Purge Water (7.6 percent), the impact of Purge Water on PW/PW blend chemistry is generally minimal. Refer again to Table 3.6. Many constituent concentrations hardly change, e.g. sodium, potassium, ammonium, chloride, alkalinity. TDS of the hypothetical PW/PW blend is only 4 percent higher than produced water. Of note however, are the concentrations of magnesium and sulfate, which increase dramatically – 11 times and 8 times that of produced water, respectively. Selenium also increases in the PW/PW blend from 0.013 mg/l to 0.482 mg/l.

Volatile organic compounds (VOCs) are present at low levels in conventional produced water. VOCs in produced water commonly consist of benzene, toluene, ethyl benzene and xylene, which are known collectively as BTEX. CBM water has very low levels of BTEX relative to conventional water – 0.1 to 0.2 mg/l BTX in CBM water versus 10 to 20 mg/l in conventional water. VOCs and VOC removal are discussed in more detail later in this deliverable.

The chemistry just discussed is used to evaluate commercially available technologies in the next section. Water collected from Close-in, Tri-City and Fairway production are assessed as well as the PW/PW blend.

3.4.2 Commercially Available Technology

As discussed previously, small amounts of high-TDS produced water fed to the cooling towers or absorbers would generate excessive volumes of wastewater. Produced water as well as PW/PW must be treated before it can be reused in the plant. Table 3.7 compares operating constraints for the cooling towers, absorbers and ash system against San Juan River water (the fresh water supply to the plant), produced water and the PW/PW blend. Chloride and TDS levels in produced water and the PW/PW blend clearly exceed or approach process operating constraints before the concentrating effect in each of the systems.

²⁰ There was likely a release of CO₂ when the sample was taken, and this would have allowed the pH to rise.

Specifically, chloride and TDS concentrations must be significantly reduced before produced water or the PW/PW blend can be used as supplemental feedwater for SJGS. From a water treating perspective, there are several off-the-shelf technologies that can be used to economically lower chloride and TDS concentrations:

- Reverse osmosis (RO)
- Evaporative processes (such as the brine concentrators at SJGS)
- Process combinations of the above

Table 3.7
Process Area Constraints versus Various Water Sources
PNM – Produced Water Project – SJGS

Process Area	Constituent	System Operating Constraint	San Juan River (1)	Produced Water (2)	PW/PW (2)
Cooling Towers	Ca, mg/l _{CaCO₃}	1,600	135	200	275
	SiO ₂ , mg/l	150	12	20	20
	Cl, mg/l	1,000	22	5,040	4,960
Absorber	Cl, mg/l	5,000	22	5,040	4,960
Ash System	TDS, mg/l	2,000	360	18,930	19,320

Notes.....

1. SJGS fresh water supply.
2. Close-in, Tri-City and Fairway produced water blend and PW/PW data from Table 3.6. Concentrations were rounded for simplicity.

A significant amount of pilot testing (government and private funding) of produced water has been done in the recent past to evaluate proven and developmental technologies. Many of the major oil companies in California have either tested or considered treating produced water. A produced water treatment plant is in final design in San Ardo, California (150 miles south of San Francisco and 35 miles inland from the coast). Likewise, similar studies have been conducted in Alberta, Canada. The focus of most of the testing (and investment) has been on membranes configurations – RO with a variety of pretreatment options, and in some cases, post treatment of RO reject (concentrated waste stream). RO has proven to be a robust process for this service as long as pretreatment is applied correctly and rigorously maintained (discussed more later).

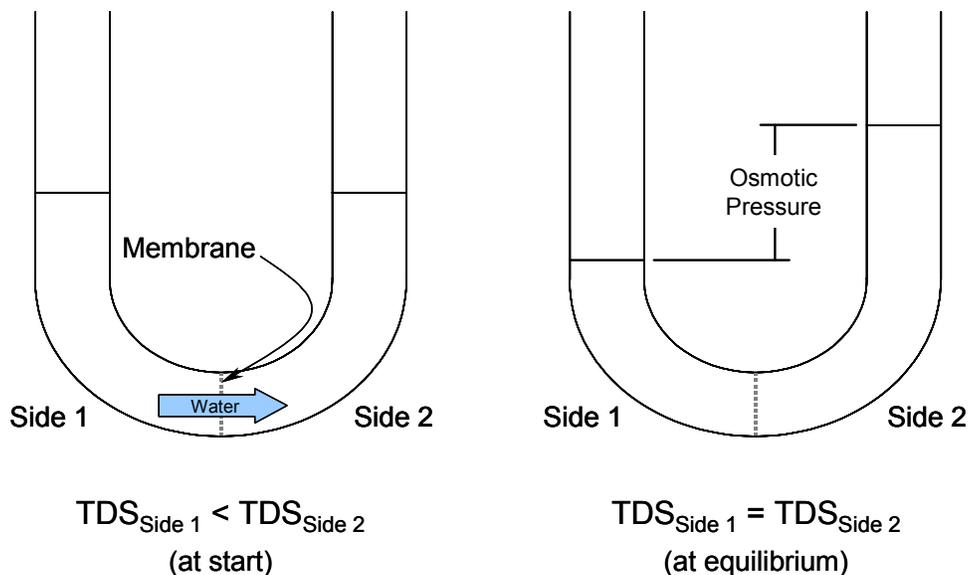
There are other commercial technologies – ion exchange and electrodialysis – capable of reducing TDS, but they are untested (pilot testing or otherwise) in this service, and therefore, are not considered in this analysis. Also, at these levels of TDS, ion exchange would be very costly to operate and would generate large volumes of wastewater.

Reverse osmosis is discussed in the next section of the deliverable. Brine concentration is discussed in the context of SJGS. The plant has two idled brine concentrators (typical of those found in power plants throughout the Southwest) that are capable of treating produced water.

3.4.3 Reverse Osmosis

Osmosis occurs naturally in membrane systems. A simple example is the passage of water through the root cells of a plant. Water in soil has a lower concentration of salts than in root cells. The cell wall (membrane) allows water to enter the root cell in an attempt to equalize the concentration of salts on each side of the membrane. Experimentally, if equal volumes of water – one saltier than the other – are placed in a u-shaped tube with a permeable membrane separating them, osmosis takes place. Refer to figure 3.3. Water from the side with the lower salt concentration diffuses through the membrane to the saltier side. At equilibrium, the salt concentrations on both sides of the membrane are equal and the difference in water levels is sustained by osmotic pressure.

Figure 3.3
Osmotic Pressure



Early research in water purification revealed that if pressure is applied to the side of a membrane with the higher salt concentration, water is forced back through the membrane leaving the salts behind. This phenomenon was coined reverse osmosis. In the past 50 years, membrane design has advanced to a high level of sophistication. RO has become a very common process and is used extensively throughout the world to desalinate seawater, purify water for industrial use, and more typical in the past few years, recycle wastewater.

Membrane Configurations

There are two common membrane configurations:

- Spiral wound – the membrane assembly consists of sheets bound to a hollow core. The membrane sheets are wrapped around the core to form a cylinder. Water flows across the surface of the membrane to allow permeate (water that passes through the membrane) to flow to the collection core.

- Hollow fiber – the membrane consists of a bundle of densely-packed hair-thin hollow fibers. The fibers are embedded into an anchor cap at one end and a collection cap at the other. The permeate travels through the hollow passages in the fibers and exits at the collection end of the membrane assembly.

Spiral wound membranes are the most commonly used configuration. Hollow fiber membranes are now used mostly for non-fouling service, because they are very difficult to clean if fouled²¹. Other membrane configurations exist but are not very common, e.g. tubular membranes and plate and frame membranes.

Because spiral wound membranes are more suited for the fouling potential of produced water service, the remainder of the deliverable concentrates on this membrane configuration.

Spiral Wound Membranes

As described previously, layers of membrane sheets are wrapped around a hollow core to form a spiral wound element. Refer to Figure 3.4. Feedwater passes through the membrane face and is channeled inside the membrane envelope to the core for permeate collection. Also, sheet geometry permits turbulent flow to occur across the face of the membrane. Scouring created by turbulence at the plane of the membrane surface makes this configuration better suited for the fouling potential of produced water.

In industrial applications, the elements are either 4 or 8 inches in diameter and typically 40 inches long. The membranes are loaded into a pressure tube – two to six to a tube depending on the size of the system. Water is fed to one end of the pressure tube, and at the other end, permeate and reject (concentrated wastewater) exit in separate lines. Pressure tubes are arrayed such that feedwater is distributed to the tubes equally. In a staged RO system, the first stage receives feedwater and the second stage receives RO reject as feedwater. If there were a third stage, it would receive second-stage reject as feedwater. Refer to Figure 3.5 for a simplified two-stage, three-tube RO system. The number of elements, pressure tubes and stages is dependent on feedwater rate, feedwater quality, recovery goals (how much permeate is desired), etc.

Membrane Types

There are three common types of membrane materials – thin-film polyamide (PA), cellulose acetate (CA) and polysulfone (PS). PA membranes are currently the most widely-used membranes. They have higher flux rates (flow rate per unit of membrane surface area), lower energy requirements (for the same feedwater TDS and flow rate) and better salt rejection than CA membranes. CA was one of the first commercial types of RO membranes, but has lost significant market share to more-efficient PA membranes. CA membranes have better oxidation resistance²² than PA membranes.

²¹ The pores in the membrane surface are believed to be less than 0.001 microns (10^{-9} meters) and are easily fouled without proper pretreatment. Human hair has a diameter of 30 microns.

²² Disinfecting agents are used to prevent bacteria from growing in RO systems. Bacteria form films which blanket and clog membrane surfaces. Common disinfecting agents (sodium hypochlorite – bleach solution) are used to control biological fouling, however they can destroy membrane functionality.

Figure 3.4

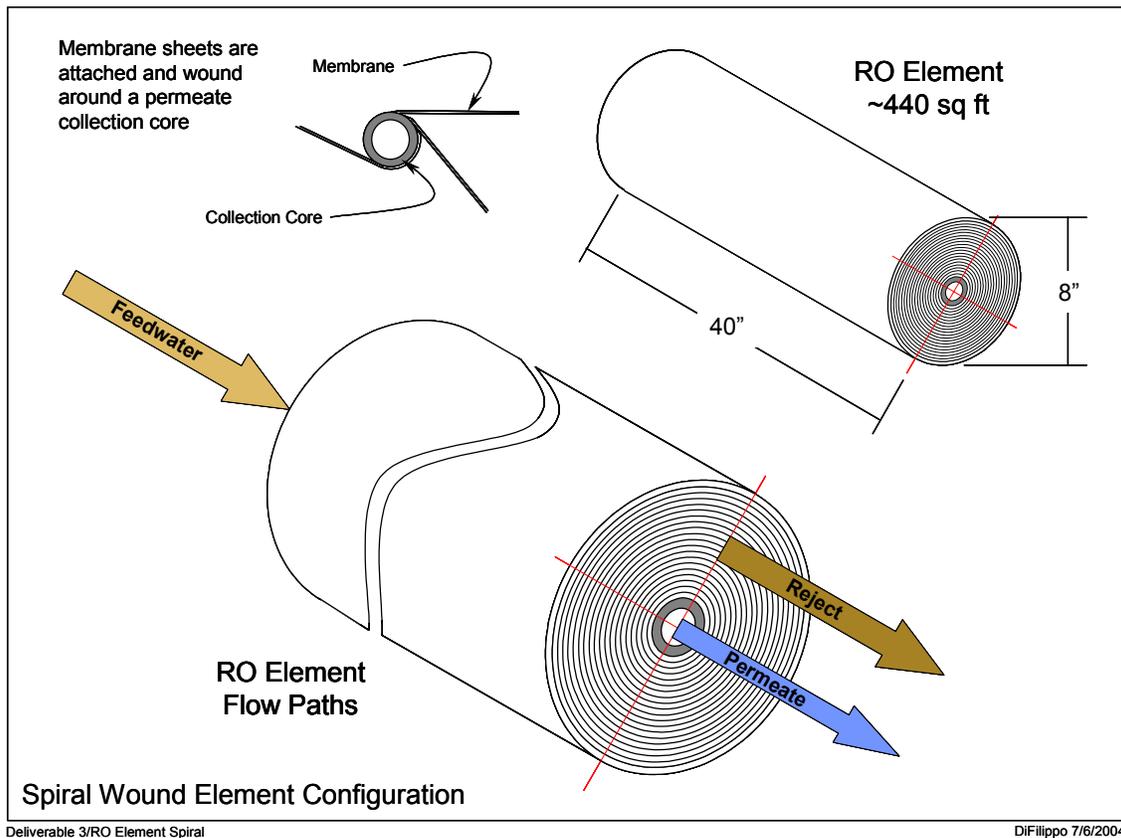
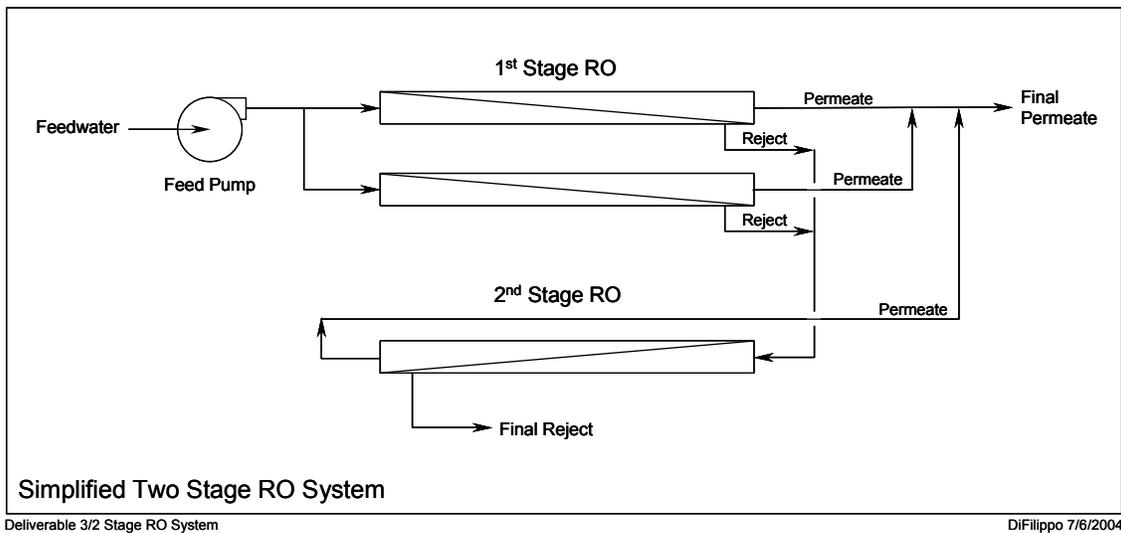


Figure 3.5



PS membranes have the best oxidizing resistance so they perform well in waters with biological fouling tendencies, however, PS membrane feedwater must be softened²³ or the membranes lose their salt rejection capability.

