REVIEW OF UPGRADER WATER TREATMENT TECHNOLOGY

Alberta Environment

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GLOSSARY

AIF	Induced Air Flotation
API	American Petroleum Institute
ATM Sep	Atmospheric Separation
BATEA	Best Available Technology Economically Achievable
BFW	Boiler Feed Water
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
bpd	Barrels Per Day
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DGF	Dissolved Gas Flotation
EIA	Environmental Impact Assessment
HP Boiler	High Pressure Boiler
HVAC	Heating, Ventilation and Air Conditioning
IE	Ion Exchange
IGF	Induced Gas Flotation
MBR	Membrane Bio-reactors
N	Nitrogen
O&G	Oil and Gas
P	Phosphorous
pbb	Per Barrel of Bitumen
PBC Treatment	Physical/Biological/Chemical Treatment
RO	Reverse Osmosis

SSW	Stripped Sour Water
SW	Sour Water
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	Ultrafiltration
VAC Sep.	Vacuum Separation
WW	Waste Water

SUMMARY

Alberta's oil sands are the key to the Province's future growth. The bitumen produced from the oil sands must be upgraded into synthetic crude oil before it can be processed by existing oil refineries into products that can be sold to end use customers. A number of companies are taking advantage of the rapidly increasing demand for upgrading and have proposed to construct upgraders in Alberta's Industrial Heartland.

Upgraders consume large quantities of water for process, cooling and other demands. Currently, little data are publicly available about the volume of water required for the upgrading process, and the data which are available quote a wide range of water quantity and quality demands.

This study provides an analysis of water volumes and qualities and a process to select Best Available Technology Economically Achievable (BATEA) for upgrader wastewater treatment. The results of the study are intended to help regulators and other interested parties assess the impacts of proposed upgrader projects in the Heartland.

The study was carried out in stages. First, data were collected on the potential raw water sources, specifically the North Saskatchewan River and the GoldBar Wastewater Treatment Plant secondary effluent. Second, upgrader water demands and wastewater treatment technologies used by upgraders were identified. Third, options for wastewater recycle were identified. Fourth, a representative model of the upgrader bitumen upgrading process and the water and wastewater treatment processes was developed. Fifth, the model was used to identify upgrading wastewater treatment BATEA technologies. Finally, results were summarized and next steps identified.

Investigation of background data confirmed that evaporative cooling is the largest water demand in the upgrading process, followed by desalting, and then gasification. Other significant demands include hydrotreating sour water stripping and water treatment. Significantly, neither of the two upgrading technologies used in the Heartland, delayed coking and hydro conversion, require large volumes of water. However, hydro conversion requires large volumes of hydrogen, which can be produced either by natural gas reforming or gasification; gasification requires large volumes of water.

Investigation of inputs to the development of upgrader BATEA wastewater treatment technologies showed that upgrader wastewater treatment technologies are established and vary little. As such, BATEA opportunities will not come from implementing individual technologies but from changing process configurations, focusing on which process streams are treated individually or combined for treatment.

One exception is in the bioreactors where the biological nutrient removal has become standard. The recent introduction of ultrafiltration membranes as a replacement for clarification, or Membrane Bio Reactors (MBR), has opened up the opportunity for lower nutrient discharge levels. However, the additional cost premium is significant. The BATEA analysis shows that the use of ultrafiltration in place of clarification adds a 25 percent premium to the entire upgrader wastewater treatment process. Further, ultrafiltration membranes have almost no references in refining and upgrading applications and therefore would be considered as high risk.

The results of the BATEA analysis of various treatment scenarios clearly show that the greatest improvements in water use can be realized through the separate treatment of wastewater, specifically Stripped Sour Water (SSW). Today it is standard industry practice to use SSW as feed for the desalters. Significant further savings in fresh water demand can be achieved by the separate treatment of SSW rather than combined treatment with oily and other wastewater, reducing fresh water demand from 0.85 cubic meters of water per cubic meter of bitumen processed to 0.62 cubic meters of water, with minimal additional cost.

Cooling water is the single largest water demand in the upgrading process and needs further consideration during the design phase. The need for cooling should be minimized through the maximization of heat exchangers in the upgrading process, alternative outside uses for waste heat, and careful attention to design parameters and metallurgy. System operation and chemical demand need to be optimized and blowdown monitored to catch any leaks of oil into the cooling system.

Finally, there are a number of areas where research should be focused on solutions to reduce water use, including: large scale wet dry cooling systems, allowing the continual optimization of water and energy demand; sour water stripping process configurations to optimize contaminant removal from SSW prior to treatment; investigation of the cost of piping secondary effluent from the GoldBar Wastewater Treatment Plant to the Heartland; gasifiers which demand large quantities of water, but for which there is little operational data available; and finally a detailed examination of evaporation. Evaporative cooling is expensive, energy intensive, removes water from the hydrological cycle, and is not always needed to produce effluent suitable for discharge to the environment.

1.0 INTRODUCTION

Alberta's oil sands are the key to the Province's future growth. According to the Alberta Energy and Utilities board, bitumen production from oil sands mining and in-situ projects will increase from 1.26 million barrels per day in 2006 to a projected 2.74 million barrels per day of non-upgraded bitumen and synthetic crude oil in 2016. This bitumen must be upgraded into synthetic crude oil before it can be processed by existing oil refineries into products that can be sold to end use customers.

A number of companies are taking advantage of the demand for upgrading and have proposed to construct upgraders in Alberta's Industrial Heartland, which is several hundred kilometers to the south of where the bitumen is extracted. The Industrial Heartland is located to the northeast of Edmonton in the counties of Strathcona and Sturgeon. This area has been selected due to its proximity to Edmonton which has a well trained labour force, and access to the North Saskatchewan River, one of Alberta's major rivers.

Although the North Saskatchewan River has a mean flow of 163 cubic meters per second, it is under stress due to nutrient loading. To ensure environmentally sustainable development in the Heartland Region, a clear understanding of upgrader raw water demand, and water return quantities and qualities is required, and this document can be used as one input to the water management plans for upgrader development in the region.

Upgraders consume large quantities of water for process, cooling and other demands. Currently little data are publicly available about the volume of water required for the upgrading process, and the data which are available quote a wide range of water quantity and quality demands. This study examines upgrader water management technologies and provides tools to assist in the assessment of the water quality and quantity impacts of upgrader development.

1.1 Objective/Scope

The objective of this document is to provide a reference for upgrader water quantity and quality scenarios, and relative costs, for selected upgrader process configurations.

The scope of this study includes the following:

- Comparison of separate versus combined treatment of internal waste streams;
- Comparison of treatment with and without evaporative cooling;
- Internal reuse and recycle options;
- Identification of waste streams which would benefit from larger regional treatment systems;
- Comparison of disposal versus recycle alternatives;
- Evaluation of cooling alternatives equipment and their relative:
  - Economics (capital and operational),
  - Water consumption,
  - Water quality effect,
  - Chemical demand and detrimental effect of various classes, and,
- Evaluation of boiler chemical alternatives and their relative impact.

The scenario analyses presented in this report are based upon computer modeling of upgrader water quantity demands. Wastewater stream qualities and the treated water qualities for each stage of treatment are presented in a series of tables.

The computer model was built in Microsoft Excel by Alberta WaterSMART and outlines water demand by various upgrading technologies. The model was built using standard upgrader hydrocarbon process configurations and flow rates using publicly available information, and information obtained through conversations with industry experts.

The report provides users with a tool and the background information to carry out basic analysis of upgrader water demand and water qualities and the attached computer model allows further detailed analysis of water quantities. It provides a fundamental understanding of the upgrading process, and aids in the identification of opportunities for sustainable design. It is expected that the data in this report will continue to be refined by upgrader proponents and public interest groups as water management plans are further developed and upgrader designs are finalized.

2.0 METHODOLOGY

The project was broken into six steps, as shown in Figure 1. Each step builds incrementally on the previous, beginning with collecting input data. The final result of the project is a model that predicts water demand and relative costing of equipment options. This model can be further refined and updated as upgrader designs are finalized.

2.1 Input Data Collection

Water quantity and quality input data were collected from a variety of public and informal conversations with domain experts. It must be understood by reading this document that unlike an academic journal, this document was produced with the assistance of many domain experts many of whom had differing opinions. Thus as experts in the field read this document and take exception to figures, they are invited to submit examples from their own experience leading to a continual improvement of the document.

A detailed review of Applications for Approval submitted by upgrader proponents including: Petro Canada, Shell, North West Upgraders, Synenco and others was conducted to collect input data. The data collected from this review were used extensively in the analysis and modeling. In the area of upgrader configurations and water quantities and qualities, a significant effort has been made beyond the initial project scope to collect representative data.

Where data were not available, assumptions were made to allow the project to move forward. The assumptions made were minor, the exception being in the area of gasification where little and poor data were available, and is identified as an area which needs greater exploration.

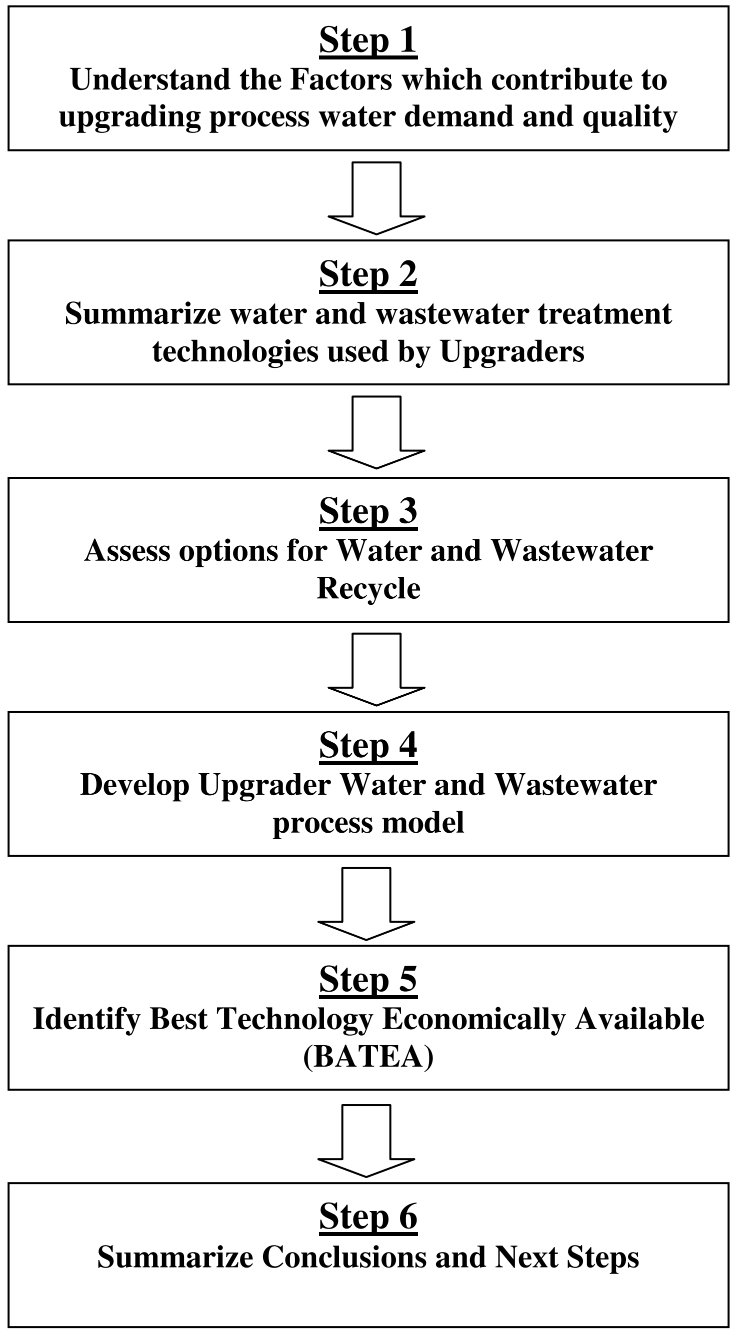


Figure 1-Project Flow Chart

3.0 UNDERSTANDING FACTORS WHICH CONTRIBUTE TO UPGRADING PROCESS WATER DEMAND AND QUALITY

Within the hydrocarbon stream, all processes use boiler feed water, with the exception of desalting and cooling towers. The representative flows described in this section were selected based upon conversations with experts and review of public documents. These flows also form the basis for construction of the computer model.