In modern membranes, 95 to 99 percent salt rejection is achievable (depending on membrane type and feedwater conditions). Therefore, only 1 to 5 percent of the salts in the feedwater (salt passage) pass through the membrane with the permeate.

Produced Water Service

Spiral wound, thin-film polyamide RO membranes are evaluated for produced water service in this deliverable. Produced water pilot studies have focused on this membrane because:

- The membrane exhibits better resistance to produced water foulants – mineral scale, particulate matter, oil and biological fouling.
- Permeate has lower salt passage characteristics (lower permeate TDS).
- The membranes require less energy, i.e. they operate at lower pressure.

RO fouling remains a real concern for RO systems treating produced water, making pretreatment critical. Pretreatment, which is often more complex than the RO system itself, is developed later in the deliverable.

3.4.4 Brine Concentrator Equipment at SJGS

The brine concentrators at SJGS are typical of evaporation equipment found in power plants in the Southwest. The plant has four brine concentrators – two operating and two idled. SJGS treats and recycles much of its wastewater with two brine concentrators – capacities of 240 gpm and 560 gpm (800 gpm total) – BC 4 and BC 5, respectively. There are also two idled brine concentrators at the plant – BC 2 and BC 3 – each has a capacity of 580 gpm (1,160 gpm total). The idled brine concentrators are evaluated for treating and reusing produced water at SJGS since the operating BCs are fully utilized.

The brine concentrators at SJGS operate in the seeded mode, i.e. crystal formation²⁴ is encouraged in the concentration process to enable higher recoveries of water. Refer to Figure 3.6. Feedwater to the brine concentrators is acidified to between 4.0 and 5.0. Acidification²⁵ converts all the alkalinity to carbonic acid. Before the feedwater is introduced into the brine concentrator, it is preheated by hot distillate exiting the brine concentrator. A scale inhibitor²⁶ is also added to the feedwater to modify crystal growth, keep crystals in the bulk fluid and minimize scale adhesion to heat transfer surfaces. After preheating, the acidified water enters a deaerating section where dissolved gasses

²³ Softening in this context consists of the removal of divalent (calcium, magnesium, iron, etc.) and trivalent ions (iron, aluminum, etc.).

²⁴ Crystal formation as calcium sulfate (CaSO_4). Calcium sulfate crystals in the presence of scale inhibitors move freely in the recirculating brine and along the heat transfer surfaces. If the BC were not operated in this mode, recovery would be severely reduced to prevent scale formation.

²⁵ Alkalinity removal via acidification is critical because calcium carbonate tends to foul heat transfer surfaces in the brine concentrator.

²⁶ Scale inhibitors are proprietary products sold by specialty chemical providers.

(primarily oxygen and carbon dioxide) are released to minimize corrosion. The acidified and deaerated water is then added to the sump of the brine concentrator.

Water in the sump is pumped to the top of the brine concentrator and allowed to fall (in film-like fashion) in vertical tubes. Each tube has swirl device at the tube sheet to encourage film formation and minimize scale buildup at its entrance. As the film of water moves down the tubes, a small fraction of it evaporates as steam. The steam is collected in the top of the brine concentrator and compressed. After compression, it is admitted to the vapor space on the outside of the vertical tubes where it provides the heat source for evaporation. This type of brine concentrator is known as a vapor compression evaporator, since the compressor provides the thermal input to evaporate the recirculating brine. Brine concentrator distillate is usually of excellent quality – TDS is approximately 1 to 2 mg/l.

The in-service brine concentrators (BC 4 and BC 5) are susceptible to chloride pitting corrosion (at an operating pH of 4.0 to 5.0), because much of the metallurgy (sump, vapor space, recirculation piping, etc.) is 316L stainless steel. For this reason, the chloride concentration in the recirculating brine must be kept under 9,000 mg/l (as recommended by the manufacturer). The vertical tubes (and tube sheet) are titanium, and as such, could withstand much higher levels of chloride.

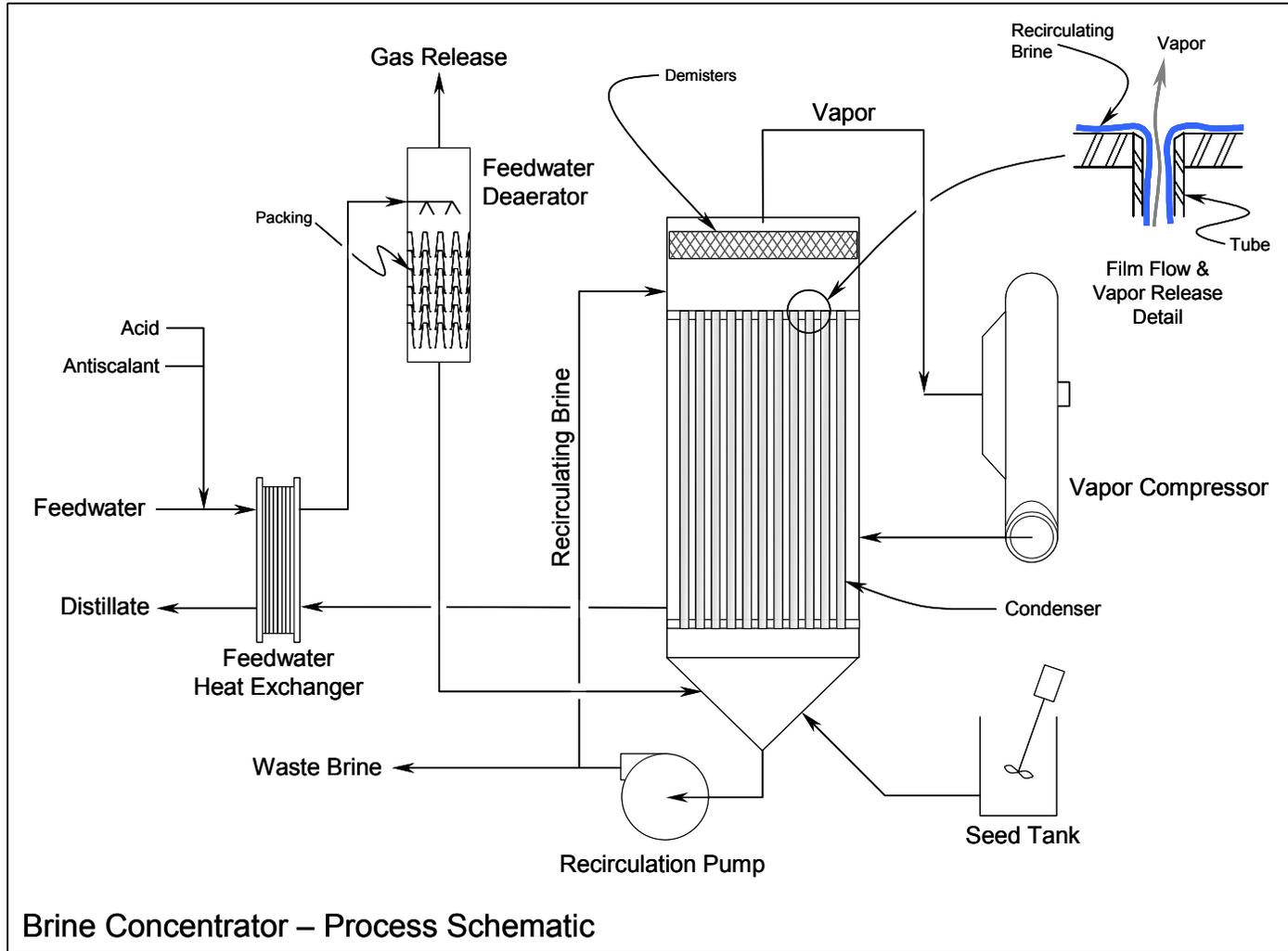
The brine concentrators are well suited for the wastewater currently being treated at the plant, i.e. low levels of chloride, and a good ratio of calcium and sulfate for seeded-mode operation. Some seeding is required depending on feed chemistry (calcium chloride is added for this purpose). The brine concentrators at SJGS recover over 98 percent of the feedwater (even with their chloride operating constraint). Recirculating brine at the plant can have a dissolved and suspended solids loading exceeding 200,000 mg/l.

The brine concentrator manufacturer was consulted several years ago to determine which of the two idled brine concentrators (BC 2 and BC 3) was best suited for refurbishment, disassembly and reassembly at another PNM power plant (relocation was never implemented). It was later determined that both could be refurbished – BC 3 would require significantly less repair than BC 2. Also, of note is the fact that these brine concentrators have 316 LM metallurgy²⁷ and are much more resistant to chloride pitting corrosion. If refurbished²⁸, the chloride operating limit for these brine concentrators would be 50,000 mg/l.

²⁷ 316 LM is a high-moly content stainless steel alloy with 5+% of molybdenum.

²⁸ Several minor components would still require metallurgical upgrades to 316LM to operate at higher chloride levels.

Figure 3.6



Deliverable 3 Figures

DiFilippo 7/5/2004

3.4.5 Produced Water Treatment Alternatives

Treatment alternatives that incorporate off-the-shelf technology – reverse osmosis and brine concentration – are developed in this section of the deliverable. Alternatives specifically include spiral-wound thin-film polyamide RO and the BC equipment at SJGS (both discussed in the previous sections of this deliverable). Refer to Figure 3.7 for a schematic overview of the three basic combinations of RO and BC technologies:

- Treat with only RO.
- Treat only with BC 2 and BC 3.
- Treat with a combination of RO and BC 3 (better of the two BCs).

This analysis evaluates treatment of produced water delivered to SJGS. Pretreatment at the Bloomfield Collection Center is discussed in Section 3.5 of this deliverable.

Two sub-alternatives are investigated for each RO and RO-BC alternative:

- Conventional RO (CRO) – includes standard spiral-wound PA membranes operating at low pH. This is a traditional approach to operating RO systems.
- High-efficiency RO (HERO®)²⁹ – includes standard spiral-wound PA membranes operating at high pH. This is a relatively new approach with inherent advantages to treating produced water.

Lastly, five treatment alternatives were evaluated for produced water and the same five for the produced water and Purge Water (PW/PW) blend. A total of 10 alternatives are evaluated as described in Table 3.8.

RO Pretreatment - General

Pretreatment for RO focuses on the prevention of membrane fouling, which occurs when foreign matter blocks membrane pores. Membrane fouling concerns include:

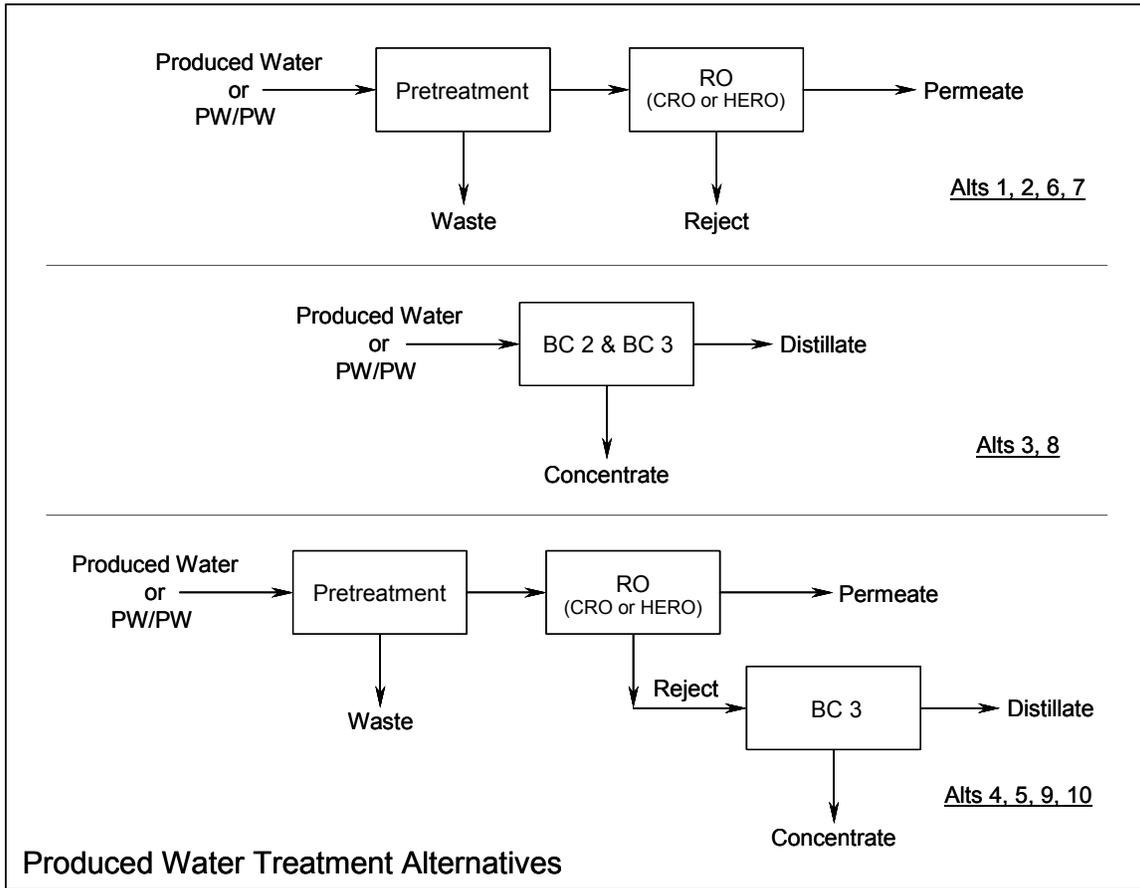
- Mineral scale occurs when foulant constituents are concentrated in the RO element beyond their saturation levels. Crystals nucleate and attach to membrane surfaces. Examples include calcium carbonate, barium sulfate and silica³⁰. Scale can be prevented either by lowering mineral constituent concentrations in RO feedwater or by operating the RO at lower recovery (to avoid over saturation). Precipitation softening is sometimes used to lower metals (calcium, magnesium, etc.) and silica levels³¹. Scale inhibitors are also used to reduce scale formation potential by extending solubility or slowing/modifying crystal growth.

²⁹ Aquatech International (water treatment OEM) is the sole licensee of HERO® technology for power plant applications.

³⁰ At concentrations exceeding 150 mg/l and at a pH of less than 10.0, silica polymerizes and forms an amorphous (non-crystalline) deposit that is very difficult to remove.

³¹ Depending on the amount of magnesium removed, water temperature and contact time, precipitation softeners can also be used to remove silica from feedwater. Silica sorbs onto magnesium hydroxide floc.

Figure 3.7



Produced Water Treatment Alternatives

Table 3.8
Produced Water Treatment Alternatives Summary
PNM – Produced Water Project - SJGS

	CRO	HERO®	BC 2	BC 3	Produced Water Only	PW/PW Blend
Alternative 1	X				X	
Alternative 2		X			X	
Alternative 3			X	X	X	
Alternative 4	X			X	X	
Alternative 5		X		X	X	
Alternative 6	X					X
Alternative 7		X				X
Alternative 8			X	X		X
Alternative 9	X			X		X
Alternative 10		X		X		X

- Particulate matter in the form of inert (non-reactive) particles accumulates on membrane surfaces. Particulate matter can be removed with filtration.
- Biological films, in the form of bacterial colonies, spread over membrane surfaces. In the past, bacteria were a serious concern with CA membranes because they literally metabolized the membrane – PA membranes are not metabolized. Control is usually accomplished by adding oxidizing biocides to RO feedwater followed by a reducing agent³² to protect the membrane. PA membranes are susceptible to oxidation if the residual chlorine levels continuously exceed 0.1 to 0.2 mg/l_{Cl₂} during the operating life of the membrane. Once bacteria colonies are established on the membrane, periodic cleaning of the membrane assemblies using non-oxidizing biocides may be required to control their growth³³.
- Non-soluble oil is a common constituent of produced water. Petroleum is mostly comprised of a variety of carbon-hydrogen compounds (light to heavy, straight chain to complex aromatics). Some constituents³⁴ tenaciously adhere to surfaces. Oil can also form emulsions in water, i.e. small droplets that are difficult to separate from water. Oil can be removed from RO feedwater by a combination of gravity separation, air flotation and filtration. Chemical additives are often used to break emulsions during treatment.
- Colloidal matter in the form of charged clusters of large organic molecules or nucleating precipitants can accumulate on membrane surfaces. Like-charged colloidal clusters repel each other, and as such, tend to spread over the membrane surface. These materials can be neutralized with polymers (carrying an opposite charge, e.g. cationic polymer) and filtered from RO feedwater.

A complicating factor with fouling is that combinations of certain foulants can exacerbate the problem. For example, bacterial foulants form sticky slimes that can embed mineral scale or inert particles. Oil can also provide base material for mineral scales and particulate matter.

Produced water in the San Juan Basin has the potential to generate all of the above fouling problems. Pretreatment is discussed in more detail as the alternatives are developed (next section).

Produced Water Treatment Alternatives

By intention, wastewater generation is minimized in all of the alternatives discussed next. Waste streams generated by produced water treatment are recycled to the “front end” of the treatment system. Depending on the treatment alternative, final (non-recyclable) wastewater is either RO reject or BC brine. These streams would be sent to the evaporation ponds for final disposal. No wastes would be sent offsite for disposal. Sludge generated by precipitation softening would be sent to the SO₂ absorbers as

³² Reducing agents, e.g. sodium bisulfite, readily react with excess oxidizing agents. They are injected into the feedwater after the oxidizing agent has had sufficient residence time for disinfection.

³³ These compounds, which are sold as formulations by specialty chemical providers, are toxic and must be applied under controlled conditions, i.e. offline during a membrane cleaning cycle.

³⁴ Two compounds of concern are paraffins and asphaltenes. Paraffins are high-molecular weight hydrocarbons that form paste-like deposits under high pressure (such as the operating pressure in RO membranes). Asphaltenes, which are commonly found in oil, are large charged molecules that readily adhere to surfaces.

supplemental limestone feedstock³⁵. Use Table 3.8 as a guideline for the process configuration of each alternative, i.e. combinations of CRO, HERO® and BC. Refer to Table A.1 in Appendix A in for detailed process information (flows, chemicals, power requirements, etc.) for all of the alternatives and Table A.2 for process chemistry.

CRO Only - Alternatives 1 and 6

These alternatives would use conventional reverse osmosis to treat produced water (Alternative 1) and the produced water/purge water (PW/PW) blend (Alternative 6). Refer to Figure 3.8³⁶ for a process schematic of Alternatives 1 and 6. CRO systems are operated at low pH to reduce the calcium carbonate scaling potential of feedwater³⁷. Pretreatment would include softening via lime precipitation (reactor clarifier) to reduce calcium, magnesium, barium, strontium and dissolved iron. Without softening, RO recovery would be quite low, rendering the technology infeasible. Ultrafiltration (UF)³⁸ would be used upstream of the RO to filter particulate matter and remove organic foulants. Basket strainers would be used protect the UF from particulate loading generated by the reactor clarifier. Sodium hypochlorite (disinfectant) would be added upstream of the strainers and reduced with sodium bisulfate upstream of the UF and RO to protect membranes. A degasifier would be used to remove CO₂ generated by acid addition (for pH control). Softening and UF are designed to minimize, but not eliminate, scaling formation and organic fouling. Additionally, at low pH, RO is more susceptible to oil fouling³⁹ making UF critical to successful RO operation.

Softener sludge, which is mostly calcium carbonate (limestone) would be dewatered in a thickener and sent to the limestone preparation for use as feedstock in the absorbers. A coagulant aide and cationic polymer would be used to assist the reactor clarifier and thickener in dewatering sludge.

UF bleed and sludge thickener overflow – would be recycled to the front end of the system. After softening and filtration of the feedwater, the CRO would operate at 77 percent recovery. Calcium sulfate, barium sulfate and strontium sulfate would still form at this recovery level and would have to be controlled with a scale inhibitor/crystal modifier. Even with all the pretreatment precautions, the CRO would likely require cleaning every one to two months to remove mineral scale, organic foulants and biological growth.

³⁵ Sludge generated by precipitation softening would be similar in assay to the dolomitic limestone used by SJGS for SO₂ scrubbing. Depending on the produced water treatment configuration, precipitation softener sludge would replace 2 to 10 percent of the limestone used by the plant. Based on known produced water chemistry, there are no observed or obvious constituents that would interfere with the SO₂ absorption process or SO₂ absorber sludge stability (leaching characteristics). This would require more review if implemented.

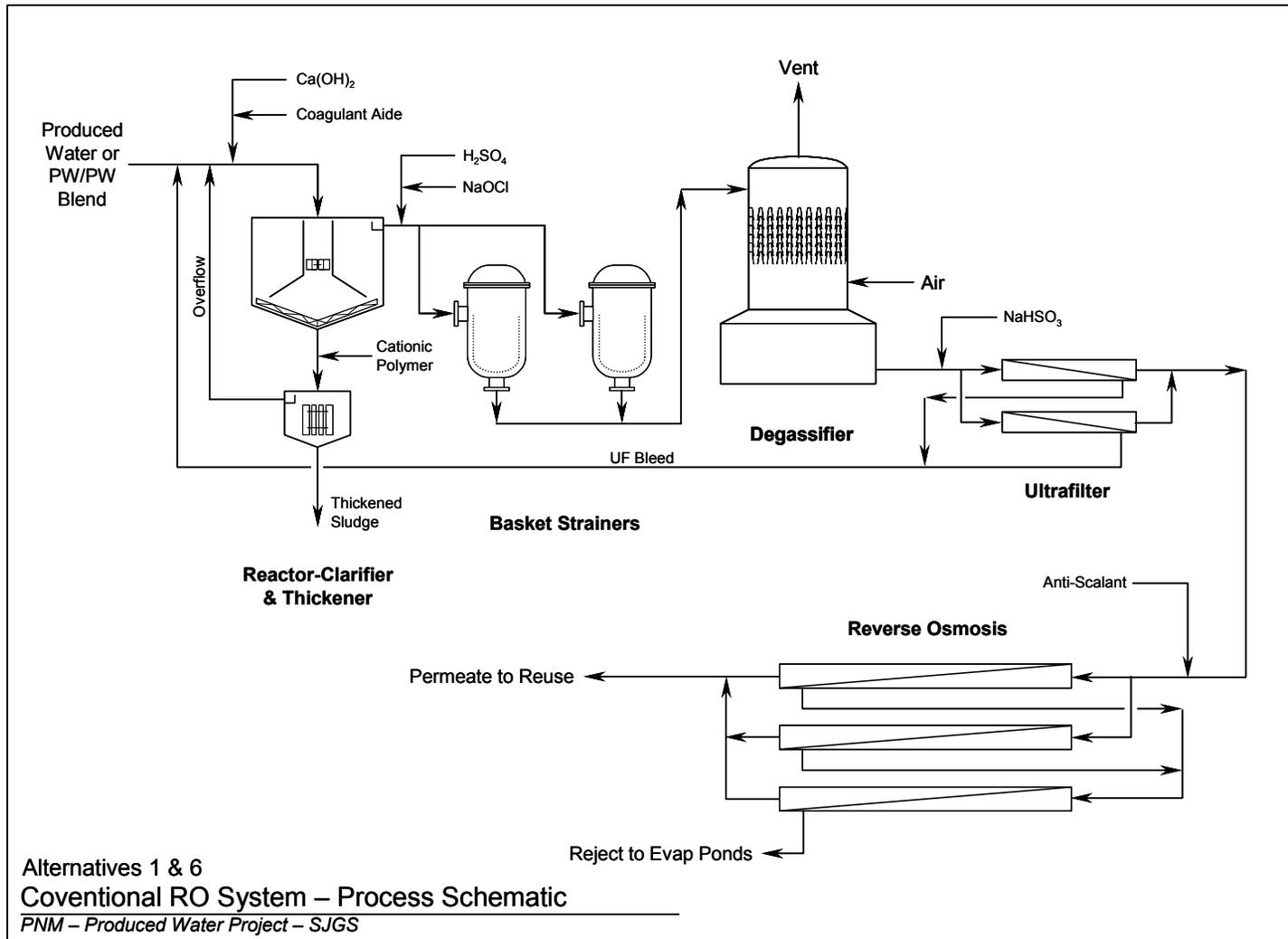
³⁶ Figure 3.8 is a simplified schematic – an actual RO system would have more pressure tubes, inter-stage pumping, etc.

³⁷ At low pH (typical range is 4.5 to 5.5), carbonate alkalinity in the feedwater is converted from a mixture of carbon dioxide (CO₂), bicarbonate (HCO₃⁻¹) and carbonate (CO₃⁻¹) to mostly CO₂. This reduces the likelihood of calcium carbonate (CaCO₃) formation.

³⁸ Ultrafiltration (or a similar type membrane process, such as micro-filtration), is usually recommended for water with a high fouling potential such as produced water. There are a number of membrane configurations – some similar to RO, e.g. spiral wound and tubular membranes. There are also ceramic media configurations.

³⁹ At low pH, certain oils become less soluble and present a greater potential for deposition.

Figure 3.8



Cleaning would be accomplished by isolating one section of the RO, connecting it (via portable hoses) to a clean-in-place (CIP) skid and flushing it with one or more cleaning solutions. Cleanings are planned around RO performance, e.g. they are initiated when RO flux (throughput at a given feed pressure) drops below a certain threshold. Treatment is usually customized for whatever problem is expected. On occasion, one membrane element is removed and cut apart to determine the types of foulants present and the overall condition of the membrane.

HERO® Only - Alternatives 2 and 7

High-efficiency reverse osmosis consists of pre-softening for the complete removal of hardness and the operation of the RO at high pH (9.5 to 10.5). Refer to Figure 3.9 for a process schematic. This mode of operation would significantly minimize common RO operating problems such as hardness (calcium, magnesium, barium and strontium) and silica scaling. Also, at high pH, organic fouling and certain oil constituents would dissolve, minimizing fouling in the RO.

Pretreatment would include softening via lime precipitation (reactor clarifier) to reduce calcium, magnesium, barium, strontium and dissolved iron (same as Alternatives 1 and 6). Media filters (sand and anthracite) would be used to protect weak acid cation (WAC)⁴⁰ ion exchangers from particulate fouling. WAC would be used to completely remove effluent hardness from the reactor clarifier, thus removing the potential of mineral scale in the RO. A degasifier would be used to remove CO₂ generated by the WACs. Sodium hypochlorite would be added upstream of the degasifier and reduced with sodium bisulfite upstream of RO to protect membranes.

Softener sludge would be dewatered in a thickener and sent to limestone preparation (similar to Alternates 1 and 6). Alternatives 2 and 7 would generate more solids than Alternatives 1 and 6 because all of the hardness is eventually returned to and removed by the reactor clarifier. Wastewater generated by the pretreatment system – filter backwash, WAC spent regenerant and sludge thicker overflow – would be recycled to the front end of the system.