3.1 Hydrocarbon Process Factors Influencing Water Demand and Quality

The bitumen upgrading process produces multiple wastewater streams including:

- Water Treatment Waste
- Stripped Sour Water (SSW)
- Oily Wastewater
- Cooling Tower Blowdown
- Boiler Blowdown
- Gasification Wastewater.

The volume of each wastewater stream will vary according to the selected treatment process and the quality of the incoming bitumen.

Table 1 shows a range of upgrader process water demands.

Table 1 - Upgrader Process Water Demands

Primary Treated Water Demands		
Stream	**Criteria**	**Range**
Utiltiy (service)	% of inlet barrels of Oil	1-4%
Traditional Cooling Evaporation	% of inlet barrels of Oil	40-60%
Desalting	% of inlet barrels of Oil	3-10%
Gasifier	% of inlet barrels of Oil	35-65%
Boiler Feed Water (Used as water rather than steam)		
Flash Water	% of inlet barrels of Oil	1-2%
Atm. Sep.		0.0%
Vac. Sep		0.0%
Delayed Coking (10% Weight of coke produced)		1-2%
Hydro Conversion		0.0%
Hydro Cracking	% of inlet barrels of Oil	0.0%
Hydro. Treat	% of inlet barrels of Oil	8-12%
Gasifier	% of inlet barrels of Oil	2-16%
Steam Demands		
PreFlash	% of inlet barrels of Oil	1-2%
Atm. Sep.	% of inlet barrels of Oil	1-2%
Vac. Sep	% of inlet barrels of Oil	1.5-2.5%
Delayed Coking		0.0%
Hydro Conversion		0.0%
Hydro Cracking	No Steam	0.0%
Hydro. Treat		0.0%
Sulpher Recovery Unit		
Gasifier	% of inlet barrels of Oil	3-16%
STEAM GENERATION		
Stream	**Criteria**	**Range**
Total Steam Required(1)	% of inlet barrels of Oil	40-55%
Gasifier Steam Generated	% of inlet barrels of Oil	25-40%
HP Boiler Steam Generated	60 cycles	40-55%
HP Boiler Blowdown	60 cycles	0.5-1%
Steam Losses (1% of steam generated)	% of inlet barrels of Oil	0.50%
Condensate from Process Heating	75% of Steam generated	45-60%
Condensate from Gasifier	% of inlet barrels of Oil	0.50%
WASTEWATER GENERATED		
Wastewaters		
Stream	**Criteria**	**Range**
Cooling Tower Blowdown	5 cycles, (20% cooling evap)	8-18%
Gasifier Blowdown	% of inlet barrels of Oil	5-10%
HP Boiler Blowdown	60 cycles	0.5-1%
Sour Water		
Preflash Wash	Same as water Inlet	1-2%
Atmopheric Separation (SW)	% of inlet barrels of Oil	1-3%
Vacuum Distilation Unit (SW)	% of inlet barrels of Oil	1-3%
HydroConversion		0%
Delayed Coker	% of inlet barrels of Oil	1-2%
Hydro Cracking		
HydroTreater	% of inlet barrels of Oil	8-12%
Sour Water Stripper	% of inlet barrels of Oil	3-5%
Oily Wastewater		
Desalting - Sour Water Stripper	% of inlet barrels of Oil	3-10%

Notes:

1. Total Steam Required includes both steam required by the process and steam used for heating and other none contact uses resulting in the recapture of the steam as condensate.

3.1.1 Primary Upgrading Technology Alternatives

The primary hydrocarbon process alternatives, their influence on the quantity of water required, and the characteristics of the wastewater streams produced are discussed below.

The two primary upgrading technologies selected by upgrader proponents in the Industrial Heartland are delayed coking and hydro conversion. Other important hydrocarbon process options include desalting and/or gasification.

Assuming that hydrogen is generated from natural gas, water consumption for both delayed coking and hydro conversion is similar. Delayed coking consumes slightly more water, since water is consumed quenching the coke as it is removed from the cokers. Due to the scope of this study, the slight difference in water consumption between delayed coking and hydro conversion was determined to be immaterial.

3.1.1.1 Delayed Coking

Delayed coking is a semi-continuous thermal cracking process in which a heavy hydrocarbon feedstock is converted to lighter and more valuable products and coke. The mechanism of coking can be broken down into three distinct stages.

- The feed undergoes partial vaporization and mild cracking as it passes through a specially designed coking furnace.
- The vapors undergo cracking as they pass through the coke drum to fractionation facilities downstream where products of gas, naphtha, and jet fuel and gas oil are separated. The petroleum coke remains in the drum.
- The heavy hydrocarbon liquid trapped in the coke drum is subjected to successive cracking and polymerization until it is converted into vapors and coke.

Water Considerations

Source Water and Use: Full coke drums are cooled by filling with water. Steam that is formed is condensed and the water reused. The drum is then opened and the coke cut with high pressure water jets. Coke and water fall into a sump and the water is recycled. A small amount of makeup water is required for this process. The steam for process heating and stripping is recovered.
Wastewater: Sour water

3.1.1.2 Hydro Conversion

Hydro Conversion is the process of cracking large hydrogen molecules in a hydrogen rich, high pressure atmosphere in the presence of a catalyst to produce lighter hydrocarbons.

If coke is gasified to produce the hydrogen needed for the hydro conversion process, then additional water is used in the process. If natural gas is used as the hydrogen source, then no additional water is required for hydro conversion.

Water Considerations

Source Water & Use: No Water required
Wastewater: None

Figures 1 and 2 in Appendix A illustrate the upgrading process flow diagrams for each of the two primary upgrading technology alternatives. **Figure 1** depicts "Upgrading with Delayed Coking" and **Figure 2** depicts "Upgrading with Hydro Conversion". These figures are referenced throughout the report.

3.1.2 Option: Desalting

Desalting, if required, is the first step in the upgrading process.

Desalting is required if there is salt in the bitumen. Desalting is more common for bitumen produced from in-situ projects than from mines. The bitumen extraction and floatation processes used in mining operations uses water, which desalts the bitumen. For in-situ operations, the need for desalting is a function of the bitumen salt content.

Desalting uses large volumes of water (see Table 1 – Upgrader Process Water Demands); however, the water can be of a lower quality than that used for other upgrading processes. Further discussion of water qualities can be found in Section 3.4. Water and Wastewater Qualities. Lower quality wastewater streams, such as stripped sour water, are an option for use in desalting. Using stripped sour water for desalting has no effect on the volume of fresh water used, as only stripped sour water is used for desalting, requiring no additional intake of raw water.

The oily wastewater produced by the desalting process is the most difficult wastewater to treat in the upgrading process. Some of the primary parameters of concern in the oily wastewater stream are:

- Total Dissolved Solids (TDS),
- Total Suspended Solids (TSS),
- Oil and Grease (O&G),
- Biochemical Oxygen Demand (BOD),
- Chemical Oxygen Demand (COD),
- Chloride, and
- Temperature.

Water Considerations

Source Water & Use: • Stripped sour water is used in the desalting process.
Desalter Wastewater Characteristics: • In the upgrading process, desalter effluent is the most difficult stream to treat and the most difficult stream to recycle, as high concentrations of oil and grease and BOD/COD must be removed. See Table 6 - Typical Wastewater Qualities for typical desalter effluent characteristics.

3.1.3 Other Equipment/Processes within the Hydrocarbon Flow Diagram

Atmospheric Distillation (Diluent recovery) and Vacuum Distillation

After desalting, bitumen is sent to atmospheric distillation and vacuum distillation. Atmospheric distillation and vacuum distillation are common to all upgraders. In the distillation process, the diluent is recovered and some lighter ends separated. Vacuum distillation follows atmospheric distillation and further separates light ends, leaving a heavy vacuum residual. Steam is injected into the process streams for heating and stripping.

Water Considerations

Source Water: Steam for process heating and stripping.
Wastewater: Sour water

Residual Hydrocracking

Following delayed coking, residual hydrocracking is a catalyst-driven process which further breaks large hydrocarbons into smaller molecules.

Water Considerations

Source Water & Use: No Water required
Wastewater: None

Hydro Treating

Hydro treating is a catalytic process in which hydrogen is contacted with the product stream to remove impurities, such as oxygen, sulfur, nitrogen, or unsaturated hydrocarbons to a level acceptable to conventional refinery processes. Impurities are dissolved in the process water as sour water.

Water Considerations

Source Water & Use: Boiler Feed Water
Wastewater: Sour Water

Sour Water Stripping

This unit strips hydrogen sulphide and ammonia from the sour water to allow its reuse in the process units. The sour water from the process units is fed to a stripping tower where heat, in the form of steam, is applied. The ammonia and hydrogen sulphide contained in the water is released by the heat and exits the top of the tower. Any excess steam is condensed by cooling the overhead stream and returning the condensate to the tower.

Water Considerations

Source Water & Use: Sour Water & Steam
Wastewater: Stripped Sour Water

Steam Generation

Steam generation conditioning chemicals are dosed to the boiler feed water (BFW) in low concentrations and comprise the following groups of chemicals:

- C*orrosion inhibitors*: mainly oxygen scavengers and alkaline compounds. Sulphite (< 60 bar), oximes, hydroxyl amines, and hydrazine (declining use due to safety issues) etc. are commonly applied as oxygen scavengers for deaerated boiler feed water prior to pumping into the boiler. Commonly applied alkaline compounds are sodium phosphates (which are also hardness binders), caustic, ammonia and neutralizing amines.
- A*nti-scaling agents*: such as polyacrylates and phosphonates that are rest hardness binders and dispersing agents.
- A*nti-foaming agent*s: in general intermittently dosed, to combat foaming in case the condensate contains oil or organics.

A 100 t/h steam generation system requires approximately 1.5 - 3 t/yr corrosion inhibitors and 2 - 4 t/yr anti-scaling agents.

3.1.4 Option: Gasification

Gasification can be used to produce fuel gas from which energy can be extracted, steam and hydrogen.

Upgraders which use hydro conversion, a process requiring large amount of hydrogen, typically use gasifiers as they can produce hydrogen cheaper than through natural gas reforming. But as gasifiers also produce fuel gas and steam they are also used by some upgraders using delayed coking for upgrading.

3.2 Cooling Factors Influencing Water Demand and Quality

3.2.1 Cooling Systems

Cooling is a critical part of any upgrading facility, enabling excess heat to be eliminated from the upgrader. For conventional designs, cooling water demand is the single largest demand in typical upgrading facilities and ranging anywhere from 35 percent for conventional upgraders with discharge streams to near over 90 percent by volume of incoming water for zero discharge facilities.

There are a number of different cooling technologies available, a number of which are listed in Table 2 - Cooling Technologies. Evaporative cooling is the most common type of cooling system proposed in areas where water is available, and uses water in three ways (evaporation, drift or blowndown) to maintain dissolved solids within acceptable levels. Evaporative cooling is the most common type of cooling proposed in the Industrial Heartland Region.

Table 2 - Cooling Technologies

1. Wet or Evaporative • Typical industrial cooling tower where air and water make contact and cool the water • High water demand/ low capital • Operate well year round
2. Dry cooling • Uses air-cooled heat exchangers using fin fans where there is no contact between the water (or other stream) and air. • Zero water demand • High capital cost • Effective in winter, but challenged in summer
3. Wet Surface Cooling • Air and water is distributed over a cooling tower • The tower is equipped with bundles of tubes and heat transfer is through cooling water and air on the outer diameter of the tube with condensate flowing through the inner diameter of the tube. • Used to some extent in the power industry on cogeneration units and large condensing turbines; TransAlta have at least two installations in Alberta. • Higher capital cost • No oil industry references.
4. Parallel Wet Dry • Parallel all wet or all dry • Used only in power and cogeneration plants currently • Hot condensate from the condensing turbine / hot well is cooled using an exchanger with cooling water on the tube side which is pumped back to a conventional cooling tower • Alternatively the hot condensate can pass through an air cooled heat exchanger rather than the cooling tower • Condensate flow can also be split between the air cooler and cooling tower, providing a number of flow alternatives to optimize water or power demand • High capital cost • Optimized water and power consumption

3.2.2 Cooling Water Treatment Factors Influencing Water Demand and Quality

Evaporative cooling systems are able to operate with less stringent water qualities than the upgrading process (See Table 3 – Cooling Water Quality Limits). As a result, these systems can use primary treated water, or recycled water, which has had the suspended solids removed, but still contains all the dissolved solids of the incoming water.

Typically cooling water quality parameters must be less than those presented in Table 3 – Cooling Water Quality Limited (suggested by Manufacturers), and Table 4 – Fouling Contaminant Limits.

Cooling tower feed water quality must be below the levels in Table 3 – Cooling Water Quality Limits (suggested by Manufacturers), and Table 4 – Fouling Contaminant Limits. The purer the quality of the incoming waters, the lower the blowdown volume. For instance, if the limit for TDS is 5000 mg/L and the incoming TDS level is 2500, a blowdown of 50 percent is required, while if the feed water TDS is 1000, only 20 percent blowdown is required.

Table 3 - Cooling Water Quality Limits (suggested by Manufacturers)

Parameter	Marley Recommendation	BAC Recommendation	EVAPCO Recommendation	Impact on Tower Operation/ Remedy
pH	6.5 to 9.0	7.0 to 9.0	6.5 to 8.0	OK
Temperature		125° F maximum		OK
Langelier Sat. Index	0.0 to 1.0			Scale, Increase inhibitor
M-Alkalinity, as CaCO3	100 to 500 ppm	500ppm maximum	50 to 300 ppm	Scale, Increase inhibitor
Silica, as SiO2	150ppm,maximum			OK
Ammonia	50 ppm, Corrosion 10-25ppm Biogrowth			OK
Chlorine	1 ppm shock residual, or 0.4 ppm continuous			Very high, Wood delignification, Remove Cl- or alt. materials
TDS	5000ppm maximum	1000ppm maximum	<10,000 ppm	Thermal Performance and wood in wet/dry, reduce cycles
Calcium, as CaCO3	800 ppm,	30 to 500 ppm	50 to 300 ppm	OK
Chlorides Galvanized Steel	750 ppm as NaCl 455 ppm as Cl-	206 ppm as NaCl 125 ppm as Cl-	200 ppm as Cl-	Corrosion, Add inhibitor
Chlorides Stainless Steel	1500 ppm as NaCl 910 ppm as Cl-	400 ppm as Cl-		OK, Corrosion
Sulfates as CaCO3	800 ppm	125ppm maximum		OK scale w/moderate calcium, Corrosion of concrete basins
Nitrates as NO3	300 ppm			Bio-growth, Increase Biocide

Table 4 - Fouling Contaminant Limits

Fill Type	Aerobic Bacteria Standard Plate Count	Total Suspended Solids (TSS)	Oil and Grease
HVAC Cross-Corrugated Film	10,000 CFU/ml	25 ppm	1 ppm
HVAC Crossflow	100,000 CFU/ml	50 ppm	
Chevron Film	10,000 CFU/ml	150 ppm	1 ppm
HVAC Splash	1,000,000 CFU/ml target	No specific limit	10 ppm

3.2.3 Cooling Water Sources

Both river water and secondary effluent can be used as source water for evaporative cooling.

Both sources require pretreatment for the removal of suspended solids. While both river water and secondary effluent are suitable feeds, there are differences in the way that cooling towers are operated, including chemical demand, blowdown volumes and tower material selection.

When secondary effluent is used as the feed water source, more expensive pretreatment, increased use of chemicals including biocides and corrosion inhibitors, and increased blowdown are needed. This will increase the volume of water consumed to maintain TDS within acceptable discharge limits.

To optimize the operation of cooling tower, chemicals are added. Section 3.2.4 Cooling Water Treatment examines the chemicals which are added and their purpose.

3.2.4 Cooling Water Treatment Chemicals

Cooling water treatment programs will vary depending on the quality of water make up and the target for the number of cycles of concentration. The cycles of concentration will be determined by the maximum acceptable water quality parameter levels.

A critical aspect for designing a cooling water system is the circulating system itself, including metallurgy of distribution piping, water velocities, heat exchanger tube metal temperatures, and bulk water temperature. A system will usually have a carbon steel distribution system and heat exchangers are usually a carbon steel shell with tube bundles of carbon steel, admiralty or stainless steel. Cooling water is on the tube side. However, there are designs where cooling is on the shell side and the potential for low water velocities is a concern.

A typical treatment program is as follows:

(1) Addition of sulphuric acid for pH control (usually 7.0 to 7.5 depending on calcium temperature). Consumption is based on the level of alkalinity desired.
(2) A calcium phosphate dispersing agent usually 5 to 20 ppm active. These are copolymers such as Sulfoninc / acrylic acids. There are many new polymeric materials that increase the solubility of calcium phosphate.

(3) Tolytriazole or benzotriazole in the amount of 1 to 3 ppm for copper inhibition.
(4) The possible use of a blended chemical corrosion inhibitor package that may contain inorganic phosphates, the above mentioned azoles, and molybdates.
(5) Mechanical methods to maintain the cooling water system low in suspended solids with a target of 50 ppm. There are polymers designed to keep suspended solids from precipitating and are typically fed in the amount of 5 to 20 ppm.
(6) Microbiological control by the addition of chlorine (sodium hypochlorite) to maintain a continuous residual of 0.3 to 0.5 ppm.

3.2.5 Cooling Water Emissions

Emissions into the surface water from cooling systems can be caused by:

- applied cooling water additives and their reactants, including conditioners, biocides, and corrosion inhibitors.
- airborne substances entering through a cooling tower,
- corrosion products caused by corrosion of the cooling systems' equipment, and
- leakage of process chemicals (product) and their reaction products.

The main pollutants to be considered in water cooling systems are the phosphates, chlorinated and/or brominated antifouling additives, and anticorrosion additives containing zinc, chromium, molybdenum etc.

Any phosphates added during cooling must be removed by the waste water treatment plant, and the North Saskatchewan River phosphorus concentration currently often exceeds quality parameters.

3.3 Recycle Streams Influencing Water Demand and Quality

Recycle streams may have a positive or negative impact on the operation of a cooling tower system. There are two primary recycle sources with the upgrading process, treated stripped sour water and treated combined bioreactor effluent.

Stripped Sour Water Recycle

Stripped sour water (SSW) can be biologically treated and recycled into the cooling tower, offsetting raw water demand. SSW has a relatively low TDS (Table 6 - Typical Wastewater Qualities), comparable to that of source water, thus little effect can be expected in terms of blowdown volume. However, treated SSW will have a higher BOD/COD than primary treated water thus we can expect an increase in chemical demand in the cooling tower.

Combined Bioreactor

Combined bioreactor effluent (see Table 6 - Typical Wastewater Qualities*)* has considerably greater dissolved solids and other parameters than treated stripped sour water, thus greater treatment is required. Assuming that the effluent is treated with reverse osmosis (RO) and then sent to the cooling tower, the result is very high quality source water for the cooling tower, lowering chemical demand while simultaneously decreasing the volume of blowdown required.

The drawback to RO treatment of combined effluent is the possibility that the reject may have levels of dissolved solids at levels unsuitable for river discharge and must be sent to deep well or evaporation for disposal.

3.4 Water and Wastewater Qualities

3.4.1 Source Water Alternatives & Qualities

Raw water is available from four sources within Alberta's Industrial Heartland:

- North Saskatchewan River,
- Goldbar Wastewater Treatment Plant treated effluent,
- Groundwater, and
- Local municipal potable water supplies.

The North Saskatchewan River and the Goldbar Wastewater Plant treated effluent are the only sources which can provide the quantities of water required for all the upgrader and other projects currently planned for the area.

North Saskatchewan River Water

North Saskatchewan River water quality data have been extracted from Applications for Approval that have been filed with project applications. The values of the water quality parameters are similar across the EIAs, therefore the water quality data from the stations at Fort Saskatchewan Bridge were chosen as representative locations for measurement (Refer to Table 5 - Potential Source Water Qualities). Potential Source Water Table water qualities which exceed water quality parameters are bolded, it should be noted that there are already a number of water quality parameters that exceed water quality objectives in the raw water

Goldbar Wastewater Treatment Plant Treated Effluent

The quality of treated secondary effluent from Goldbar Wastewater Treatment plant was provided by the Goldbar Wastewater Treatment plant for 2007 (Refer to Table 5 - Potential Source Water Qualities).

Table 5 - Potential Source Water Qualities

Parameter (units)	INFLUENT: GOLDBAR BACKGROUND WATER QUALITY PARAMETERS		NORTH SASK. RIVER: North Saskatchewan River at Fort Saskatchewan Bridge						North Saskatchewan River at Vinca Bridge						Guidelines: ASWQG Guideline			US EPA Guideline	
	Average	Max	Min	Median	Max	Count	Mean	SD	Min	Median	Max	Count	Mean	SD	Acute	Chronic	CWQG Guideline	Maximum	Continuous
pH			7.6	8.1	8.6	119	8.1	0.2	7.2	8.24	9	129	8.21	0.29	6.5 to 8.5, but not altered by 0.5 from background		6.5-9.0		6.5-9.0
Temperature (℃)			-0.6	11.22	24.6	185	10.65	7.99	-0.21	13.34	24.5	133	11.7	8.12	Not to be increased by >3℃		Narrative[1]		
Standard Parameters																			
Total Suspended Solids (mg/L)	4.3275	22.7	1	20	179	129	29	31	0.5	11	165	150	20.3	30.4	Not to be increased by > 10 mg/L above background		Narrative[2]		
Chloride (mg/L)			2	3	6	86	3	1	1.2	2.9	5.6	95	2.9	1				860	230
Sodium (mg/L)	82.81	120	2	7	11	113	7	2	4	5	14	106	6	2					
Potassium (mg/L)	12.01	14.1	0.6	1	2.4	116	1.1	0.3	0.7	1	3.05	38	1.3	0.7					
Magnesium (mg/L)	24.45	29.4	7	12	15	113	12	1	10.2	13	31	42	14	3					
Calcium (mg/L)	63.29	71.3	34	42	55	137	43	4	36.8	44	52.7	51	45.01	3.8					
Sulphate (mg/L)			20	40	62	113	39	7	33	42	54	34	43	6					
Sulphide (mg/L)				0.05															
Tot. Alkalinity (mg/L)			116	132	153	114	132.3	7.9	122	127.9	145	30	131.2	6.1					
Total Hardness (mg/L)			145	161.5	184	58	160	10	149	160	187	29	162	9					
TDS (mg/L)			137	182	210	111	182	14	177	188	227	28	192	13					
Colour (TCU)			2	4	4	5	3	1	7	10	10	10	9	1	Narrative[3]		Narrative[4]		Narrative[5]
Specific Conductance (µS/cm)			224	338	444	221	343	34	144	325	434	157	329	38					
Turbidity (NTU)			1.21	8.35	83	42	16	22	0.5	5	28	24	9	8	Narrative[3]				
Dissolved Oxygen (mg/L)			5.9	10.6	14	185	10.4	1.9	6.39	10.39	12.7	133	10.2	1.8	5.0 (1-day min)	6.5 (7-day mean)	5.5 to 9.5	3.0 to 9.5	
Nutrients																			
Total Ammonia (mg/L)	3.33	15.1	0.07	0.26	**1.4**	17	0.48	0.47	0.03	0.06	0.48	9 0.	12	0.14			1.37 (at pH 8 to 10)	4.64 (at pH of 8.1)	1.09 (at pH of 8.1)
Un-ionized Ammonia (mg/L)																			
Total Phosphorus (mg/L)	0.64	2.69	0.01	**0.08**	**0.89**	157	**0.14**	0.19	0.012	**0.058**	**0.29**	127	**0.071**	0.048		0.05			
Phosphorus Dissolved (mg/L)			0.002	0.039	0.285	87	0.057	0.049	0.005	0.0365	0.14	62	0.041	0.028					
Total Kjeldahl Nitrogen (mg/L)			0.12	0.48	3.11	145	0.68	0.66	0.14	0.38	1.11	119	0.42	0.2					
NO_3 and NO_2 (mg/L)			0.04	0.17	0.99	141	0.23	0.2	0.06	0.275	0.641	62	0.31	0.15			NO_3 = concentrations that avoid weed growth, NO_2 = 0.06		
Dissolved NO_3-N (mg/L)			0.006	0.021	0.25	67	0.036	0.039	0.006	0.034	0.115	19	0.041	0.031					
Dissolved Ammonia (mg/L)			0.01	0.16	1.58	127	0.3	0.34	0.015	0.142	0.445	54	0.153	0.105					
Total Nitrogen (mg/L)			0.02	0.09	**2.34**	63	0.21	0.38	0.03	0.08	0.2	13	0.08	0.04		1			
Organics																			
COD (mg/L)	35.89	91.6	5.2	13	37.7	55	14.2	6.9	5	6	7	5	6	0.7					
BOD (mg/L)	3.72	35	0.3	1.5	7	80	1.8	1	0.72	1.7	3.4	33	1.8	0.7					
BTEX (mg/L)																			
Benzene (mg/L)			0.0001	0.0001	0.0003	13	0.00008	0.00008	0.0001	0.0001	0.0001	3	0.0001	0			0.37		
Toluene (mg/L)			0.0001	0.0001	0.0001	13	0.0001	0	0.0001	0.0001	0.0001	3	0.0001	0			0.002		
Ethylbenze (mg/L)																	0.09		
Xylene (mg/L)			0.0001	0.0001	0.0001	13	0.0001	0	0.0001	0.0001	0.0001	3	0.0001	0			0.09		
Total Organic Carbon (mg/L)			0.39	7	11.6	54	6.1	3.5	0.6	1.3	22	74	1.8	2.5					
Dissolved Organic Carbon (mg/L)			0.6	2.39	45	72	3.66	5.36	0.9	2.5	6	19	2.8	1.1					
Dissolved Inorganic Carbon (mg/L)			30.7	33	37.3	71	33.5	2.1	27.3	32.5	37.9	13	32.6	4.2					
Oil and Grease(mg/L)																			