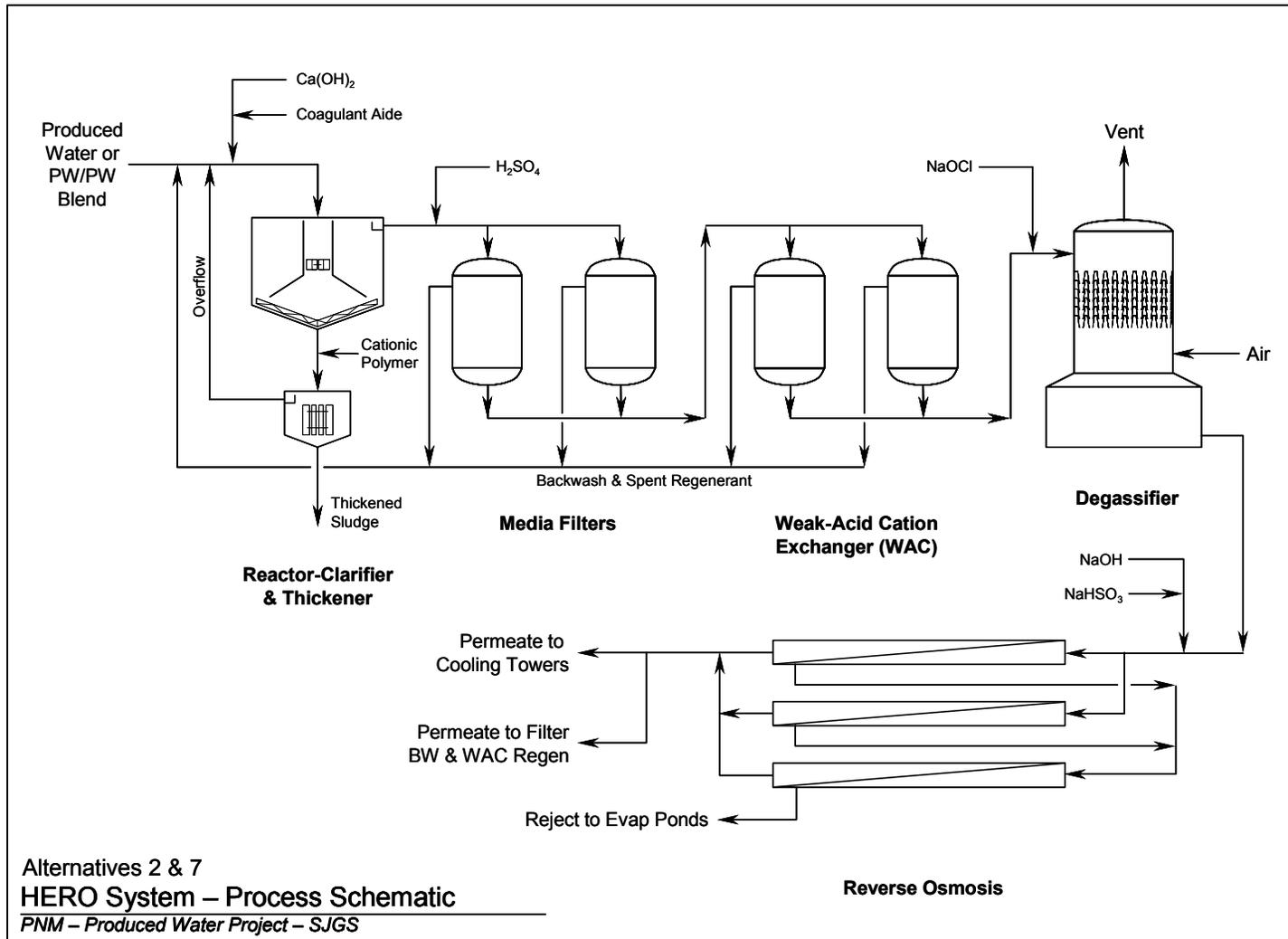
After softening and filtration, HERO® could operate at 86 percent recovery. Recovery would be higher than CRO, because calcium, barium, strontium, etc. were removed from the feedwater (no concern of mineral scales). At elevated pH (>10), silica⁴¹ dissociates to form silicates and does not form silica scale. Also, in the absence of divalent and trivalent metal ions, silicate scales do not form.

As a precautionary measure, HERO should be cleaned every twelve months to remove trace amounts of mineral scale, organic foulants and biological growth.

⁴⁰ In this service, WAC ion exchangers would be operated in the hydrogen form, i.e. they would exchange hydrogen ions (H⁺¹) for divalent (calcium, magnesium, barium, strontium, etc.) and trivalent ions (aluminum, iron, etc.) associated with alkalinity. If 100 equivalents of alkalinity were in the feedwater, WAC would exchange 100 equivalents of H⁺¹ for 100 equivalents of hardness ions. Produced water and the PW/PW blend have alkalinity concentrations significantly higher than divalent/trivalent metals so all of the hardness would be removed by the WACs.

⁴¹ Soluble SiO₂ is a weak acid in water – H₄SiO₄ – silicic acid. Silicic acid dissociates to H₃SiO₄⁻¹ at pH greater than 10, and at higher pH, H₂SiO₄⁻².

Figure 3.9



SJGS BCs Only - Alternatives 3 and 8

In these alternatives, produced water and PW/PW would be fed to refurbished brine concentrators, BC 2 and BC 3. The combined capacity of the BCs is 1,160 gpm (580 gpm each). This falls just short of the required capacity for Alternative 3 of 1,216 gpm of produced water and Alternative 8 of 1,316 gpm of PW/PW.

The BCs would be operated in the seeded mode, because of the presence of scaling constituents in the feedwater. Refer again to Figure 3.6. In the seeded mode, the pH would be kept between 4.0 and 5.0 to minimize scale deposition in the feedwater heat exchanger and condenser. Low pH also converts feedwater alkalinity to CO₂ (to eliminate CaCO₃ scale). CO₂ would be removed in the deaerator (along with oxygen to minimize corrosion potential). Anti-scalant would also be required to minimize scale deposition on BC heat transfer surfaces.

A significant amount of calcium chloride (CaCl₂) would be added to the BCs to promote seed formation – 16.0 tpd and 21.6 tpd, respectively for Alternatives 3 and 8. There is not enough calcium relative to sulfate in produced water or the PW/PW blend to promote crystal formation. Insufficient crystal formation would lead to severe scaling problems in the BCs. With sufficient nucleation sites available, crystals circulate with the BC bulk fluid and tend not to deposit.

BC 2 and BC 3 have the requisite 316 LM stainless steel (5+% molybdenum) metallurgy to operate at low pH and very high chloride levels. Some minor metallurgy upgrades would have to be made to both BCs (316LM cladding in certain areas) to operate in this mode. The operating limit for chloride would be 50,000 mg/l in the BCs and would limit recovery to 87 and 86 percent for Alternatives 3 and 8, respectively.

BC 2 and BC 3 would have to be cleaned (hydro-lancing the condenser tubes) every 12 months to maintain operating recovery and throughput.

CRO & SJGS BCs - Alternatives 4 and 9

In these alternatives, CRO would be operated as a pre-concentrating device ahead refurbished BC 3 (the better of the two idled BCs). Pretreatment for Alternatives 4 and 9 would be the same as Alternatives 1 and 6 (refer to Table 3.8). The BC would be operated in the seeded mode, because saturated levels of scaling salts in the reject from the CRO would be fed to the BC. Some minor metallurgy upgrades (316LM cladding in certain areas) would have to be made to BC 3 to enable it to operate in this mode.

A significant amount of calcium chloride (CaCl₂) would also be added to the BCs to promote seed formation – 15.2 tpd and 15.3 tpd, respectively for Alternatives 4 and 9. BC recovery would be limited to 48 and 53 percent of RO reject for Alternatives 4 and 9, respectively. Chloride levels would limit recovery. The overall recovery (CRO and BC) would be 88 percent for Alternatives 4 and 9.

BC 3 would have to be cleaned (hydro-lancing the condenser tubes) every 12 months to maintain operating recovery and throughput.

HERO® & SJGS BCs - Alternatives 5 and 10

In these alternatives, HERO® would be operated as pre-concentrating device ahead of refurbished BC 3 (the better of the two idled BCs). Pretreatment for Alternatives 5 and 10 would be the same as Alternatives 2 and 7 (refer to Table 3.8). The BC would be operated at high pH in the un-seeded mode. The benefit of high-pH operation (10 to 11)⁴² is that the BC could be operated at high levels of chloride without any alloy upgrades to stainless steel wetted parts. The need for acid, anti-scalant and CaCl₂ would be eliminated, because there would be no scaling salts in the BC feedwater.

BC recovery would be limited to 73 percent of RO reject for Alternatives 5 and 10. This is significantly higher than seed-mode operation, because total solids is the limiting factor rather than chloride. Total solids would be controlled between 200,000 mg/l to 250,000 mg/l. The overall recovery (HERO® and BC) for Alternatives 5 and 10 would be 95 and 97 percent, respectively.

As a precaution, BC 3 should be cleaned (hydro-lancing the condenser tubes) every 36 to 48 months.

3.4.6 Preliminary Economic Analysis of Treatment Alternatives

A preliminary cost analysis is presented in this section of the report. The analysis is used to determine which alternative is the most economically feasible to treat and reuse produced water at SJGS. Table 3.9 is a summary the results of the analysis and includes:

- Feedwater flow, overall system percent recovery and recovered water flow
- Recovered water quality (TDS)
- Additional evaporation pond capacity required for produced water treatment
- Additional operating and maintenance staff
- Power requirements
- Capital and operating costs
- Unit operating cost (\$/1,000 gallons of recovered water)

A detailed analysis of produced water recovery is presented in Deliverable 6, Cost/Benefit Analysis. Produced water flow is predicted over the life of the project for five recovery cases and three production declination scenarios⁴³ (for a total of 15 evaluations). The flow rate selected here for preliminary economic analysis is within the likely produced water recovery envelop (roughly midway).

Process and cost support information is presented in Appendix A for all of the alternatives. Refer to Table A.1 for process information details, Table A.2 for process chemistry, Table A.3 for capital and operating cost development and Table A.4 for the assumptions used in the cost analysis.

⁴² The BC must be operated at a pH less than 12.0 to avoid embrittlement of the titanium tubes (Ti2 alloy) in the BC heat exchanger. Titanium embrittlement information was provided by James Grauman of Timet Corp. (April 14, 2004 phone conversation). Timet provides titanium tubes and sheet to BC manufactures.

⁴³ As oil and gas fields mature, production and produced water generation decline.

Table 3.9

Produced Water Treatment - Preliminary Economic Analysis

PNM - Produced Water Project - SJGS

Alternative	Produced Water	FGD Purge	CRO	HERO	BC 2	BC 3	Flow Basis gpm (4)	Overall Recovery	Recov'd Water gpm	Recov'd Water TDS mg/l	Add'l Required Evap Ponds acres (3)	Total Addl Staff	Total Power Reqm't kw	Capital Cost (2) \$MM	Total Annual Cost (1) \$MM	Unit Op Cost \$/kgal Net
1	X		X				1,216	76.9%	935	270	140	5.2	650	\$46.09	\$6.42	\$13.07
2	X			X			1,216	86.1%	1,047	260	87	5.2	600	\$31.35	\$4.08	\$7.41
3	X				X	X	1,160	87.0%	1,009	10	75	5.2	4,830	\$29.12	\$7.23	\$13.64
4	X		X			X	1,216	87.8%	1,068	240	73	5.2	1,718	\$32.58	\$6.54	\$11.65
5	X			X		X	1,216	96.6%	1,174	240	24	5.2	1,774	\$18.92	\$3.13	\$5.07
6	X	X	X				1,316	74.6%	981	260	114	5.2	720	\$39.77	\$5.68	\$11.01
7	X	X		X			1,316	82.3%	1,083	270	67	5.2	660	\$26.53	\$3.86	\$6.78
8	X	X			X	X	1,160	86.1%	999	10	31	5.2	4,780	\$17.46	\$6.43	\$12.24
9	X	X	X			X	1,316	87.8%	1,155	230	27	5.2	1,875	\$21.13	\$5.37	\$8.85
10	X	X		X		X	1,316	95.3%	1,255	230	0	5.2	1,915	\$14.12	\$2.98	\$4.52

Notes.....

1. Includes capital recovery at 7.5% for 20 years.
2. Does not include costs for offsite equipment - Collection Center in Bloomfield and the 28.5-mile pipeline.
3. Alternatives 6 to 10 receive a 50-acre credit for Purge Water capacity.
4. The flow basis is approximate and within the likely produced water recovery range.

Based on the analysis, Alternative 10 is the most economically feasible approach. Alternative 10 consists of treating the PW/PW blend with HERO® and BC 3 (the better of the idled BCs). The alternative has the lowest evaluated capital cost (\$14.1 million) and operating cost (\$2.98 million per year), would recover the most produced water for reuse (1,255 gpm) and would require no additional evaporation ponds.

Of the alternatives that use combinations of RO and BC (4, 5, 9 and 10), Alternative 10 would use the most power – 1,915 kw (there is a 200 kw spread among these alternatives). Alternatives 3 and 8, which employ both BC 2 and BC 3, clearly would require the most power (4,830 kw) and are limited in total treatment capacity.

SJGS determined that additional operating and maintenance coverage would be the same for all of the alternatives. One additional operator for each shift (8,760 hours per year – equivalent to 4.2 staff) and one shift of maintenance coverage (1 person) would be required.

Produced water feed rate, produced water reclaimed for reuse, and capital and operating costs for Alternative 10 are refined in Deliverable 6, Cost/Benefit Analysis. Full project costs (Bloomfield Collection Center, pipeline and treatment at SJGS) are also presented in Deliverable 6. PNM's implementation plan is discussed in Deliverable 7.

3.4.7 Disposition of Treatment Wastes

Heavy Metals

As shown in Table 3.6, heavy metals are present at detectable levels in produced water and purge water. The metals fall into two groups:

- Cations – Cu, Zn, Pb, Hg and Ag
- Anions – AsO₄, CrO₃, SeO₃/SeO₄ and UO₃

In the alternatives employing precipitation softening, most of the Cu and Zn, almost all of the Pb and Hg, and some of the AsO₄ and SeO₃/SeO₄ would be removed as precipitants in reactor clarifier sludge. The cations would be removed as Cu(OH)₂, Zn(OH)₂, etc. and the AsO₄ and SeO₃/SeO₄ would be co-precipitated⁴⁴. If some of the precipitated metals resolubilized⁴⁵ in the absorber (recall that reactor clarifier sludge would be blended with limestone feedstock), they would be either be removed:

- By softening the Purge Water.
- Along with waters of moisture in absorber gypsum sludge.
- Via co-precipitation in absorber gypsum sludge.

Metals not removed by softening would be in the RO reject stream⁴⁶ in alternatives employing membrane processes. Reject would either be sent to the evaporation ponds or to BC 3. All of the heavy metals in BC feedwater would be in the waste brine stream to the evaporation ponds.

⁴⁴ AsO₄ and SeO₃/SeO₄ sorb onto nucleating crystals and become entrapped as precipitate forms.

⁴⁵ This is not likely for the highly insoluble salts like Pb(OH)₂ and Hg(OH)₂.

⁴⁶ Salt passage for heavy metals is very low – 99.7 to 99.9 percent rejection should be expected at the membrane

Lastly, the amount of heavy metals loading⁴⁷ in produced water is equivalent to 2.72 kilograms per day (kg/day) at the assumed feedwater flow rate. Based on the analytical data found in Table 3.6, the Purge Water stream alone generates 3.90 kg/day of metals loading. Even though the combined waste stream would generate a 70 percent increase in metals loading, most of it would be bound in either precipitation softener sludge or SO₂ absorber sludge or lost as waters of moisture in SO₂ absorber sludge. Therefore, if the Purge Water stream were treated (Alternative 10), the resultant metals loading to the evaporation ponds would be less than present day.