Table 5 - Potential Source Water Qualities

Table 5 - Potential Source Water Qualities - **Continued**

Parameter (units)	INFLUENT GOLDBAR		NORTH SASK. RIVER North Saskatchewan River at Fort Saskatchewan Bridge						North Saskatchewan River at Vinca Bridge						Guidelines ASWQG Guideline			US EPA Guideline	
	Average	Max	Min	Median	Max	Count	Mean	SD	Min	Median	Max	Count	Mean	SD	Acute	Chronic	CWQG Guideline	Maximum	Continuous
Miscellaneous																			
Cyanide (mg/L)			0.002	0.002	0.002	5	0.002	0	0.001	0.001	0.001	5	0.001	0	0.01		0.005	0.022	0.0052
Phenols (mg/L)			<0.001	0.003	**0.012**	47	0.004	0.002	<0.001	0.002	**0.005**	82	0.002	0.001		0.0051	0.004	10.2	2.56
Total Coliforms (No/100 mL)			26	7000	72000	83	11501	13232	700	8400	24000	9	9267	6730					
Fecal Coliforms (No/dL)			1	775	70000	110	4681	10740	8	380	24000	124	1736	3837					
Metals																			
Aluminum (mg/L)	0.07617	0.311	0	**0.235**	**5.08**	121	**0.462**	0.741	0.005	**0.355**	**4.21**	37	**0.973**	1.272			0.1	0.75	0.087
Antimony (mg/L)			0.00005	0.00007	0.00015	39	0.0001	0.00002	0.00001	0.000088	0.00038	35	0.00011	0.00007					0.014
Arsenic (mg/L)	0.00156	0.005	<0.0001	0.0005	0.0023	105	0.0006	0.0004	0.0003	0.0006	0.0024	44	0.0008	0.0006		0.01	0.005	0.34	0.15
Barium (mg/L)	0.0366	0.046	0.054	0.074	0.113	53	0.076	0.017	0.0099	0.0786	0.116	43	0.0778	0.0203					
Berylliuym (mg/L)			0.0000038	0.00002	0.00009	31	0.00003	0.00002	<0.00004	<0.00004	0.0002	35	0.00006	0.00006				0.13	0.0053
Bismuth (mg/L)			<0.0000001	0.000007	0.00003	39	0.00001	0.00001	<0.000005	0.00001	0.000052	30 0.000015	0.000015						
Boron (mg/L)	0.1934	0.211	0.01	0.015	0.028	42	0.016	0.004	0.000013	0.000019	0.0228	30	0.0037	0.0071		0.5			
Cadmium (mg/L)	0.00012	0.00025	<0.000001	<0.000001	**0.00003**	103	**0.000001**	0.000003	<0.001	<0.001	**0.04**	49	**0.005**	0.01		0.01	0.000054	0.0078	0.0034 [8]
Chromium (mg/L)	0.00375	0.01	0.00014	0.003	**0.027**	140	0.003	0.003	<0.001	0.00095	**0.014**	114	0.002	0.002		0.05 [9]	0.00895	0.9 [8, 10]	0.12 [8,10]
Hexavalent Cr (mg/L)	0.00375	0.01															0.001	0.016	0.011
Cobalt (mg/L)	0.00132	0.0025	0.00007	<0.0001	0.004	123	0.00074	0.00088	<0.001	0.0005	0.005	39	0.001	0.001			0.05		
Copper mg/L	0.0118	0.02	<0.00005	0.002	**0.024**	111	0.003	0.003	<0.001	0.001	**0.012**	112	0.002	0.002	0.028 [8]	0.007	0.003 [11]	0.023 [8]	0.014 [8]
Iron (mg/L)	0.625	2	0.035	0.154	**1.309**	46	**0.4**	0.418	0.026	**0.655**	**4.96**	30	**1.216**	1.574		0.3	0.3		1
Lead (mg/L)	0.00126	0.002	0.000096	0.0015	**0.104**	64	**0.006**	0.019	<0.0001	0.001	**0.05**	101	0.0022	0.0057		0.05	0.004	0.12 [8]	0.0046 [8]
Lithium (mg/L)			0.0031	0.004	0.0063	39	0.0042	0.0007	0.00344	0.0048	0.0111	30	0.0056	0.0022					
Manganese (mg/L)	0.06	0.1	0.006	0.02	**0.121**	116	0.027	0.024	0.0072	0.0196	**0.107**	37	0.0299	0.0293		0.05			0.05
Mercury (mg/L)	0.0001	0.0001	<0.00004	<0.00004	**0.0002**	89	**0.00004**	0.00002	<0.00004	<0.0001	**0.0002**	98	**0.00008**	0.00005	0.000013	0.000005	0.00003 (2003)	0.0014	0.00077
Molyebdeum (mg/L)	0.0163	0.029	<0.001	<0.001	0.007	92	0.0011	0.0016	0.00088	0.0012	0.005	29	0.0015	0.0009			0.073		
Nickel (mg/L)	0.01089	0.0133	0.000123	0.004	0.039	132	0.004	0.004	0.00008	0.003	0.019	46	0.0036	0.0035			0.11 [11]	0.75	0.083 [8]
Selenium (mg/L)			<0.0001	<0.0001	0.001	100	0.0002	0.0001	<0.0005	0.00023	0.0009	40	0.00032	0.00026			0.001		0.005
Silver (mg/L)	0.001075	0.002	<0.000005	0.0000084	0.00003	39	0.00001	0.000007	<0.000005	0.00001	0.00011	30	0.00002	0.00003		0.05	0.0001	0.009 [8]	
Strontium (mg/L)	0.5101	0.552	0.307	0.396	0.446	42	0.39	0.036	0.309	0.396	0.472	30	0.395	0.046					
Thallium (mg/L)	0.00068333	0.001	<0.0000003	0.000018	0.0000572	39	0.00002	0.00001	<0.000003	0.000021	0.000078	30	0.00003	0.00002			0.0008		
Vanadium (mg/L)	0.00126	0.002	0.00016	0.003	0.013	115	0.003	0.003	<0.002	0.003	0.012	37	0.0035	0.0033			0.1		
Zinc (mg/L)	0.0585	0.08	0.001	0.006	**0.064**	91	0.017	0.017	<0.001	0.006	**1.4**	91	0.026	0.146		0.05	0.03	0.19 [8]	0.19 [8]

Notes:

BOLD Boldface values exceed one or more guidelines

1. Thermal inputs should not alter thermal stratification, turnover dates, exceed maximum weekly average temperatures, nor exceed short term temperatures.
2. Max Increase 25 mg/L (for 24 hours to 30 days).
3. Not to increase by more than 30 colour units above natural values.
4. Any colour change (true or apparent) should be within the seasonal variation for the system in question.
5. Water will be virtually free from substances producing objectional colour for aesthetic purposes. Increased colour (along with turbidity) should not reduce the depth of the compensation point by more than 10% from the seasonally established norm for acquatic life.
6. For Clear flow - maximum increase of 8 NTU above background for short term exposure (24h hours) and 2 NTU above background for long term exposure (between 24 hours and 30 days), For higher flow or turbid waters - maximum increase of 8 NTU the background for between (8 and 80 NTUand not more than 10% for background values above 80 NTU.)
7. Guide for Phenolics.
8. For hardness of 175 mg/L $CaCO_3$
9. Total Chromium
10. Chromium III.
11. For Hardness values between 120 and 180 mg/L $CaCO_3$.

Source: Alberta Environment NAQUADT; CWQG Canadian Water Quality Guidelines for freshwater aquatic life (CWQG 2001); ASWQG Surface Water Quality Guidelines for Alberta (AENV 1999a); ASWQG Water Quality Based Effluent Limits Proceedures Manual (1995)

3.4.2 Wastewater Qualities

Sources of wastewater include oily wastewater, sour water, stripped sour water, water treatment waste, and blowdown streams (cooling tower, boiler and gasifier). Each of these sources produces wastewater with slightly different characteristics and treatment requirements.

Table 6 - Typical Wastewater Qualities provides typical wastewater qualities for each of the wastewater streams generated.

Table 6 - Typical Wastewater Qualities

	Units	Oily Wastewater	Stripped Sour Water	Combined High TDS Waters(1)	Cooling Tower Blowdown
Temperature	°C	30-60	30-35	30-40	NS
pH		7-8	7-8	7-8	8
TDS	mg/L	150-5000	50-150	500-2500	5000-6000
TSS	mg/L	300-800	10-20	50-100	18,537.0
Cl2 Residual					0.3-0.5
O&G	mg/L	3000-5000	5-20	<5	0.1-1.0
BOD	mg/L	300-500	100-300	5-150	NS
COD	mg/L	300-1200	200-500	100-500	NS
TOC	mg/L	NS	NS	<100	NS
Hardness	mg/L as CaCO3	NS	NS	NS	1200-1400
Total Alkalinity	mg/L as CaCO3	NS	NS	NS	100-125
Ca2+	mg/L	NS	NS	NS	1,000
Cl-	mg/L	50-2000	NS	NS	1000-1500
NH3	mg/L	20-50	40-80	NS	<5
P	mg/L	NS	Minimal	NS	NS(2)
Cyanides	mg/L	1-3	-	NS	NS
Phenols	mg/L	5-20	20-80	NS	NS
H2S	mg/L	5-10	10-40	NS	NS

NS=Not Specified
1. Ion Exchange Waste, Boiler Blowdown, RO Reject
2. Function of inlet water quality and chemcials added.

3.5 Discharge Options & Quality Requirements

The four discharge alternatives listed below are all technically feasible. The selection of the preferred alternative is a function of the selected process, recycle opportunities, economics, regulatory limitations and social requirements. Process effects, which relate primarily to dissolved solids concentrations and financial implications, will be examined.

- Physical and Biological Treatment followed by discharge to the River;
- Physical, Biological, Chemical Treatment followed by discharge to the River;
- Physical, Biological and recycle with deep well injection, thus no surface discharge; and
- Physical, Biological, evaporation, and crystallization, thus no discharge.

4.0 WATER AND WASTEWATER TREATMENT TECHNOLOGIES

4.1 Introduction

To facilitate the development of the wastewater model, water/wastewater process flow diagrams were developed. These process flow diagrams were based upon commercially available technologies and consider the following sources and demands:

- Source Water (River or Secondary Effluent)
- Cooling Tower
- Utility Water
- Boiler Feed Water
- Oily Wastewater
- Stripped Sour Water
- Recycle.

Within the upgrading process two types of water are produced: service or utility water, and boiler feed water (BFW). Within the upgrading process BFW is used for all processes with the exception of cooling and desalting water. Cooling water requires only primary treatment to remove suspended solids, while BFW requires the additional removal of dissolved solids which is a much more complex process.