Volatile Organic Compounds

VOCs are commonly found in produced water. They are usually comprised of a group of aromatic compounds collectively known as BTEX – benzene, toluene, ethylbenzene and xylene. BTEX is expressed as the sum of the concentrations of these compounds. The compounds are volatile, i.e. given good water-air contact, BTEX constituents readily vaporize from water into air. Table 3.10 summarizes BTEX data for conventional and CBM produced water. Conventional water clearly has higher levels of BTEX than CBM produced water. Also note that McGrath SWD receives a mix of conventional and CBM produced water.

Table 3.10
BTEX Concentrations – Conventional and CBM Sources
San Juan Basin

Produced Water Site	Type	BTEX mg/l	Benzene mg/l	Toluene mg/l	Ethylbenzene mg/l	Xylene mg/l
McGrath SWD	Conv/CBM	22.610	4.700	11.000	0.510	6.400
McGrath SWD	Conv/CBM	9.960	0.900	0.940	3.200	4.920
Taber Battery	CBM	0.562	0.060	0.150	0.050	0.302
Taber Battery	CBM	0.207	0.069	0.017	0.037	0.084
Turk's Toast	CBM	0.198	0.002	0.012	0.160	0.023
Salty Dog 2 SWD	CBM	0.124	0.036	0.007	0.057	0.024
Middle Mesa SWD	CBM	0.166	0.008	0.047	0.013	0.098
Pump Canyon SWD	CBM	0.288	0.004	0.120	0.011	0.151

Approximately 50 percent of the BTEX in the produced water delivered to the Collection Center in Bloomfield would be removed by one of the oil removal processes – gas flotation (discussed next section). The remaining BTEX would be diluted with Close-in produced water, cooling tower blowdown from Prax Air, BHP Billiton mine water and absorber Purge Water. The concentration of BTEX in the produced water blend to be treated at SJGS would likely range from 1 to 4 mg/l (equivalent to 14 to 56 pounds per day of BTEX at

⁴⁷ Loading is calculated by summing the heavy metals concentrations found in Table 3.6. If a concentration is less than the PQL (non-detectable), then the PQL is used as its concentration. Mass loading is calculated as follows:

$$\text{Mass Loading, kg/day} = 0.00545 \times \text{Flow Rate, gpm} \times \sum (Me_i, \text{mg/l})$$

40,000 BPD produced water delivery). Most of it should be removed to atmosphere in the degasifier air stream and the BC deaerator.

Finally, there could be trace levels in the treated produced water. Given dilution with fresh water and gas-liquid contact in end-use processes, BTEX should be at non-detectable levels in the SO₂ absorber liquor or cooling tower circulating water, i.e. most of the BTEX should be lost to the flue gas or cooling tower air stream.

3.5 Collection Center in Bloomfield

The Collection Center in Bloomfield would have three functions:

- Provide a collection point for produced water delivered by the CO₂ Gas Line and the Hart Canyon Line.
- Pretreat produced water to remove oil and grit prior to conveyance.
- Equalize the chemistry of the produced water prior to charging the pipeline from Bloomfield to SJGS.

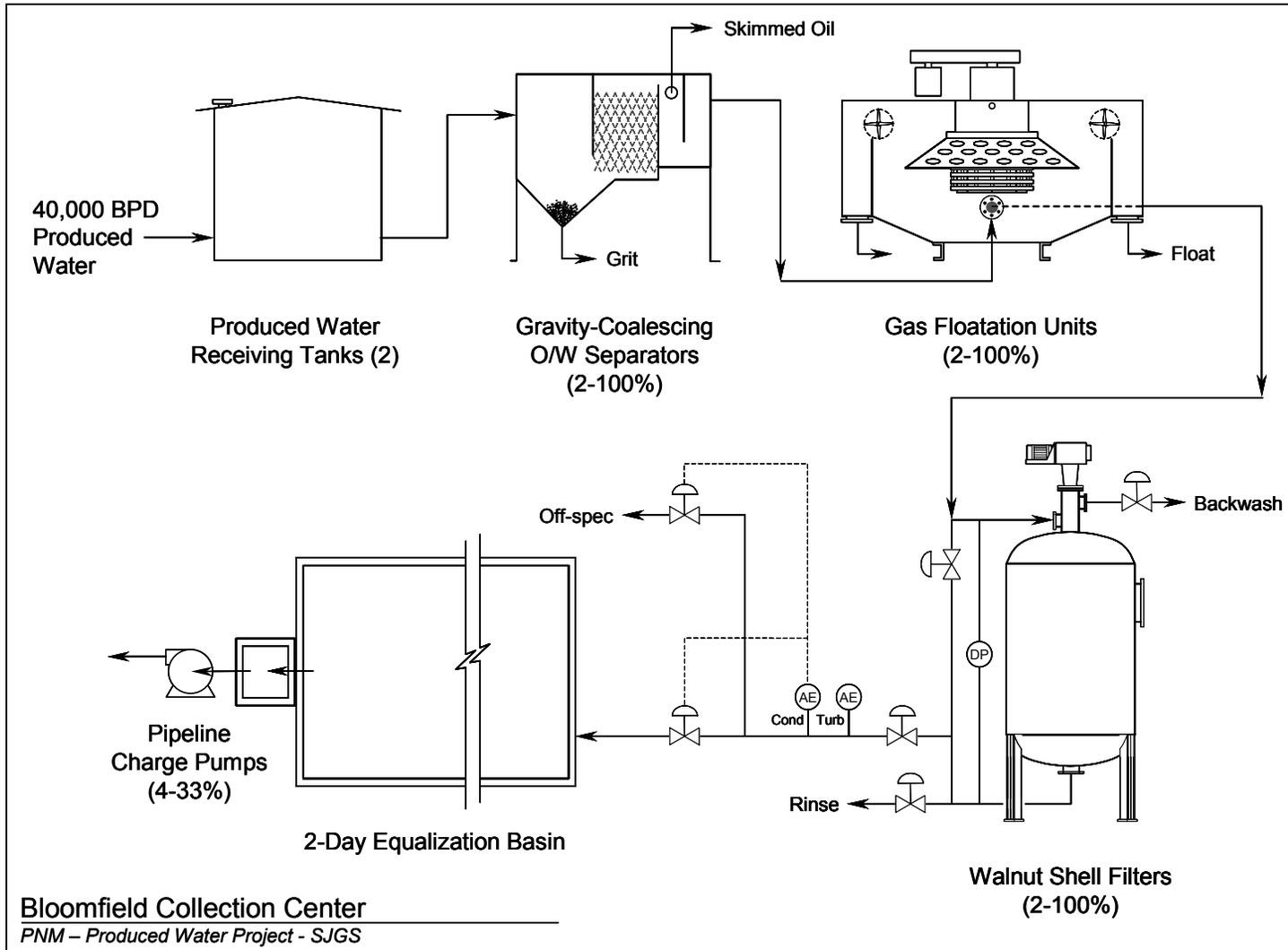
Refer to Figure 3.10 for a process schematic of the Collection Center. The Collection Center would process produced water from conventional oil and gas production and CBM wells (mostly from CBM wells). Two tanks would be used to receive and store produced water delivered to the Collection Center. Three oil-removal technologies would be used to pretreat the water – gravity separation, gas flotation and media filtration.

A gravity-coalescing oil/water separator would be used to remove un-dissolved⁴⁸ and floatable oil as well as grit. An emulsion breaker (EB) would be fed to the water prior to the oil/water separator to de-emulsify oil that is finely dispersed. The separator allows oil to float to the surface in the forward compartment and inclined plates in the rear compartment collect and agglomerate smaller droplets of oil. Grit falls to the bottom of the separator in both compartments. Oil and grit comes from convention oil and gas production. Produced water from CBM wells is almost free of oil byproducts. Skimmed oil from the separator would be stored separately in a tank and sold to the Giant Oil Refinery in Bloomfield for reclamation. Grit would be removed occasionally to a grit tank and disposed offsite at an approved landfill.

Water from the separator would then be fed to a gas flotation unit where additional oil would be removed. Fine bubbles of air are used to float oil droplets to the surface which are removed to side troughs (this foamy mixture is also known as float). Float would also be removed to a grit tank for disposal offsite. The flotation units should also remove up to 50 percent of volatile BTEX constituents found in conventional produced water (discussed previously in Section 3.4.7 of this deliverable).

⁴⁸ Some petroleum-based organic chemicals are water soluble and cannot be removed by physical means, e.g. gravity separation, flotation or filtration. The compounds would be eventually be removed by the HERO process at SJGS.

Figure 3.10



Finally, water would be fed to a walnut shell media filter to remove trace levels of oil that escape the oil/water separator. Walnut shell media is used extensively in oil field applications to remove separable oil. Backwash from the walnut filters would be recycled back to the produced water receiving tanks for reprocessing. Rinse from the filters would be recycled back to the walnut filter feed tank. The filter effluent would be monitored for turbidity to initiate the backwash cycle. Filter effluent would also be monitored for conductivity to segregate produced water with very high salinity to an off-spec hold tank. Additional automated testing could be added at this point to identify other off-spec water parameters.

Filtered water would be held in a two-day basin to allow its chemistry to equalize prior to conveyance to San Juan Generating Station. Water from the off-spec tank would be slowly blended into the equalization basin. Water that is significantly off-spec (or that cannot be blended in a timely manner) would be trucked offsite and disposed of via deep well injection at one of two licensed facilities in the Bloomfield area.

Capital and operating costs for the Collection Center in Bloomfield are found in Tables A.5 and A.6 in Appendix A.

Disposition of Volatile Organics

About 50 percent of the BTEX delivered to the Collection Center would be removed by the gas flotation unit to atmosphere. Fine air bubbles, which buoy oil droplets to the surface in the flotation unit, also provide extensive water/air contact to allow BTEX to volatilize into air. About 4 to 12 mg/l of BTEX should be in the produced water delivered to the Collection Center. If half is removed to the gas flotation unit air stream (14 to 56 pounds per day of BTEX), water shipped to SJGS should have a BTEX content of 2 to 6 mg/l. Produced water BTEX levels would be diluted by Close-in CBM water and a number of non-petroleum streams to 1 to 4 mg/l by the time it reaches SJGS.

3.6 Summary

Produced water is available to SJGS for reuse from three sources:

- Close-in CBM production including mine water from BHP Billiton (primary coal source for SJGS) and a small amount of industrial wastewater from Prax Air in Kirtland
- Conventional and CBM production gathered in the Tri-City area by the Hart Canyon Line
- CBM production gathered in the Fairway area by the CO₂ Line

The Hart Canyon Line and CO₂ Line are owned by Burlington Resources. Water gathered by these lines would be sent to the Collection Center in Bloomfield where oil and grit would be removed.

Produced water, which has a TDS of approximately 14,000 mg/l, was first evaluated for use at SJGS without treatment. Its use was evaluated against plant operating criteria for certain key chemistry constituents (primarily chloride and TDS). Even small amounts of untreated produced water could not be used without generating significant quantities of wastewater. This approach was considered impractical.

Absorber Purge Water was also considered for treatment and reuse (blended with produced water) because it would free up 50 acres of evaporation pond capacity (66 percent of total). Currently, the plant must blowdown Purge Water from the absorbers to control chloride levels.

An assessment of off-the-shelf treatment technologies determined that reverse osmosis (RO) and brine concentration (BC) were the most feasible. Only off-the-shelf technologies were considered because PNM is currently evaluating supplemental water supplies for SJGS and proven technology is required to implement any plan. Two types of RO were evaluated:

- Conventional RO (CRO) – includes standard spiral-wound PA membranes operating at low pH. This is a traditional approach to operating RO systems.
- High-efficiency RO (HERO®) – includes standard spiral-wound PA membranes operating at high pH. This is a relatively new approach with inherent advantages to treating produced water.

Pretreatment was considered critical for produced water because it has a high potential for membrane fouling. Of the two RO types, HERO® appeared to be best suited because all the feedwater hardness is removed to minimize the potential for mineral scale and it operates at high pH so silica scale and oil/organic fouling are minimized as well.

Two idled BCs at SJGS (BC 2 and BC 3) were included in the evaluation. They were previously inspected for refurbishment and reuse at another PNM power plant. BC 3 was considered the best of the two.

Five treatment alternatives (CRO, HERO, BC 2/BC 3, CRO/BC 3 and HERO/BC 3) were evaluated for produced water and the same five for the produced water and Purge Water (PW/PW) blend.

It was determined that Alternative 10, the HERO® and BC 3 combination, was the most economically feasible – it had the lowest evaluated capital cost (\$14.1 million) and operating cost (\$2.98 million per year), would recover the most produced water for reuse (1,255 gpm) and would require no additional evaporation ponds. Alternative 10 would require 1,915 kw of power. Alternatives 3 and 8, which employ both BC 2 and BC 3, clearly would require the most power (4,830 kw) and were limited in the amount of water they could treat because of corrosion due to high chlorides.

SJGS determined that additional manpower needs for operating and maintenance coverage would be the same for all of the alternatives. One additional operator for each shift and one shift of maintenance coverage would be required.

Appendix A

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Table A.1 (page 1 of 3)

Produced Water Treatment Alternatives Summary

PNM - Produced Water Project - SJGS

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
	CRO	HERO	BC	CRO-BC	HERO-BC	CRO	HERO	BC	CRO-BC	HERO-BC
System Flows										
Produced Water, gpm (10)	1,216	1,216	1,160	1,216	1,216	1,216	1,216	1,060	1,216	1,216
Purge Water, gpm (1)	N/A	N/A	N/A	N/A	N/A	100	100	100	100	100
Softener Feed Rate, gpm	1,280	1,250	1,160	1,280	1,250	1,385	1,352	1,160	1,385	1,352
Water Lost to Sludge, gpm	1.6	2.6	N/A	1.6	2.6	7.4	8.6	N/A	7.4	8.6
UF Recycle, gpm (2)	63.9	N/A	N/A	63.9	N/A	68.9	N/A	N/A	68.9	N/A
Media Filter, WAC Recycle, gpm (2,4)	N/A	34.4	N/A	N/A	34.4	N/A	36.4	N/A	N/A	36.4
RO Feed Rate, gpm	1214.4	1247.8	N/A	1214.4	1247.8	1308.6	1343.9	N/A	1308.6	1343.9
RO Net Permeate, gpm (4)	935.1	1047.5	N/A	935.1	1047.5	981.5	1082.7	N/A	981.5	1082.7
RO Reject, gpm	279.3	174.7	N/A	279.3	174.7	327.2	234.5	N/A	327.2	234.5
BC Distillate, gpm	N/A	N/A	1009.1	133.0	126.8	N/A	N/A	998.9	173.7	171.9
Total Recovered Water, gpm	935.1	1047.5	1009.1	1068.2	1174.2	981.5	1082.7	998.9	1155.2	1254.6
BC Brine, gpm	N/A	N/A	150.9	146.3	47.9	N/A	N/A	161.1	153.5	62.6
Pretreatment										
Lime, Ca(OH) ₂ , tpd (1)	2.39	3.68	N/A	2.39	3.68	11.3	12.7	N/A	11.3	12.7
Coagulant Aide, ppd (1)	231	225	N/A	231	225	250	244	N/A	250	244
Cationic Polymer, ppd	46.1	45.1	N/A	46.1	45.1	49.9	48.8	N/A	49.9	48.8
Sludge (dry basis), tpd	5.02	8.38	N/A	5.02	8.38	23.8	27.6	N/A	23.8	27.6
Sludge Moisture Content	65%	65%	N/A	65%	65%	65%	65%	N/A	65%	65%
Thickened Sludge (wet basis), tpd	14.3	23.9	N/A	14.3	23.9	68.0	78.9	N/A	68.0	78.9
Sludge - CaCO ₃ Content, tpd	4.05	6.91	N/A	4.05	6.91	15.9	19.1	N/A	15.9	19.1
Sludge - Mg(OH) ₂ Content, tpd	0.48	0.65	N/A	0.48	0.65	6.48	6.66	N/A	6.48	6.66
93% Sulfuric Acid, H ₂ SO ₄ , tpd	19.9	0.58	N/A	19.9	0.58	9.05	0.65	N/A	9.05	0.65
Sodium Hypochlorite, NaOCl, ppd	76.9	75.1	N/A	76.9	75.1	83.2	81.3	N/A	83.2	81.3
Sodium Bisulfite, NaHSO ₃ , ppd	55.0	53.8	N/A	55.0	53.8	59.6	58.2	N/A	59.6	58.2
Anti-Scalant, ppd	76.9	0.00	N/A	76.9	0.00	83.2	0.00	N/A	83.2	0.00

Table A.1 (page 2 of 3)

Produced Water Treatment Alternatives Summary

PNM - Produced Water Project - SJGS

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
	CRO	HERO	BC	CRO-BC	HERO-BC	CRO	HERO	BC	CRO-BC	HERO-BC
Pretreatment (continued)										
Strainer, UF Op Pressure, psi	100	N/A	N/A	100	N/A	100	N/A	N/A	100	N/A
Media Filter, WAC Op Pressure, psi	N/A	100	N/A	N/A	100	N/A	100	N/A	N/A	100
Power Requirement, kw (5)	90	90	N/A	90	90	100	90	N/A	100	90
RO System (3)										
Sodium Hydroxide, NaOH, tpd	N/A	0.91	N/A	N/A	0.91	N/A	1.44	N/A	N/A	1.44
Recovery	77.0%	83.9%	N/A	77.0%	83.9%	75.0%	80.6%	N/A	75.0%	80.6%
Permeate TDS, mg/l	270	260	N/A	270	260	260	270	N/A	260	270
Reject TDS, mg/l	51,400	61,800	N/A	51,400	61,800	46,100	60,400	N/A	46,100	60,400
Cleanings per Year (9)	18	1	N/A	18	1	18	1	N/A	18	1
Op Pressure, psi	400	400	N/A	400	400	400	400	N/A	400	400
Inter-Stage Op Pressure, psi	N/A	800	N/A	N/A	800	N/A	800	N/A	N/A	800
Power Requirement, kw (5)	560	510	N/A	560	510	620	570	N/A	620	570
Brine Concentrator										
93% Sulfuric Acid, H ₂ SO ₄ , tpd	N/A	N/A	22.4	0.39	0.00	N/A	N/A	20.7	0.18	0.00
Anti-Scalant, ppd	N/A	N/A	209	50.3	0.00	N/A	N/A	209	59.0	0.00
Calcium Chloride, CaCl ₂ , tpd	N/A	N/A	16.0	15.2	0.00	N/A	N/A	21.6	15.3	0.00
Recovery	N/A	N/A	86.99%	47.63%	72.57%	N/A	N/A	86.12%	53.10%	73.29%
Distillate TDS, mg/l	N/A	N/A	10	10	10	N/A	N/A	10	10	10
BC Op pH	N/A	N/A	5.0	5.0	11.0	N/A	N/A	5.0	5.0	11.0
BC Op Cl, mg/l	N/A	N/A	50,000	50,000	124,270	N/A	N/A	50,000	50,000	101,020
BC Op Total Solids, mg/l	N/A	N/A	117,800	115,200	225,000	N/A	N/A	126,000	114,700	225,000
Cleanings per Year	N/A	N/A	1	1	0.3	N/A	N/A	1	1	0.3
Power Requirement, kw (6)	N/A	N/A	4,830	640	610	N/A	N/A	4,780	840	830

Table A.1 (page 3 of 3)

Produced Water Treatment Alternatives Summary

PNM - Produced Water Project - SJGS

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
	CRO	HERO	BC	CRO-BC	HERO-BC	CRO	HERO	BC	CRO-BC	HERO-BC
Overall										
Feed Rate, gpm (10)	1,216	1,216	1,160	1,216	1,216	1,316	1,316	1,160	1,316	1,316
Recovery	76.90%	86.14%	86.99%	87.84%	96.57%	74.58%	82.27%	86.12%	87.78%	95.33%
Recoverable Water, gpm	935	1,047	1,009	1,068	1,174	981	1,083	999	1,155	1,255
Total Power Requirement, kw	650	600	4,830	1,718	1,774	720	660	4,780	1,875	1,915
Recoverable Water TDS, mg/l	270	260	10	240	240	260	270	10	230	230
Wastewater to Evap Ponds, gpm	279	175	151	146	48	327	235	161	153	63
Additional Evap Ponds, acres (7,8)	140	87.3	75.4	73.1	24.0	114	67.3	30.5	26.7	0.00

Notes.....

1. N/A = not applicable, tpd = tons per day, ppd = pounds per day.
2. Recycle is sent to softener and comprised of UF bleed, media filter backwash and WAC spent regenerant.
3. All RO systems contain spiral wound, thin-film polyamide membranes.
4. A portion of the last stage RO permeate is used for filter backwash and WAC regeneration.
5. Includes 5% allowance for miscellaneous process power and rounded up to nearest 10 kw.
6. Assume 78.1 kwh/1,000 distillate. Includes 2% allowance for miscellaneous process power and rounded up to nearest 10 kw.
7. SJGS assumes that the equivalent of 2 gpm/acre evaporates from the ponds.
8. Alternatives 6 to 10 take a 50-acre credit for freed-up Purge Water capacity.
9. For alternatives with UF and CRO, assume 9 RO and 9 UF cleanings per year.
10. The flow basis is approximate and within the likely produced water recovery range.

Table A.2 (1 of 10)
Process Chemistry – Alternative 1 – Produced Water – CRO
PNM – Produced Water Project – SJGS

		Average FW	5% UF Bleed (to R-C)	Lime Clarifier Feed	Lime Clarifier Effluent	UF Eff	Decarb Effluent	CRO Feed pH	1st Stg Perm	1st Stg Rej	2nd Stg Perm	2nd Stg Rej	3rd Stg Perm	3rd Stg Rej	Total CRO Perm
Flow Rate	gpm	1216	63.9	1279.9	1278.4	1214.4	1214.4	1214.4	470.6	743.9	288.2	455.6	176.3	279.3	935.1
Solids	tpd														
Waters of Moisture	gpm				1.55										
Na	mg/l _{CaCO3}	9858	390	9386	9386	9386	9386	9386	149	15229	241	24711	390	40063	223
K	mg/l _{CaCO3}	97.8	4.9	93.2	93.2	93.2	93.2	93.2	1.86	151	3.02	244.5	4.89	396	2.79
Ca	mg/l _{CaCO3}	198	0.70	188	52.5	52.5	52.5	52.5	0.26	85.5	0.43	139	0.70	227	0.40
Mg	mg/l _{CaCO3}	126	0.16	119	12.0	12.0	12.0	12.0	0.06	19.6	0.10	31.9	0.16	51.9	0.09
Ba	mg/l _{CaCO3}	0.05	0.00	0.05	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.04	0.00	0.06	0.00
Sr	mg/l _{CaCO3}	15.5	0.05	14.7	4.13	4.13	4.13	4.13	0.02	6.72	0.03	11.0	0.05	17.8	0.03
Fe	mg/l _{CaCO3}	20.2	0.00	19.2	0.10	0.10	0.10	0.10	0.00	0.16	0.00	0.27	0.00	0.43	0.00
HCO ₃	mg/l _{CaCO3}	3019	4.64	2869	124	49.7	57.4	57.4	1.89	88.6	2.98	138.6	4.64	218.9	2.77
CO ₃	mg/l _{CaCO3}	32.0	0.00	30.0	2366	0.00	0.06	0.06	0.00	0.15	0.00	0.38	0.00	0.98	0.00
Cl	mg/l _{CaCO3}	7111	355	6773	6773	6773	6773	6773	135	10972	219	17774	355	28770	203
Br	mg/l _{CaCO3}	8.95	0.45	8.52	8.52	8.52	8.52	8.52	0.17	13.8	0.28	22.4	0.45	36.2	0.26
NO ₃	mg/l _{CaCO3}	1.60	0.08	1.53	1.53	1.53	1.53	1.53	0.03	2.48	0.05	4.01	0.08	6.49	0.05
SO ₄	mg/l _{CaCO3}	196	36.8	188	188	2771	2771	2771	13.9	4515	22.6	7356	36.8	11976	20.9
Total SiO ₂	mg/l	18.5	1.60	17.7	17.66	17.66	17.66	17.66	0.62	28.43	1.00	45.79	1.60	73.69	0.92
Total NH ₃ , mg/l _N	mg/l _N	15.8	0.38	15.0	15.03	15.03	15.03	15.03	0.06	24.50	0.15	39.91	0.38	64.86	0.15
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	3105	21.1	2951	2490	2490	68.1	68.1	19.5	98.9	20.1	149	21.1	229	20.0
B, mg/l _B	mg/l _B	2.51	0.22	2.40	2.40	2.40	2.40	2.40	0.08	3.86	0.14	6.21	0.22	10.0	0.12
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS	mg/l	13757	481	13095	11033	12020	12030	12030	183	19519	297	31673	481	51358	275
pH		7.84	5.72	7.84	11.09	4.40	6.82	6.82	5.33	7.02	5.52	7.23	5.72	7.44	5.49

System Net Recovery 76.90%

Table A.2 (2 of 10)
Process Chemistry – Alternative 2 – Produced Water – HERO®
PNM – Produced Water Project – SJGS

		Average FW	Media	Avg WAC			Lime	Lime	H-Form	Decarb Effluent	HERO	1st Stg Perm	1st Stg Rej	2nd Stg Perm	2nd Stg Rej	3rd Stg Perm	Net	3rd Stg Rej	Total HERO Perm
			Filter B/W (to R-C)	WAC B/W (to R-C)	Regen+ S Rinse (to R-C)	Avg WAC F Rinse (to R-C)	Clarifier Feed	Clarifier Effluent	WAC Effluent		Feed pH Adjust						3rd Stg Perm		
Flow Rate	gpm	1216	15.2	4.8	5.7	8.8	1250.4	1247.8	1247.8	1247.8	1247.8	599.7	648.2	311.5	336.7	162.0	136.3	174.7	1047.5
Solids	tpd																		
Waters of Moisture	gpm							2.59											
Na	mg/l _{CaCO3}	9858	461	461	461	461	9600	9600	7259	7259	7335	109	14020	216	26792	461		51208	182
K	mg/l _{CaCO3}	97.8	6.93	6.93	6.93	6.93	95.3	95.3	95.3	95.3	95.3	1.91	182	3.63	346	6.93		661	3.00
Ca	mg/l _{CaCO3}	198	0.00	0.00	33609	1680	357	52.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Mg	mg/l _{CaCO3}	126	0.00	0.00	7682	384	160	12.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Ba	mg/l _{CaCO3}	0.05	0.00	0.00	9.27	0.46	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Sr	mg/l _{CaCO3}	15.5	0.00	0.00	2641	132	28.1	4.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Fe	mg/l _{CaCO3}	20.2	0.00	0.00	64.0	3.20	20.0	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
HCO ₃	mg/l _{CaCO3}	3019	5.04	5.04	0.00	0.00	2931	115	56	63	51.1	1.45	38.8	2.72	44.3	5.04		48.0	2.26
CO ₃	mg/l _{CaCO3}	32.0	0.34	0.34	0.00	0.00	25.9	2204	0.00	0.07	22.9	0.02	102	0.09	225	0.34		466	0.06
Cl	mg/l _{CaCO3}	7111	504	504	504	504	6929	6929	6929	6929	6929	139	13211	264	25188	504		48077	218
Br	mg/l _{CaCO3}	8.95	0.63	0.63	0.63	0.63	8.72	8.72	8.72	8.72	8.72	0.17	16.6	0.33	31.7	0.63		60.5	0.27
NO ₃	mg/l _{CaCO3}	1.60	0.11	0.11	0.11	0.11	1.56	1.56	1.56	1.56	1.56	0.03	2.98	0.06	5.68	0.11		10.9	0.05
SO ₄	mg/l _{CaCO3}	196	7.72	7.72	46447	2322	419	419	419	419	419	2.09	804	4.02	1544	7.72		2969	3.32
Total SiO ₂	mg/l	18.5	2.26	2.26	2.26	2.26	18.1	18.1	18.1	18.1	18.1	0.63	34.2	1.20	64.7	2.26		123	0.99
Total NH ₃ , mg/l _N	mg/l _N	15.8	21.9	21.9	21.9	21.9	16.0	16.0	16.0	16.0	16.0	10.3	21.2	19.2	23.1	21.9		24.2	14.1
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	3105	5.38	5.38	5.38	5.38	3020	2319	2319	74.0	74.0	1.48	141	2.82	269	5.38		514	2.33
B, mg/l _B	mg/l _B	2.51	0.31	0.31	0.31	0.31	2.45	2.45	2.45	2.45	2.45	0.09	4.64	0.16	8.77	0.31		16.6	0.13
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.0	0.00
TDS	mg/l	13757	613	613	62940	3725	13692	11358	8873	8882	8908	167	16963	319	32356	613		61777	264
pH		7.84	8.97	8.97	1.32	2.79	7.76	11.09	4.50	6.89	9.50	8.45	10.21	8.71	10.49	8.97		10.77	8.63