4.2 Water Treatment

4.2.1 Source Water Treatment

There are two options for source water available to the upgraders: river water and secondary effluent. As the focus of this report is wastewater treatment alternatives, only one alternative has been selected for each water source. Either of the two source water options can be used to produce water suitable for use in the upgrading process. Although both source waters may be technically suitable there are a number of considerations in the source selection including availability, security of supply, and financial implications. These factors are outside the scope of this report and have not been considered.

4.2.2 Primary Treatment

Following primary treatment, the treated water is suitable for use as cooling water and utility water but will require further treatment to be used as boiler feed water.

<u>Primary Treatment for River Water</u>
Given the quality of North Saskatchewan River water (Refer to Table 5), primary treatment will require settling, clarification and media filtration. The finished water is low in suspended solids, but still contains the original levels of dissolved solids.

Primary Treatment for Wastewater Secondary Effluent
Wastewater secondary effluent is used successfully by industry in many locations. The Petro-Canada Refinery, located less than two kilometers from the Goldbar Treatment Plant is currently using treated Goldbar effluent to meet some of its needs. Secondary effluent must be treated to a higher standard than raw river water. Typically ultrafiltration is used to provide this superior treatment ensuring a consistent, high quality water supply.

Effluent treated by ultrafiltration is low in suspended solids but still contains the original levels of dissolved solids. As secondary wastewater has higher levels of dissolved solids than river water, additional care must be taken in the design of processes downstream to allow additional design capacity to increase cooling tower blowdown, as an example. See Table 6 - Typical Wastewater Qualities for blowdown qualities

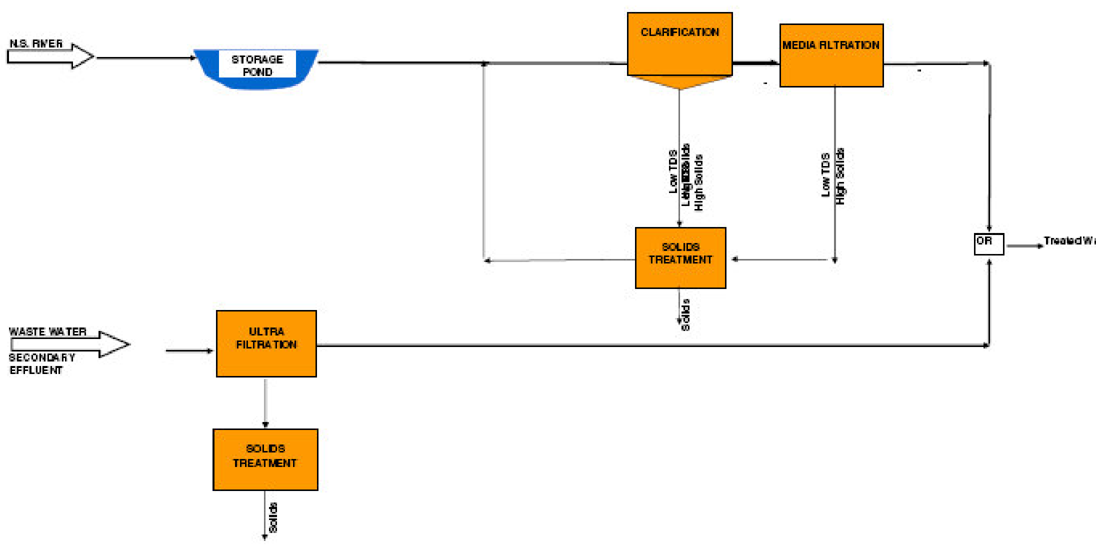
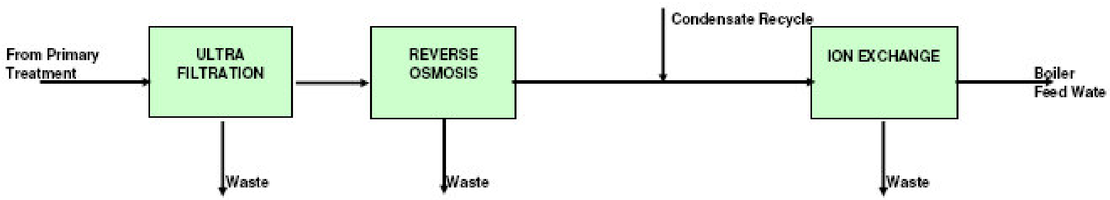


Figure 2 - Primary Treatment Alternatives (see Appendix for details)

4.2.3 Secondary Treatment

Boiler feed water requires additional treatment to remove dissolved solids. Treatment for the purposes of the model has been assumed to include ultrafiltration, followed by Reverse Osmosis (RO) and Ion Exchange (IX). The finished water is extremely low in dissolved and suspended solids. See Figure 3 – Boiler Feed Water Treatment & Table 7- Boiler Feed Water Chemistry Limits.



Note: Ultrafiltration media filtration can be used in place of ultrafiltration, but the use of ultrafiltration will reduce the number of membranes required and extend RO membrane life.

Figure 3 - Boiler Feed Water Treatment (see Appendix for details)

Table 7- Boiler Feed Water Chemistry Limits

DRUM PRESSURE, psig	MAXIMUM BOILER WATER SOLIDS(1), ppm	STEAM TDS CORRESPONDING TO MAX. BW TDS, ppm	MAXIMUM SUSPENDED SOLIDS, ppm
0 - 300	3500	1	15
301 - 450	3000	1	10
451 - 600	2500	1	8
601 - 750	1000	0.5	3
751 - 900	750	0.5	2
901 - 1000	625	0.5	1
1001 - 1800	100	0.1	1
1801 – 2350	50	0.1	1
2351 – 2600	25	0.05	1
2601 - 2900	15	0.05	1

Notes:
1. 20% Actual Boiler Feed Water Solids.
2. For TDS <100ppm, the total alkalinity is dictated by the boiler water treatment.

4.3 Wastewater Treatment Technologies

The wastewater treatment process can be more complex process than the water treatment process. Multiple wastewater streams, treatment technologies and the availability of recycle alternatives contribute to the complexity of wastewater treatment. There are three basic levels of treatment for wastewater:

- Removal of suspended solids, oils and grease;
- Removal of Biochemical/Chemical Oxygen Demand (BOD/COD);
- Sulphide ammonia; and,
- Removal of dissolved solids.

Sources of wastewater include oily wastewater, sour water, stripped sour water, water treatment waste, and blowdown streams (cooling tower, boiler and gasifier). (See Table 6 - Typical Wastewater Qualities). Each of these sources produces wastewater with slightly different characteristics and treatment requirements. Table 8 - Wastewater Details provides further details on each wastewater stream considered in the generation of the computer model.

Table 8 - Wastewater Details

Stream	**Source/Treatment Alternatives**	**Discussion**
Oily Wastewater	Desalter/High volume poor quality, high oil and grease, BOD/COD, and Cl-. (See Table 9 - Oily Wastewater Treatment Efficiencies)	This is the worse quality water produced in the entire process and requires the most treatment.
Sour Water	Sour Water is produced in the upgrading process from water and condensate which comes in contact with the bitumen. It is very high in sulphur and ammonia. It is collected from all the process locations and treated centrally in the sour water strippers.	The removal of both sulphur and ammonia are pH and temperature dependent, with sulphur removed at low pH and ammonia at higher pH. One or two strippers can be used. If one stripper is used it is operated at a near neutral pH which can result in suboptimal treatment and sulphur and ammonia left in the stripped water making its treatment for discharge or reuse more difficult.
Stripped Sour Water	High volume, high quality wastewater from the sour water stripper, high in ammonia, sulphur, nitrates and BOD/COD. (See **Table 10 - SSW Characteristics Treatment Efficiencies)**	Quality of wastewater is highly dependent on efficiency of operation of the sour water strippers, and if a single or dual stripping tower is used.
Combined High TDS (RO & IX Reject)	High volume high TDS. Large portion is RO reject with high dissolved solids but minimal suspended solids. Concerns include concentrated raw water phosphorus and chemical additives. (See **Table 11 - High TDS Waste Treatment Efficiencies**)	Sent to Evaporator or other disposal alternative.
Cooling Tower Blowdown	Moderate volume which is a concentration of the cooling tower inlet; additional suspended solids will accumulate from the air.	Sent to biological treatment due to high phosphorus, (and potentially hydrocarbons as a result of exchanger leakage) or recycled to

Stream	Source/Treatment Alternatives	Discussion
		the desalter.
BFW Preparation	The BFW preparation regeneration stream is combined with NaOH/HCl for pH neutralization. Normally no biotreatment is required.	After neutralization can be recycled into process.
HP Boiler Blowdown	Small Volume Low Strength The main pollutants and composition of the first stream are COD: 100 mg/l N-Kj; 0 - 30 mg/l PO4; 0 - 10 mg/l.	Low volume thus minimal effect on wastewater treatment; should be sent to biological treatment.

Table 9, Table 10 and Table 11, give standard water quality parameters entering and exiting each of the processes discussed in this section.

4.4 Oily Water Treatment

The majority of oily wastewater is produced in the desalting process. Oily wastewater is also produced in other areas of the upgraders such as slops and drains, but these quantities are generally smaller on average, and have not been considered in this analysis.

Treatment of oily water is a standard process common across industry. Oily water is first sent to an API gravity separator, followed by Dissolved Air (or Gas) or Induced Air (or Gas) Flotation (DAF/AIF or DGF/IGF) which generates tiny air (or gas) bubbles. The bubbles adhere to small oil particulates and float to the top of the tank where they are skimmed off.

Following floatation, oily wastewater can be combined with other waste streams and treated biologically.

Table 9 lists oily water qualitative characteristic ranges, and the treatment capabilities of each piece of equipment.

Table 9 - Oily Wastewater Treatment Efficiencies

		Untreated	API Separator			IGF/DGF			Conventional Activated Sludge			Activated Sludge with UF + RO		
		Range	Inlet Range	% Reduction	Outlet Range	Inlet Range	% Reduction	Outlet Range		% Reduction	Outlet Range	Inlet Range	% Reduction	Outlet Range
Temperature	°C	30-60	30-60	NA	30-60	30-60	NA	30-60	30-40	NA	30-40	30-40	NA	30-40
pH		7-8	7-8	NA	7-8	7-8	NA	7-8	7-8	NA	7-8	7-8	NA	7-8
TDS	mg/L	150-5000	150-5000	NA	150-5000	150-5000	NA	150-5000	150-5000	NA	150-5000	150-5000	NA	150-300
TSS	mg/L	300-800	300-800	67%-75%	100-200	100-200	80%-75%	20-50	20-50	75%-80%	5-10	20-50	>95%	<1
O&G	mg/L	3000-5000	3000-5000	90.0%	200-500	200-500	90.0%	10-30	10-30	95%-90%	2-5	30-50	>97%	<1
BOD	mg/L	300-500	900-1400	50.0%	450-700	450-700	30.0%	300-500	300-500	90.0%	20-30	300-500	90.0%	<15
COD	mg/L	300-1200	1700-3400	50.0%	850-1700	850-1700	30.0%	600-1200	600-1200	73%-80%	80-100	600-1200	73%-84%	<80
TOC	mg/L	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS
Hardness	mg/L as CaCO3	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS
M Alkalinity	mg/L as CaCO3	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	NS
Cl-	mg/L	50-2000	50-2000	0.0%	50-2000	50-2000	0.0%	50-2000	50-2000	0.0%	50-2000	50-2000	0.0%	50-200
NH3	mg/L	20-50	50-100	0.0%	50-100	50-100	0.0%	50-100	50-100	85%-94%	<3	50-100	85%-94%	<3
P	mg/L	NS	NS	0.0%	NS	NS	0.0%	NS	NS	0.0%	<0.5	NS	0.0%	<0.1
Cyanides	mg/L	1-3	1-3	0.0%	1-3	1-3	0.0%	1-3	1-3	95%-98%	<0.05	1-3	95%-98%	<0.05
Phenols	mg/L	5-20	5-20	0.0%	5-20	5-20	0.0%	5-20	5-20	80%-95%	<0.5	5-20	80%-95%	<0.5
H2S	mg/L	5-10	5-10	0.0%	5-10	5-10	0.0%	5-10	5-10	>99%	<0.05	5-10	>99%	<0.05

Note:

If the biological treatment inlet consists of just the oily wastewater stream (no dilution brought by other streams such as SSW, CT blowdown, etc.), then the required performances for the biological treatment (for BOD and COD), should be higher to meet the final here specified limits.