System Net Recovery 86.14%

Table A.2 (3 of 10)
Process Chemistry – Alternative 3 – Produced Water – BC 2 + BC 3
PNM – Produced Water Project – SJGS

		Produced Water	BC FW	BC Distillate	BC Brine
Flow Rate	gpm	1160	1160	1009.1	150.9
Solids	tpd				
Waters of Moisture	gpm				
Na	mg/l _{CaCO3}	9858	9858	8.55	75730
K	mg/l _{CaCO3}	97.8	97.8		752
Ca	mg/l _{CaCO3}	198	2265		17413
Mg	mg/l _{CaCO3}	126	126		966
Ba	mg/l _{CaCO3}	0.05	0.05		0.42
Sr	mg/l _{CaCO3}	15.5	15.5		119
Fe	mg/l _{CaCO3}	20.2	20.2		156
HCO ₃	mg/l _{CaCO3}	3019	0.04		0.99
CO ₃	mg/l _{CaCO3}	32.0	0.00		0.00
Cl	mg/l _{CaCO3}	7111	9178	8.55	70501
Br	mg/l _{CaCO3}	8.95	8.95		68.8
NO ₃	mg/l _{CaCO3}	1.60	1.60		12.3
SO ₄	mg/l _{CaCO3}	196	3298		25353
Total SiO ₂	mg/l	18.5	18.5		142
Total NH ₃ , mg/l _N	mg/l _N	15.8	15.8		121
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	3105	3.00		23.1
B, mg/l _B	mg/l _B	2.51	2.51		19.3
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00		0.00
TDS	mg/l	13757	15331	10.0	117791
pH		7.84	4.50	7.00	5.00

System Net Recovery 86.99%

Table A.2 (4 of 10)
 Process Chemistry – Alternative 4 – Produced Water – CRO + BC 2 (Alternative 1 + BC 3)
 PNM – Produced Water Project – SJGS

		Alternative 1	Total	BC FW	BC Distillate	BC Brine	Total Recov'd Water
		3rd Stg Rej	Conv RO Perm				
Flow Rate	gpm	279.3	935.1	279.3	133.0	146.3	1068.2
Solids	tpd						
Waters of Moisture	gpm						
Na	mg/l _{CaCO3}	40063	223	40063	8.55	76494	196
K	mg/l _{CaCO3}	396	2.79	396		756	2.44
Ca	mg/l _{CaCO3}	227	0.40	8381		16004	0.35
Mg	mg/l _{CaCO3}	51.9	0.09	51.9		99.0	0.08
Ba	mg/l _{CaCO3}	0.06	0.00	0.06		0.12	0.00
Sr	mg/l _{CaCO3}	17.8	0.03	17.8		34.1	0.03
Fe	mg/l _{CaCO3}	0.43	0.00	0.43		0.83	0.00
HCO ₃	mg/l _{CaCO3}	219	2.77	0.04		0.24	2.16
CO ₃	mg/l _{CaCO3}	0.98	0.00	0.00		0.00	0.00
Cl	mg/l _{CaCO3}	28770	203	36924	8.55	70500	179
Br	mg/l _{CaCO3}	36.2	0.26	36.2		69.1	0.22
NO ₃	mg/l _{CaCO3}	6.49	0.05	6.49		12.4	0.04
SO ₄	mg/l _{CaCO3}	11976	20.9	12203		23301	18.3
Total SiO ₂	mg/l	73.7	0.92	73.7		141	0.81
Total NH ₃ , mg/l _N	mg/l _N	64.9	0.15	64.9		124	0.13
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	229	20.0	3.00		5.73	17.5
B, mg/l _B	mg/l _B	10.0	0.12	10.0		19.1	0.11
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00		0.00	0.00
TDS	mg/l	51358	275	60353	10.0	115237	241
pH		7.44	5.49	4.50	7.00	5.00	5.50
				BC Recovery			47.63%
				System Net Recovery			87.84%

Table A.2 (5 of 10)
Process Chemistry – Alternative 5 – Produced Water – HERO® + BC 3 (Alternative 2 + BC 3)
PNM – Produced Water Project – SJGS

		Alternative 2 3rd Stg Rej	Total HERO Perm	BC FW	BC Distillate	BC Brine	Total Recov'd Water
Flow Rate	gpm	174.7	1047.5	174.7	126.8	47.9	1174.2
Solids	tpd						
Waters of Moisture	gpm						
Na	mg/l _{CaCO3}	51208	182	51208	8.55	186634	163
K	mg/l _{CaCO3}	661	3.00	661		2410	2.68
Ca	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Mg	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Ba	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Sr	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Fe	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
HCO ₃	mg/l _{CaCO3}	48.0	2.26	137		330	2.03
CO ₃	mg/l _{CaCO3}	466	0.06	377		1543	0.04
Cl	mg/l _{CaCO3}	48077	218	48077	8.55	175223	196
Br	mg/l _{CaCO3}	60.5	0.27	60.5		221	0.24
NO ₃	mg/l _{CaCO3}	10.9	0.05	10.9		39.6	0.04
SO ₄	mg/l _{CaCO3}	2969	3.32	2969		10821	2.96
Total SiO ₂	mg/l	123	0.99	123		447	0.88
Total NH ₃ , mg/l _N	mg/l _N	24.2	14.1	24.2		88.3	12.6
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	514	2.33	514		1873	2.08
B, mg/l _B	mg/l _B	16.6	0.13	16.6		60.6	0.12
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00		0.00	0.00
TDS	mg/l	61777	264	61763	10.0	225000	236
pH		10.77	8.63	10.77	7.00	11.00	8.63
				BC Recovery			72.57%
				System Net Recovery			96.57%

Table A.2 (6 of 10)
Process Chemistry – Alternative 6 – PW/PW Blend – CRO
PNM – Produced Water Project – SJGS

		Average	5%	Lime	Lime		Decarb	CRO	1st Stg	1st Stg	2nd Stg	2nd Stg	3rd Stg	3rd Stg	Total
		FW	UF Bleed (to R-C)	Clarifier Feed	Clarifier Effluent	UF Eff	Effluent	Feed pH	Perm	Rej	Perm	Rej	Perm	Rej	CRO Perm
Flow Rate	gpm	1316	68.9	1384.9	1377.5	1308.6	1308.6	1308.6	484.3	824.3	305.1	519.3	192.1	327.2	981.5
Solids	tpd														
Waters of Moisture	gpm				7.36										
Na	mg/l _{CaCO3}	9552	360	9095	9096	9096	9096	9096	145	14355	228	22655	360	35745	213
K	mg/l _{CaCO3}	107.6	5.1	102.5	102.5	102.5	102.5	102.5	2.05	162	3.23	254.6	5.09	401	3.01
Ca	mg/l _{CaCO3}	275	0.66	261	52.5	52.5	52.5	52.5	0.26	83.2	0.42	132	0.66	209	0.39
Mg	mg/l _{CaCO3}	1417	0.15	1347	12.0	12.0	12.0	12.0	0.06	19.0	0.10	30.1	0.15	47.7	0.09
Ba	mg/l _{CaCO3}	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Sr	mg/l _{CaCO3}	32.3	0.08	30.7	6.17	6.17	6.17	6.17	0.03	9.77	0.05	15.5	0.08	24.5	0.05
Fe	mg/l _{CaCO3}	18.8	0.00	17.9	0.10	0.10	0.10	0.10	0.00	0.16	0.00	0.25	0.00	0.40	0.00
HCO ₃	mg/l _{CaCO3}	2797	1.74	2659	46	18.3	24.5	24.5	0.72	35.9	1.12	53.2	1.74	79.8	1.05
CO ₃	mg/l _{CaCO3}	30.8	0.00	29.0	876	0.00	0.01	0.01	0.00	0.02	0.00	0.05	0.00	0.12	0.00
Cl	mg/l _{CaCO3}	6996	331	6665	6665	6665	6665	6665	133	10502	210	16549	331	26072	196
Br	mg/l _{CaCO3}	8.82	0.42	8.41	8.41	8.41	8.41	8.41	0.17	13.2	0.26	20.9	0.42	32.9	0.25
NO ₃	mg/l _{CaCO3}	20.2	0.95	19.2	19.2	19.2	19.2	19.2	0.38	30.3	0.61	47.7	0.95	75.1	0.56
SO ₄	mg/l _{CaCO3}	1603	32.9	1525	1525	2617	2617	2617	13.1	4146	20.7	6570	32.9	10409	19.3
Total SiO ₂	mg/l	19.6	1.61	18.7	18.7	18.7	18.7	18.7	0.65	29.3	1.03	45.9	1.61	72.0	0.96
Total NH ₃ , mg/l _N	mg/l _N	16.6	0.13	15.8	15.8	15.8	15.8	15.8	0.02	25.0	0.05	39.7	0.13	63.0	0.05
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	2877	19.4	2735	922	922	36.8	36.8	18.8	47.4	19.1	64	19.4	90	19.0
B, mg/l _B	mg/l _B	12.1	0.99	11.5	11.5	11.5	11.5	11.5	0.40	18.1	0.63	28.4	0.99	44.4	0.59
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS	mg/l	15062	448	14336	11202	11709	11716	11716	180	18491	284	29184	448	46052	265
pH		7.84	5.26	7.84	11.09	4.40	6.39	6.39	4.90	6.57	5.08	6.77	5.26	6.97	5.05

System Net Recovery 74.58%

Table A.2 (7 of 10)
Process Chemistry – Alternative 7 – PW/PW Blend – HERO®
PNM – Produced Water Project – SJGS

		Average FW	Media	Avg WAC			Lime Clarifier Feed	Lime Clarifier Effluent	H-Form WAC Effluent	Decarb Effluent	HERO Feed pH Adjust	1st Stg Perm	1st Stg Rej	2nd Stg Perm	2nd Stg Rej	3rd Stg Perm	Net	3rd Stg Rej	Total	
			Filter B/W (to R-C)	WAC B/W (to R-C)	Regen+ S Rinse (to R-C)	Avg WAC F Rinse (to R-C)											3rd Stg Perm		HERO Perm	
Flow Rate	gpm	1316	15.4	5.0	6.3	9.8	1352.4	1343.9	1343.9	1343.9	1343.9	593.1	750.8	331.3	419.5	185.0	158.3	234.5	1082.7	
Solids	tpd																			
Waters of Moisture	gpm							8.55												
Na	mg/l _{CaCO3}	9552	406	406	406	406	9306	9305	8494	8494	8605	112	15314	204	27248	406		48421	179	
K	mg/l _{CaCO3}	107.6	6.60	6.60	6.60	6.60	105	105	105	105	104.9	2.10	186	3.72	330	6.60		586	3.18	
Ca	mg/l _{CaCO3}	275	0.00	0.00	32647	1632	433	52.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
Mg	mg/l _{CaCO3}	1417	0.00	0.00	7462	373	1417	12.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
Ba	mg/l _{CaCO3}	0.01	0.00	0.00	0.85	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
Sr	mg/l _{CaCO3}	32.3	0.00	0.00	3834	192	50.8	6.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
Fe	mg/l _{CaCO3}	18.8	0.00	0.00	62.2	3.11	18.6	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	
HCO ₃	mg/l _{CaCO3}	2797	2.13	2.13	0.00	0.00	2717	35	17	23	24.4	0.70	17.7	1.23	20.2	2.13		21.9	1.05	
CO ₃	mg/l _{CaCO3}	30.8	0.13	0.13	0.00	0.00	24.4	672	0.00	0.01	11.5	0.01	46	0.04	93	0.13		178	0.03	
Cl	mg/l _{CaCO3}	6996	429	429	429	429	6819	6819	6819	6819	6819	136	12098	242	21463	429		38055	206	
Br	mg/l _{CaCO3}	8.82	0.54	0.54	0.54	0.54	8.60	8.60	8.60	8.60	8.60	0.17	15.3	0.31	27.1	0.54		48.0	0.26	
NO ₃	mg/l _{CaCO3}	20.2	1.24	1.24	1.24	1.24	19.7	19.7	19.7	19.7	19.7	0.39	34.9	0.70	61.8	1.24		109.7	0.59	
SO ₄	mg/l _{CaCO3}	1603	28.62	28.62	46447	2322	1795	1795	1795	1795	1795	8.97	3205	16.03	5724	28.62		10217	13.67	
Total SiO ₂	mg/l	19.6	2.08	2.08	2.08	2.08	19.1	19.1	19.1	19.1	19.1	0.67	33.7	1.18	59.4	2.08		105	1.01	
Total NH ₃ , mg/l _N	mg/l _N	16.6	21.8	21.8	21.8	21.8	16.7	16.7	16.7	16.7	16.7	10.8	21.4	19.3	23.1	21.8		24.2	14.6	
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	2877	2.26	2.26	2.26	2.26	2800	707	707	707	35.9	35.9	0.72	64	1.27	113	2.26	200	1.09	
B, mg/l _B	mg/l _B	12.1	1.28	1.28	1.28	1.28	11.8	11.8	11.8	11.8	11.8	0.41	20.8	0.73	36.7	1.28		64.6	0.62	
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.0	0.00	
TDS	mg/l	15062	558	558	63463	3683	14979	11537	10726	10733	10784	175	19151	312	34035	558		60442	267	
pH		7.84	8.93	8.93	1.32	2.90	7.75	11.09	4.50	6.37	9.50	8.46	10.20	8.70	10.45	8.93		10.70	8.64	
System Net Recovery																		82.27%		

Table A.2 (8 of 10)
Process Chemistry – Alternative 8 – PW/PW Blend – BC 2 + BC 3
PNM – Produced Water Project – SJGS