4.5 Biological Treatment

The other wastewater streams, including SSW, boiler blowdown, gasifier wastewater, and water treatment, are generally of a higher quality than oily wastewater. For these streams, BOD/COD, N, P, Oil and Grease and other parameters can be treated biologically in a process which includes biological nutrient removal. There are some parameters including chloride and a number of other dissolved constituents which cannot be removed in a bioreactor. These parameters must be considered individually. Table 10 illustrates the removal efficiency of these parameters. One particular parameter of concern is dissolved solids, which are concentrated in many of the water treatment and upgrading processes, but are typically low enough to be discharged to the river.

There are a number of biological treatment alternatives and the principles behind each process are similar. Specific biomasses are built up which consume BOD/COD and nutrients according to residence time and internal recycle rates. Contaminants are also removed through oxidation and adsorption onto the biomass. Independent of biological treatment, the additional biomass which has built up feeding on the biomass and nutrients in the wastewater must be removed from the wastewater prior to discharge. There are two alternative technologies for solids removal: Clarification and Ultrafiltration.

4.5.1 Clarification

Clarification removes solids in the bioreactors by gravity settling and sludge blanket filtration. Clarification works well for the removal of most parameters of concern, but is limited in the level of phosphorus capable of being removed, which must be maintained at or above 0.5 mg/L to ensure a viable biomass in the bioreactor.

4.5.2 Ultrafiltration (MBR)

Bioreactors using ultrafiltration operate using the same biological principles as clarification. However, rather than removing biomass by gravity settling and sludge blanket, this process strains the accumulated biomass out of the treated liquid through micropores. This process is able to produce effluent with less suspended solids than clarification and can operate with phosphorus levels as low as 0.1 mg/L while maintaining a viable biomass. It must be noted that although ultrafiltration systems provide a higher quality effluent, few systems are in refinery service and these systems are significantly more expensive to install and maintain than clarification based systems.

Table 10 - SSW Characteristics Treatment Efficiencies

Parameter			Conventional Activated Sludge or Biofilter			Activated Sludge with UF		
		Range	Inlet Range	% Reduction	Outlet Range	Inlet Range	% Reduction	Outlet Range
Temperature	°C	30-35	30-35	NA	30-50	30-35	NA	30-50
pH		7-8	7-8	NA	7-8	7-8	NA	7-8
TDS	mg/L	50-150	50-150	NA	50-150	50-150	NA	50-150
TSS	mg/L	10-20	10-20	50.0%	5-10	10-20	>90%	<1
O&G	mg/L	5-20	5-20	80%-75%	1-5	5-20	>80%	<1
BOD	mg/L	100-300	100-300	80%-90%	20-30	100-300	80%-90%	< 15
COD	mg/L	200-500	200-500	60%-80%	80-100	200-500	60%-80%	< 80
NH3	mg/L	40-80	40-80	>92%	<3	40-80	0.0%	<3
NO3	mg/L	NS	NS	0.0%	NS	NS	0.0%	5-15
TKN	mg/L	NS	NS	0.0%	NS	NS	0.0%	NS
P	mg/L	Minimal	Minimal	0.0%	<0.5	Minimal	0.0%	<0.1
Cyanides	mg/L	-	-	-	-	-	-	-
Phenols	mg/L	20-80	20-80	>95%	<1	20-80	0.0%	<1
H2S	mg/L	10-40	10-40	>99.5%	<0.05	10-40	0.0%	<0.05
Nitrate Nitrogen	(mg/L)	NS	NS		NS	NS		NS
Total Organic Nitrogen	(mg/L)	NS	NS		NS	NS		NS
Total Phosphorus	(mg/L)	NS	NS		NS	NS		NS
Total Dissolved Phosphorus	(mg/L)	minimal	minimal		minimal	minimal		minimal

1. The Biological process will remove some metals through biomass adsorption.

Table 11 - High TDS Waste Treatment Efficiencies

Parameter		High TDS Waste		Evaporation/Crystallization Condensate		
		Ref.	Range	Inlet Range	% Reduction	Outlet Range
Temperature	°C		30-40	30-40	0.0%	30-40
pH			7-8	7-8	0.0%	7-8
TDS	mg/L		500-2500	500-2500	>98%	<10
TSS	mg/L		50-100	50-100	>98%	<1
O&G	mg/L		<5	<5	>90%	<1
BOD	mg/L		5-150	5-150	>90%	<1
COD	mg/L		100-500	100-500	>90%	<1
TOC	mg/L		<100	<100	>90%	<1

Notes:
1. Metals and other parameter can be removed to greater than 99%, but must be evaluated individually.

4.6 Discharge Alternatives

There are four discharge alternatives; river discharge after biological treatment, river discharge with enhanced chemical treatment, deep well disposal and evaporation crystallization.

As the level of recycling within a particular facility increases, the concentration of dissolved solids also increases. This increase in dissolved solids is the primary concern behind the drive to zero discharge solutions like evaporation crystallization or deep well disposal. Deep well disposal and evaporation ensure that contaminants do not reach the surface environment.

5.0 ASSESSMENT OF RECYCLE OPTIONS

5.1 Recycle Options

Recycling represents significant opportunities for resource conservation and, in some cases, improved economics ranging from decreased sizes of intakes through water treatment equipment. Some recycle is already standard within refining and upgrading (i.e. use of stripped sour water (SSW) for De-salting).

Table 3 - Cooling Water Quality Limits (suggested by Manufacturers) gives the upper limits for water quality parameters within the cooling towers.

Section 5.1.1 Recycle Case History provides a brief history of recycling within refinery in the United States which has been operating since 1995, illustrating the recycle of process water is not a new practice. Sections 5.1.2 and 5.1.3 outline recycle alternatives.

5.1.1 Recycle Case History

The Cheveron El Segundo Refinery in California uses reclaimed water as make up water for their cooling towers. The water supply contains 10 to 30 ppm ammonia as NH_3 and originally contained 4 to 20 ppm phosphate as PO_4. The PO_4 level has been reduced by the use of iron-based coagulants instead of alum in their clarifier. Phosphate is actually added now as a supplement to provide the main corrosion inhibitor for carbon steel. A nitrification system was installed to remove ammonia. Sodium hypochlorite is used as the microbiological control agent. Ninety-five percent of the total make up is recycle water. The recycle program has been in place since 1995. (Ultrapure Water Journal, December 2007 Volume 24 Number 9)

5.1.2 Recycle of Combined Biological Effluent to Primary Treatment

Combined biologically treated effluent can be recycled using filtration and reverse osmosis membranes. This generates a high quality recycle stream which can be sent to the end of primary treatment for reuse in the cooling towers, significantly reducing the volume of water needed.

The disadvantage of this recycle alternative is that the concentration of dissolved solids in the RO reject may reach a level where the dissolved solids cannot be put back into the treatment system and must be deep well disposed or evaporated, both expensive, and removes water from the water cycle.

5.1.3 Recycle of SSW for Cooling

SSW is a high quality waste which, if separated and treated biologically, can be recycled and used in the cooling towers. The recycling of SSW has the ability to significantly reduce both the raw water required and the wastewater discharged. Unlike recycle of the combined bioreactor effluent, this stream does not need to be treated with reverse osmosis requiring special discharge. Unfortunately, when recycled without first passing through reverse osmosis, a higher concentration of dissolved solids is sent to the cooling tower and the cooling tower blowdown capacity must be increased.

5.2 Results/Conclusions

A number of wastewater treatment scenarios are technically feasible for biological treatment and recycle. Economic analysis is required to decide which alternatives are feasible.

6.0 WASTEWATER TREATMENT BEST AVAILABLE TREATMENT ECONOMICALLY ACHIEVABLE (BATEA) - PROCESS ALTERNATIVES

To determine wastewater treatment BATEA it is insufficient to examine only wastewater treatment technologies. A number of process scenarios must be evaluated, each with individual hydrocarbon and water treatment considerations, and multiple input variables to determine wastewater treatment BATEAs. Some of the factors which must be considered include:

- Bitumen characteristics and volume,
- Source water characteristics and volume,
- Hydrocarbon process,
- Water treatment process,
- Wastewater treatment process,
- Available disposal scenarios, and
- Cost factors associated with each scenario.

Due to the complexity resulting from the number of variables, a computer simulation was developed to model flows.

Although care has been taken to build the simulation, it is a simple model of upgrading water/wastewater demand allowing users to conduct a quick first level analysis to understand the relationship between processes and flows.

As specific questions are asked of industry, their responses can be fed into the model resulting in an improved understanding of upgrader water demand.

The computer simulation allows flows to be changed and processes to be added or removed by the simulator operator with minimal recalculation.

Based on the user's flow inputs, effluent quantities are generated by the simulation for each configuration modeled. It is important to note that wastewater quantity is modeled. Wastewater quality is considered separately, based upon the flow generated by the model and the resulting waste concentrations and wastewater parameter changes due to different treatment options. Figure 4 shows a screen shot of the simulator base process flow diagram for information purposes. For number and flows users should refer directly to the simulator.

To develop a consistent model which allows the comparison across project and upgraders, all water quantities are presented as a mass percentage of the incoming bitumen.

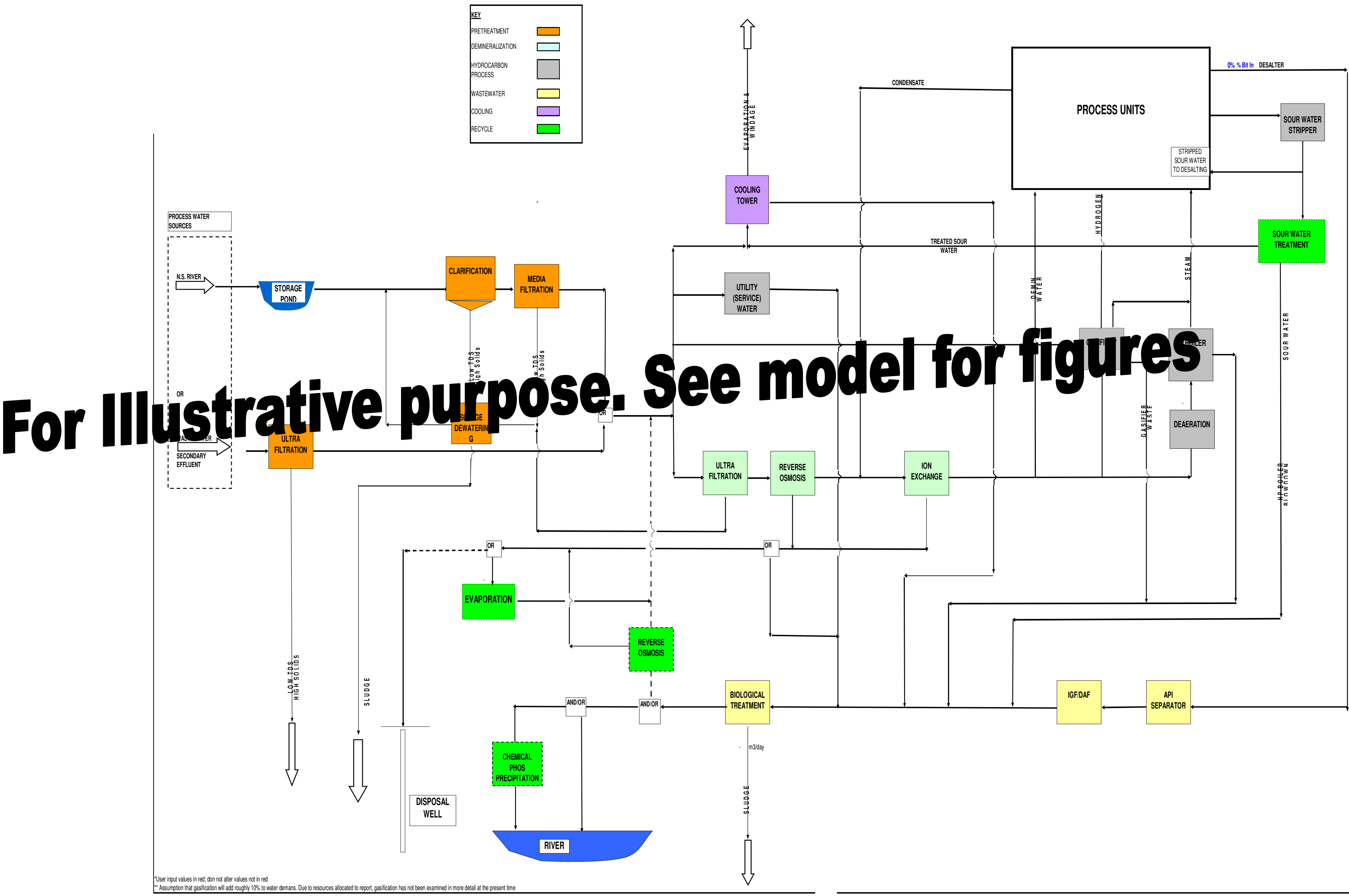
6.1 Step 3 Methodology

For each configuration, input and output flows were modeled to determine the capacity of each flow stream. Based upon the modeled flow and the typical water qualities, capital and operational costs were generated.

The base configuration assumed:

- Upgrading consisting of no desalting, no gasification and using delayed coking as the primary means of upgrading.
- Water treatment consisting of river water with settling, clarification and filtration as primary treatment, and UF, RO and IX treatment for boiler feed water.
- The wastewater treatment consisting of API and IGF treatment of Oily Waste followed by Activated Sludge (BNR) with clarification and discharge to the river.

Figure 4 - Simulation Screen Shot



6.2 Configurations

A total of eleven configurations have been modeled. These eleven configurations are based on six scenarios. Each scenario may include up to three options. Table 12 - Wastewater Configurations Modeled shows the six scenarios, each with between one and with three options:

- A. No Desalting,
- B. Desalting, and
- C. Zero Discharge or Chemical Treatment.

Table 12 - Wastewater Configurations Modeled

	Scenario	A. No Desalting	B. Desalting	C. With Evaporation
1.	**Base Scenario** A. Combined Activated Sludge Biological Nutrient Removal, and final clarification of; Oily WW, SWW , cooling & water treatment waste, → discharge to river B. Desalter wastewater to be pretreated with API → IGF/DGF, and subsequently to combined treatment	Yes	Yes	
2.	**Base Scenario w/ Ultrafiltration** A. & B. Same as Scenario 1A & B with the exception of the replacement of the final clarifier by submerged ultrafiltration.	Yes	Yes	
3.	**Base Scenario w/ SSW Recycle to Cooling Towers** A. & B same as Scenario 1A & B but rather that combined treatment of all wastewater SSW is treated separately and recycled to the cooling towers. C. Evaporation of waste products so that there is no discharge to the river.	Yes	Yes	Yes
4.	**Base Scenario w/ Combined Bioreactor Recycle to Primary Water Treatment** A & B same as scenario 1A & B with recycle of effluent rather than discharge to the river. C. Evaporation of waste products so that there is no discharge to the river.	Yes	Yes	Yes
5.	**Gasification** - Base Scenario with Gasification	Yes		
6.	**Without Evaporative Cooling** Base Scenario with evaporative cooling removed	Yes		

7.0 BATEA PROCESS RESULTS

This section discusses the simulation results considering flow economics and water qualities.

A total of eleven configurations were modeled to generate the data required for BATEA analysis.

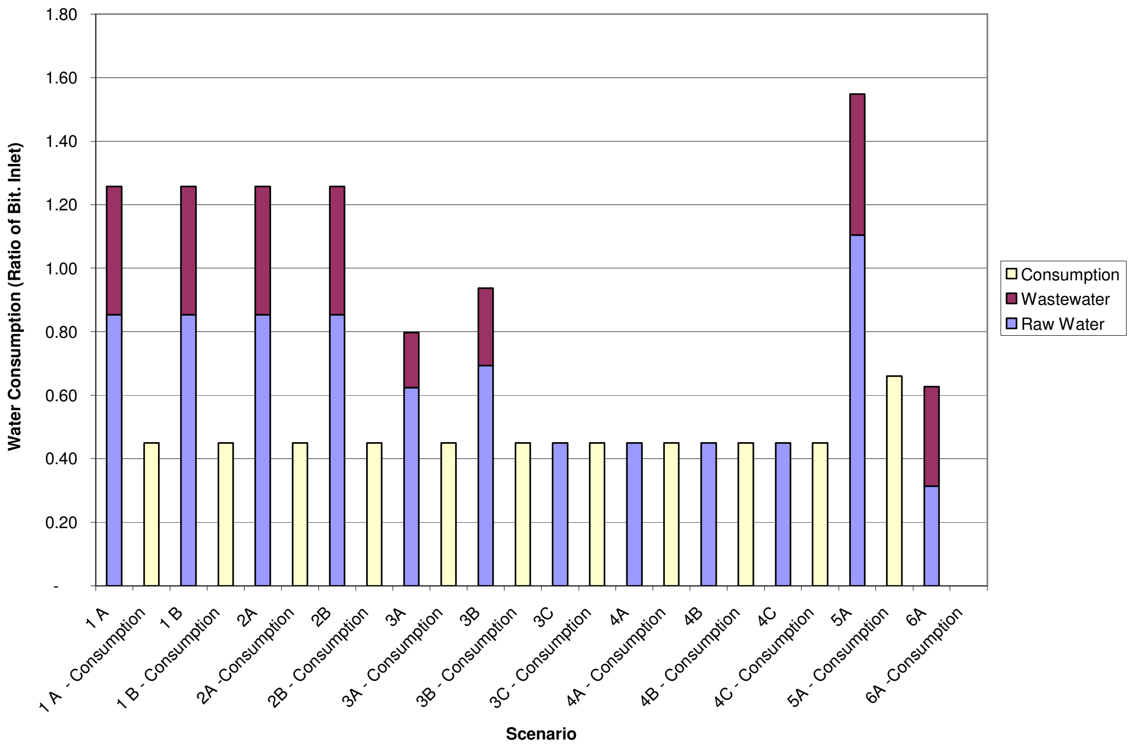
Water and wastewater number and relative costing and water of each configuration including capital and operational cost is summarized in, and illustrated in **Figure 5 – Relative Flows Chart**. To simplify the presentation, only flows and totals have been shown. Flows are presented as flow per barrel of bitumen (pbb). By presenting flow as pbb, users are able to easily compare water demand number across facilities.

Costing is presented as “relative” costing, in which all costs presented are a ratio of a base scenario which in this case has been assumed to be biological treatment followed by clarification and discharge to the river. Operational costs have been calculated using a discount rate of 15 percent.

To give this real world meaning, the European Commission Integrated Pollution Control 2003 Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries estimates that a basic refinery wastewater system for 125 m^3/hr would require a capital cost of 15 million Euros and an operational cost of 1.5 Euros/m^3. This translates to 100,000 barrels per day, and with Canadian dollars converting from Euros at 0.75:1 (2003 rate) and assuming a capacity of 100,000 bpd, a capital cost of 23 million Canadian dollars , and a operational cost of 2.3 \$/m^3 with a net present value of 15.6 million.

Also included are ratios of additional dollars spent to water conserved for scenarios 3& 4 enabling users to evaluate the benefit of various alternatives.

Figure 5 - Relative Flows Chart



The modeling results are broken into two categories: those dictated by the bitumen upgrading process; and alternatives available within the wastewater treatment and recycle process.

Table 13 - Summary of Relative Flows and Costs

			No Desalting (A)	Desalting (B)	Evaporation (C)
1.	Base Scenario	FLOW			
		Raw Water	0.85	0.85	
		Wastewater	0.40	0.40	
		Water Consumption	0.45	0.45	
		COST			
		CAPEX	0.66	0.80	
		OPEX	0.34	0.34	
		TOTAL	1.00	1.14	
2.	Base Scenario w/ Ultrafiltration	FLOW			
		Raw Water	0.85	0.85	
		Wastewater	0.40	0.40	
		Water Consumption	0.45	0.45	
		COST			
		CAPEX	0.88	0.95	
		OPEX	0.37	0.38	
		TOTAL	1.26	1.33	
3.	Base Scenario w/ SSW Recycle to Cooling Towers	FLOW			
		Raw Water	0.62	0.69	0.45
		Wastewater	0.17	0.24	-
		Water Consumption	0.45	0.45	0.45
		COST			
		CAPEX	0.66	0.80	1.15
		OPEX	0.34	0.34	0.60
		TOTAL	1.00	1.14	1.74
		Ratio $ spent to H2O saved	1.0	0.9	1.8
4.	Base Scenario w/ Combined Bioreactor Recycle to Primary Water Treatment	FLOW			
		Raw Water	0.45	0.45	0.45
		Wastewater	-	-	-
		Water Consumption	0.45	0.45	0.45
		COST			
		CAPEX	1.23	1.37	1.56
		OPEX	0.76	0.76	0.79
		TOTAL	1.99	2.14	2.35
		Ratio $ spent to H2O saved	2.5	2.8	3.3
5.	Gasification	FLOW			
		Raw Water	1.10		
		Wastewater	0.44		
		Water Consumption	0.66		
		COST			
		CAPEX	0.72		
		OPEX	0.37		
		TOTAL	1.08		
6.	With Aerial Cooling Note: there cost consider only wastewater treatment costs and not the cooling cost.	FLOW			
		Raw Water	0.31		
		Wastewater	0.31		
		Water Consumption	-		
		COST			
		CAPEX	0.41		
		OPEX	0.21		
		TOTAL	0.63		

More detailed figures are available in Appendix C – Detailed Simulation Results & Appendix D – Individual Results.

7.1 Upgrading Process Alternatives

Upgrading process alternatives are dictated by the quality of the incoming bitumen and the selected upgrading technologies. These alternatives are not within the scope of BATEA, rather are dictated inputs to the BATEA scenarios. The process alternatives include desalting versus no desalting which is dictated by incoming bitumen quality, and gasification versus no gasification.

7.1.1 Scenario 1 A&B No Desalting, Scenario 1a, versus Desalting Scenario 1b

The requirement for desalting is dictated by the quality of the incoming bitumen. If desalting is part of the upgrading process, the total cost of wastewater treatment increased by 14 percent from 100 percent (1A) to 114 percent (1B). In the desalting scenario the total volume of wastewater required stays the same, but the volume of oily wastewater increased.

As desalters are able to use recycled stripped sour water, they do not require any additional fresh water, but result in the conversion of SSW to oily wastewater. Oily wastewater requires more treatment that SSW, thus the expected increase in treatment cost.

7.1.2 Scenario 5 - Gasification

Gasification, if present, is a significant contributor to water demand and wastewater treatment requirements. Average water and steam inlet and outlet demands for the gasification alternative are shown in Table 14.

Table 14 - Average of Gasifier Water Demands

Parameter	**% Inlet Bitumen Mass**
Water In	50%
Steam In	9%
<u>Total Additional In</u>	<u>59%</u>
Water Out	8%
Steam Out	30%
<u>Total Additional Out</u>	<u>38%</u>

Note: The difference between the additional inlet water and steam and out let steam is the volume converted to hydrogen.

Gasification, if included, increases the raw water demand from 85 percent per barrel bitumen (pbb) (1a) to 110 percent (pbb) (5a) per barrel of bitumen. The increased water demand is due to increased water consumption by the gasifier for the production of hydrogen, steam and some wastewater. As a result of the addition of gasification wastewater, treatment, capital and operational costs increase from 100 percent (1a) to 108 percent (5a).

7.2 Wastewater Treatment, Recycle & Other Process Alternatives

With the exception of large volumes of oily wastewater generated if there is a desalter, wastewater and recycling process alternatives are not dictated by the incoming bitumen quality or by bitumen processing technology. Each of the alternatives focused on in the BATEA analysis had varying economic and water savings advantages.

7.2.1 Scenario 2, Base Scenario with Ultrafiltration

Scenario 2, Base Scenario with Ultrafiltration involves changing the clarifier at the end of the activated sludge bioreactor with biological nutrient removal to ultrafiltration membranes directly in the bioreactor (also known as MBR).

The use of ultrafiltration does not reduce volume of water for scenario 2a nor 2b, and adds to the overall cost of the treatment system by 26 percent without desalting and 33 percent with desalting. However, there are advantages including the ability to biologically treat effluent to phosphorus levels to 0.1 mg/L rather than 0.5 mg/L.