		Produced Water	BC FW	BC Distillate	BC Brine
Flow Rate	gpm	1160	1160	998.9	161.1
Solids	tpd				
Waters of Moisture	gpm				
Na	mg/l _{CaCO3}	9552	9552	8.55	68748
K	mg/l _{CaCO3}	107.6	107.6		775
Ca	mg/l _{CaCO3}	275	3075		22145
Mg	mg/l _{CaCO3}	1417	1417		10208
Ba	mg/l _{CaCO3}	0.01	0.01		0.05
Sr	mg/l _{CaCO3}	32.3	32.3		233
Fe	mg/l _{CaCO3}	18.8	18.8		135
HCO ₃	mg/l _{CaCO3}	2797	0.04		0.92
CO ₃	mg/l _{CaCO3}	30.8	0.00		0.00
Cl	mg/l _{CaCO3}	6996	9796	8.55	70503
Br	mg/l _{CaCO3}	8.82	8.82		63.6
NO ₃	mg/l _{CaCO3}	20.2	20.2		145.2
SO ₄	mg/l _{CaCO3}	1603	4477		32243
Total SiO ₂	mg/l	19.6	19.6		141
Total NH ₃ , mg/l _N	mg/l _N	16.6	16.6		120
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	2877	3.00		21.6
B, mg/l _B	mg/l _B	12.1	12.1		87.2
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00		0.00
TDS	mg/l	15062	17500	10.0	125984
pH		7.84	4.50	7.00	5.00

System Net Recovery 86.12%

Table A.2 (10 of 10)
Process Chemistry – Alternative 10 – PW/PW Blend – HERO® + BC 3 (Alternative 7 + BC 3)
PNM – Produced Water Project – SJGS

		Alternative 7 3rd Stg Rej	Total HERO Perm	BC FW	BC Distillate	BC Brine	Total Recov'd Water
Flow Rate	gpm	234.5	1082.7	234.5	171.9	62.6	1254.6
Solids	tpd						
Waters of Moisture	gpm						
Na	mg/l _{CaCO3}	48421	179	48421	8.55	181249	156
K	mg/l _{CaCO3}	586	3.18	586		2192	2.74
Ca	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Mg	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Ba	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Sr	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
Fe	mg/l _{CaCO3}	0.00	0.00	0.00		0.00	0.00
HCO ₃	mg/l _{CaCO3}	21.9	1.05	61		132	0.91
CO ₃	mg/l _{CaCO3}	178	0.03	139		618	0.02
Cl	mg/l _{CaCO3}	38055	206	38055	8.55	142440	179
Br	mg/l _{CaCO3}	48.0	0.26	48.0		180	0.22
NO ₃	mg/l _{CaCO3}	110	0.59	110		411	0.51
SO ₄	mg/l _{CaCO3}	10217	13.7	10217		38250	11.8
Total SiO ₂	mg/l	105	1.01	105		392	0.87
Total NH ₃ , mg/l _N	mg/l _N	24.2	14.6	24.2		90.5	12.6
Total Alk, mg/l _{CaCO3}	mg/l _{CaCO3}	200	1.09	200		750	0.94
B, mg/l _B	mg/l _B	64.6	0.62	64.6		242	0.54
o-PO ₄ , mg/l _P	mg/l _P	0.00	0.00	0.00		0.00	0.00
TDS	mg/l	60442	267	60130	10.0	225001	231
pH		10.70	8.64	10.70	7.00	11.00	8.63
				BC Recovery			73.29%
				System Net Recovery			95.33%

Table A.3

Produced Water Treatment Cost Summary - Preliminary Cost Evaluation
PNM - Produced Water Project - SJGS

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
	CRO	HERO	BC	CRO-BC	HERO-BC	CRO	HERO	BC	CRO-BC	HERO-BC
Capital Costs - SJGS Only										
Receiving, Transfer, Distribution	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000	\$1,478,000
Pretreatment + CRO	\$7,310,000	\$0	\$0	\$7,310,000	\$0	\$7,670,000	\$0	\$0	\$7,670,000	\$0
Pretreatment + HERO	\$0	\$6,390,000	\$0	\$0	\$6,390,000	\$0	\$6,700,000	\$0	\$0	\$6,700,000
Refurb BC 2	\$0	\$0	\$4,100,000	\$0	\$0	\$0	\$0	\$4,100,000	\$0	\$0
Refurb BC 3	\$0	\$0	\$2,970,000	\$2,970,000	\$2,970,000	\$0	\$0	\$2,970,000	\$2,970,000	\$2,970,000
Evap Ponds	\$27,610,000	\$16,890,000	\$14,450,000	\$13,970,000	\$4,100,000	\$22,260,000	\$12,770,000	\$5,240,000	\$4,570,000	\$0
Subtotal	\$36,398,000	\$24,758,000	\$22,998,000	\$25,728,000	\$14,938,000	\$31,408,000	\$20,948,000	\$13,788,000	\$16,688,000	\$11,148,000
6.125% New Mexico Sales Tax	\$2,229,000	\$1,516,000	\$1,409,000	\$1,576,000	\$915,000	\$1,924,000	\$1,283,000	\$845,000	\$1,022,000	\$683,000
5.5% PNM A&G	\$2,002,000	\$1,362,000	\$1,265,000	\$1,415,000	\$822,000	\$1,727,000	\$1,152,000	\$758,000	\$918,000	\$613,000
15% Contingency	\$5,460,000	\$3,714,000	\$3,450,000	\$3,859,000	\$2,241,000	\$4,711,000	\$3,142,000	\$2,068,000	\$2,503,000	\$1,672,000
Total Install Cost	\$46,089,000	\$31,350,000	\$29,122,000	\$32,578,000	\$18,916,000	\$39,770,000	\$26,525,000	\$17,459,000	\$21,131,000	\$14,116,000
Operating Costs - SJGS Only										
Chemicals	\$802,000	\$168,000	\$2,020,000	\$1,950,000	\$168,000	\$652,000	\$392,000	\$2,378,000	\$1,804,000	\$392,000
Power	\$228,000	\$210,000	\$1,692,000	\$452,000	\$424,000	\$252,000	\$231,000	\$1,675,000	\$547,000	\$522,000
UF/RO Membrane Cleaning	\$240,000	\$10,000	\$0	\$240,000	\$10,000	\$240,000	\$10,000	\$0	\$240,000	\$10,000
BC Membrane Cleaning	\$0	\$0	\$52,000	\$26,000	\$7,000	\$0	\$0	\$52,000	\$26,000	\$7,000
Labor (same for all)	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000	\$499,000
Maintenance (process eqpmt)	\$132,000	\$118,000	\$22,000	\$132,000	\$118,000	\$137,000	\$123,000	\$22,000	\$137,000	\$123,000
Maintenance (refurb'd BCs)	\$0	\$0	\$90,000	\$45,000	\$45,000	\$0	\$0	\$90,000	\$45,000	\$45,000
Capital Recovery	\$4,521,000	\$3,075,000	\$2,857,000	\$3,196,000	\$1,856,000	\$3,901,000	\$2,602,000	\$1,713,000	\$2,073,000	\$1,385,000
Total Operating Cost - SJGS Only	\$6,422,000	\$4,080,000	\$7,232,000	\$6,540,000	\$3,127,000	\$5,681,000	\$3,857,000	\$6,429,000	\$5,371,000	\$2,983,000

Note..... The flow basis is approximate and within the likely produced water recovery range.

Table A.4 (1 of 2)

Produced Water Treatment - Operating and Cost Assumptions - Preliminary Cost Evaluation

San Juan Generating Station

1.	Lime, Ca(OH) ₂ , \$/ton	\$86.02	
2.	Coagulant Aide, \$/pound	\$0.15	
3.	Cationic Polymer, \$/pound	\$1.00	
4.	Limestone, \$/ton	\$18.55	Plant cost - delivered to SJGS.
5.	93% Sulfuric Acid, H ₂ SO ₄ , \$/ton	\$90.55	Plant cost - delivered to SJGS.
6.	Sodium Hydroxide, NaOH (dry basis), \$/ton	\$77.50	Plant cost - delivered to SJGS.
7.	Sodium Hypochlorite, NaOCl, \$/pound	\$0.80	
8.	Sodium Bisulfite, NaHSO ₃ , \$/pound	\$0.20	
9.	Anti-Scalant, \$/pound	\$1.50	
10.	Calcium Chloride, CaCl ₂ , \$/ton	\$200	
11.	Limestone credit (plant cost for delivered limestone) applied for each ton of CaCO ₃ generated in pretreatment sludge.		
12.	UF, RO Cleaning Cost	\$10,000	
13.	BC Cleaning Cost (per BC)	\$26,000	
14.	BC Power, kwh/1,000 gal distillate	78.1	
15.	Power, \$/kwh	\$0.0400	Includes \$0.025/kwh plant power generation cost + \$15/Mwh power replacement cost.
16.	Maintenance Worker Time, hours/year	2,080	
17.	Operator Time, hours/year	8,760	
18.	Loaded Labor Cost, \$/hour	\$46.00	
19.	Maintenance, Pct of Eqpmt Cost	1.50%	
20.	Interest on Capital	7.50%	
21.	Capital Recovery Period, years	20	
22.	Capital Recovery Factor	0.0981	
23.	Evap Pond Cost, \$/acre	\$171,000	First 30 acres of ponds.
24.	Evap Pond Cost, \$/acre	\$205,000	Pond area in excess of 30 acres - additional 20% for wastewater piping & remote monitoring.
25.	Receiving, Transfer & Distribution Equipment		
	Receiving Basin	\$298,000	3-day basin x 10-feet operating depth and 1,316 gpm inflow (1.74 acre pond).
	Feed Pumps	\$272,000	Four 33% capacity, 440 gpm x 50 psi pumps with valves & controls.
	Product Tank	\$280,000	One 250,000 gallon tank with valves & controls.
	Product Transfer Pumps	\$368,000	Four 33% capacity, 440 gpm x 50 psi pumps (316 impellers) with valves & controls.
	Product Transfer Line	\$260,000	5000-feet 8" HDPE line routed to cooling towers with valves & controls.
	Total Plant Improvements	<u>\$1,478,000</u>	

Table A.4 (2 of 2)

Produced Water Treatment - Operating and Cost Assumptions - Preliminary Cost Evaluation
PNM - Produced Water Project - SJGS

	1,216 gpm System	1,316 gpm System	
26. Pretreatment, UF & CRO Equipment	\$5,090,000	\$5,340,000	Includes control system.
27. Pretreatment & HERO Equipment	\$4,440,000	\$4,660,000	
28. Equipment Installation Factor	0.436	0.436	Cost factor to install pretreatment, UF, RO equipment.
29. Refurbish BC 2	\$4,100,000		Includes demolition & assembly.
30. Refurbish BC 3	\$2,970,000		Includes demolition & assembly.
31. Refurbished BC Valuation	\$3,000,000		Value basis used to estimate annual BC maintenance.

Note..... The flow basis is approximate and within the likely produced water recovery range.

Table A.5

Capital Cost Estimate

Collection Center in Bloomfield

Major Processes	Equipment	Installation	Total
O/W Gravity/Coalescing Separator	\$220,000	\$100,000	\$320,000
Gas Flotation Unit	\$300,000	\$140,000	\$440,000
Walnut Shell Filter	\$480,000	\$220,000	\$700,000
Hold Basin			\$240,000
PLC/HMI			\$50,000
MCCs			\$170,000
Tanks			
Receiving Tanks (2)			\$600,000
Walnut Shell Filter Feed Tank			\$50,000
Backwash Hold Tank			\$20,000
Off-Spec Hold Tank			\$290,000
Off-Spec Waste Tank			\$20,000
Recovered Oil Tank			\$20,000
Total - Level Indicators, Misc Valves			\$110,000
Tank Insulation			\$90,000
Line Insulation			\$90,000
Pumps			
Receiving Tank Transfer Pumps	\$130,000	\$60,000	\$190,000
Walnut Shell Filter Feed Pumps	\$130,000	\$60,000	\$190,000
Walnut Shell Filter Recirc Mixer/Pump (included with filter)			
Backwash Transfer Pumps	\$10,000	\$5,000	\$15,000
Off-Spec Transfer Pumps	\$10,000	\$5,000	\$15,000
Pipeline Charge Pumps	\$250,000	\$110,000	\$360,000
Miscellaneous			
Electric Tank Heaters	\$30,000	\$10,000	\$40,000
Total - control valves, manual valves	\$290,000	\$130,000	\$420,000
Transformer/Switchgear			\$200,000
Office, Control Room, MCC Room & Shop/Storage Area			\$50,000
Add'l Site Grading @ 5% of installed cost			\$260,000
General Civil @ 5% of installed cost			\$260,000
Freight @ 1.5% of equipment cost			\$30,000
	Total		\$5,240,000

Table A.6

Operating Cost Estimate

Collection Center in Bloomfield

		<u>kwh/day</u>		
Gas Flotation Drive Motors	\$22,200	1,216		
Receiving Tank Transfer Pumps	\$12,600	689		
Walnut Shell Filter Feed Pumps	\$12,600	689		
Walnut Shell Filter Recirc Mixer	\$900	47		
Backwash Transfer Pumps	\$300	15		
Off-Spec Transfer Pumps	\$500	30		
Electric Tank Heaters	\$29,600	1,622		
Misc Power	3% of total	<u>\$2,400</u>	<u>129</u>	
Total Power		<u>\$81,100</u>	<u>4,437</u>	
Total Annual Power Cost		\$81,000 (rounded)		
Offsite Power Cost, \$/kwh		\$0.050		
Power Demkand, kw		184.9		
Chemicals				
O/W Media Pack Change-out	\$5,000	Dose	Usage	Unit
Walnut Shell Filter Media	\$800	<u>mg/l</u>	<u>#/day</u>	<u>\$/pound</u>
Emulsion Breaker	\$21,700	5	59.6	\$1.00
Filter Aide	\$21,700	5	59.6	\$1.00
Biocide	<u>\$42,500</u>			
Total Chemicals + Mat'ls	<u>\$91,700</u>			
Total Annual Chemicals + Materials		\$92,000 (rounded)		
Labor Summary				
		Burdened	Staffing	
		<u>Rate</u>	<u>hr/yr</u>	
		\$/hr		
Operators	\$201,480	\$46	4380	
Maintenance Techs	\$95,680	\$46	2080	
Clerical	\$0	\$15	0	
Supervisor	<u>\$0</u>	\$55	0	
Annual Labor Cost	<u>\$297,160</u>			
Total Annual Labor		\$297,000 (rounded)		
Equipment Maintenance		1.5% of Installed Equipment		
		\$70,000 (rounded)		