7.2.2 Combined versus Separate Treatment without Recycle

According to the relative costing analysis, separate treatment, Scenario 3a, (when SSW is treated in a separate bioreactor prior to mixing the SSW with the Oily Wastewater) had no effect on treatment costs if recycling was not required. When the SSW was treated separately and recycled water, savings would be realized (see Recycle & Reuse configurations for details).

7.2.3 Scenario 3 & 4, Recycle and Reuse Configurations

Two basic recycle and reuse configurations were evaluated: recycle from the combined bioreactor, Scenario 4, (using only one bioreactor for both SSW and Oily wastewater); and independent recycle of the SSW, Scenario 3, where SSW is treated independently from oily waste. Although both alternatives conserve water, there are significant differences in both the volume of raw water needed, and the cost for each alternative.

Independent Recycle of SSW, Scenario 3a.
The independent bio treatment of SSW and subsequent recycle to the cooling tower results in water saving of 23pbb over the base scenario, 1a. However, this would be limited to providing recycle flow only to the cooling towers.

Recycle of SSW independently requires no additional treatment over the base scenario. However, it requires separate and parallel biological treatment of the SSW and oily waste, with the SSW being recycled to the cooling towers after biological treatment.

According to the model, Scenario 3a would require no additional cost, but logic implies some additional, if minor, cost associated with providing two separate parallel treatment trains even if capacity remains the same.

Combined Recycle, Scenario 4a
Combined recycle, Scenario 4a, results in a water savings of almost 40pbb, but costs double the base Scenario, 1a, and is a zero, or minimal, discharge scenario.

The additional water saving is realized as all wastewaters generated are now recycled, rather than only SSW. Recycle from the combined bioreactor requires the added cost of biologically treating the entire wastewater flow generated and subsequent treatment by RO to enable it to be recycled. The addition of the RO system adds further complexity and expense as the reject from the RO system is sufficiently concentrated and it no longer has the option of being discharged to the river. The RO reject must be further treated through via evaporation or some other alternative for surface discharge.

Recycle with Desalting, Scenarios 3b &4b
When desalting is added, but there is no recycle, the total volume of water remains the same (see Scenarios 1a &1b). When recycle is added, and there is desalting, the volume of water required increased (Scenario 3b relative to Scenario 3a) since SSW is used in the desalting process and the lost flow is not available for recycle. With combined recycle and desalting, the recycle water volume does not change. In both cases, the cost of treatment increases due to the additional treatment equipment required to treat oily wastewater.

7.2.4 Scenario 6 - Evaporative Cooling

Evaporative cooling is the single largest user of water in the upgrading process, evaporating 35pbb to over 90pbb incoming water volumes. Evaporation losses as high as 90 percent are realized when the selected process moves towards zero discharge, and evaporation becomes one of few locations where water is lost from the process. Blowdown rates usually average 20 percent of cooling tower inlet flows and is one of the largest wastewater streams.

For the base scenario 1a, the elimination of the evaporative cooling system results in a reduction in water demand from 85pbb to 31pbb and a drop in wastewater generated by 9pbb. This results in a reduction in wastewater treatment cost of 37 percent without considering savings in water treatment costs. However, these costs are more than likely offset by the additional cost of implementing only aerial cooling, and additional analysis is required to examine the economics and treatment feasibility.

7.2.5 Scenario 3c and 4c - Zero Discharge

Two zero discharge configurations were modeled:

- Recycle of SSW directly to cooling (3c)
- Recycle of the combined bioreactor effluent (4c)

Both configurations use near identical quantities of raw water, with the recycle to cooling requiring a slightly higher blowdown rate in the cooling towers. However, while SSW recycle costs 174 percent of base capital, recycle of the combined stream costs 235 percent of the base capital.

The significant additional cost for the zero discharge scenarios is a result of the need for ROs and no surface discharge of the RO reject. Scenario 4C, combined recycle with zero discharge is the most expensive due to the higher volume treated by the RO and its subsequent reject treatment cost.

7.2.6 Disposal Alternatives

Evaporation, and crystallization, and deep well disposal are currently being discussed as solutions. The additional option of Physical/Biological/Chemical Treatment (PBC) is also a viable alternative for disposal so long as dissolved solids concentration do not reach excessive levels.

Considering both capital and operational costs of a project with a 15-year life cycle, the cost of using evaporators versus PBC treatment (if feasible) is almost double. Deep well disposal is more than four times as expensive, assuming off-site well disposal costs in the range of 30 to 40 dollars per cubic meter of fluid.

Thus PCB treatment appears to be the most attractive alternative, but will require higher return flows to the river to minimize concentration of dissolved solids. For deep well disposal costs to be competitive, disposal costs would have to drop to less than five dollars per cubic meter of fluid.

7.2.7 Scenario Water Consumption

From Figure 1 – Project Flow Chart and Table 13 – Summary of Relative Flows and Costs, it can be observed that with the exception of the introduction of gasification and the elimination of evaporative cooling that the consumptive demand will stay the same at 0.45. Although not intuitive, it does make sense as water is ether discharged to the river or recycled, reducing raw water demand, but maintaining a constant consumptive demand. The exception to this the will be in the case of deep well disposal, as all water deep well disposed of is not returned to the river or recycled offsetting raw water demand.

7.3 Waste Streams Benefiting from a Regional System

There are advantages in terms of reliability in a single system and economies of scale in the construction and operation of a regional system. However, these factors need to be balanced against the capital cost of pipelines, taking into account the distances between facilities and the effluent source, and pipeline routes. As a result, it is not possible to predict with any certainty the efficiencies achieved from regional treatment. Therefore, it is recommended that the cost benefit of a single regional system be examined as a separate task.

8.0 COOLING

As illustrated in Table 1 – Upgrader Process Water Demands, and modeled in Scenario 6, cooling is one of the largest demands in the upgrading process. This section describes some Best Practices suggested by the Integrated Pollution Prevention and Control (IPPC) Department of the European Union.

Measures which can be taken in the design phase of wet cooling systems to reduce demand and reduce their impact include:

- Maximum usage of heat exchangers within the process to minimize the need for cooling,
- Selection of the appropriate material for heat exchangers combining both process conditions and cooling water characteristics,
- Selection of the appropriate material for other parts of the cooling system,
- Identification of operational requirements of the cooling system, and
- Selection of feasible cooling water treatment (chemical composition) using less hazardous chemicals or chemicals that have lower potential for impact on the environment.

Measures which can be taken during operation of wet cooling systems to reduce their impact include:

- Recycle of blowdown to the desalter, if dissolved solids are acceptable:,
- Optimization of chemical dosage regimes by:
  - Monitoring of cooling water and systems conditions,
  - Improving the cooling water chemistry by pre-treatment,
  - Mechanical cleaning of the cooling system, and
  - Alternative treatments, such as thermal, UV and side stream filtration.
- Reduction of leakage of process substances into the cooling circuit through:
  - Selection material of equipment for wet cooling systems according to the applied water quality,
  - Operation of the system according to its design,
  - Selection of the right cooling water treatment program, if cooling water treatment is needed, and
  - Monitoring of leakage in the cooling water discharge in recirculating wet cooling systems by analyzing the blowdown.

9.0 CONCLUSIONS

This study is not intended to be exhaustive. However, the upgrader water model should provide a basis for understanding and assessing water demands generated by upgraders, and aid in the development of public knowledge.

A number of conclusions were generated through the process of collecting input data and the constructing and running the upgrader computer model. These conclusions are summarized below:

1. Most upgrader wastewater treatment technologies, with the exception of bioreactor technologies, are established, and vary little. As such, the BATEA opportunities come not from technologies but from what flow streams are treated as combined or individual streams.

2. The consumptive demand of an upgrader is relatively consistent no matter how much recycling is implemented. This demand is primarily a function of the evaporative cooling load, gasification, and the volume of water deep well disposed of.

3. Options are available in the selection of bioreactor technology, however it is clear that nutrient removal including nitrification and denitrification is crucial. The recent introduction of ultrafiltration membranes (MBR systems) in the place of final clarifiers has created opportunities for enhanced treatment, but the use of ultrafiltration membranes have a cost premium and they have almost no track record of application in refining or upgrading applications.

4. Regarding hydrocarbon process considerations, the choice of delayed coking or hydrocracking as a primary process cannot be used as an indicator of additional water demand, as neither process has a significant effect on water demand. The inclusion of a gasifier to produce hydrogen for hydroconversion or other purposes has a larger affect.

5. As a result of the Upgrader BATEA analysis, the following conclusions can be drawn:
    - Recycling process water can reduce the volume of fresh water consumed, but the selection of the process stream recycled has a dramatic influence on the system cost.
    - The greatest cost benefits were achieved through the separate treatment of waste streams prior to recycle. This conclusion is echoed by the European Commission's Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries.
    - An examination of the ratio of raw water saved to additional wastewater dollars spent revealed:
        - Recycle of SSW to cooling captures the greatest value with the lowest ratio of dollars spent, at one, to source water consumed, both with and without desalting. (See scenarios 3a & 3b)
        - Recycle of SSW and zero discharge is next at 1.8 requiring almost double the dollars per units of water conserved. (See scenario 3c)
        - Recycle of combined bioreactor effluent is significantly more at 2.5 through 2.8 times the dollars per unit of water conserved. (Scenario 4)

Table 15 - Dollars Spent to Source Water Reduction

Scenario	Dollars to Source Water Ratio
3a – SWS Recycle – No Desalting	1
3b – SWS recycle – Desalting	0.9
3c SWS recycle – No Desalting, Zero Discharge	1.8
4a - Combined Recycle – No Desalting	2.5
4b – Combined Recycle – Desalting – Zero Discharge	2.8
4c - – Combined Recycle – No Desalting – Zero Discharge	3.3

In conclusion, upgrader wastewater BATEA has revealed that rather than equipment selection, the selection of which flows are recycled is the critical factor.

When examining recycle flow options, the more stripped sour water that can be recycled prior to mixing with oily wastewater the greater the reduction in water demand, and possibly overall treatment costs, for both raw water and wastewater. Wastewater streams which have TDS levels sufficiently low for direct discharge disposal need to consider physical/chemical/biological treatment combinations.

10.0 RECOMMENDATIONS FOR FURTHER STUDY

The following areas are recommended to further study either as information was difficult to obtain in these areas or time was insufficient to fully research their water demands and relative costs.

1. Cooling is the single largest consumptive demand and currently evaporative cooling appears to be the only viable alternative. Further analysis of cooling is required to examine:

    a. Opportunities for the use of heat exchangers in the upgrading process to recover waste heat and reduce cooling loads.
    b. Large scale wet dry cooling systems.
    c. Opportunities for the use of waste low grade heat by other industries in the region.
    d. Cooling system metallurgy selection to reduce the need for treatment chemicals.
    e. Cooling water optimization studies to establish cooling system water demands using best practices.

2. Using secondary effluent as a raw water source for upgrading in Alberta's Industrial Heartland will require piping effluent from the Goldbar Wastewater Treatment Plant to the Heartland is not known. This cost must be determined to establish the feasibility of secondary effluent source water.

3. Stripped sour water is the second largest wastewater source after evaporative cooling. There are a number of options available to treat sour water, and a detailed analysis examining these alternatives, their treatment effectiveness versus additional expense relative to more expensive SSW treatment is needed.

4. Gasifiers are a large consumer of water and produce significant quantities of wastewater. A wide range of values for water demand and wastewater generation are being presented, indicating uncertainty. Additional study is warranted to understand water demand and waste generation.

5. Once North Saskatchewan River water quality objectives are set, a detailed comparison of wastewater treatment and discharge to the river versus recycle is needed to establish optimum recycle rates at which dissolved solid level are not elevated beyond the level of acceptable discharge to the river requiring deep well disposal increasing raw water demand or the need for the introduction of expensive technologies to remove the dissolved solids.

11.0 REFERENCES

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APPENDIX A

UPGRADER PROCESS FLOW DIAGRAMS

Figure 1 Upgrading with Delayed Coking

File: Figure 3-1

AENV - Upgrader Project

Rev			Date		By	Comments
0			21-Oct-07		CJG	Original
1			11-Mar-08		CJG	Final

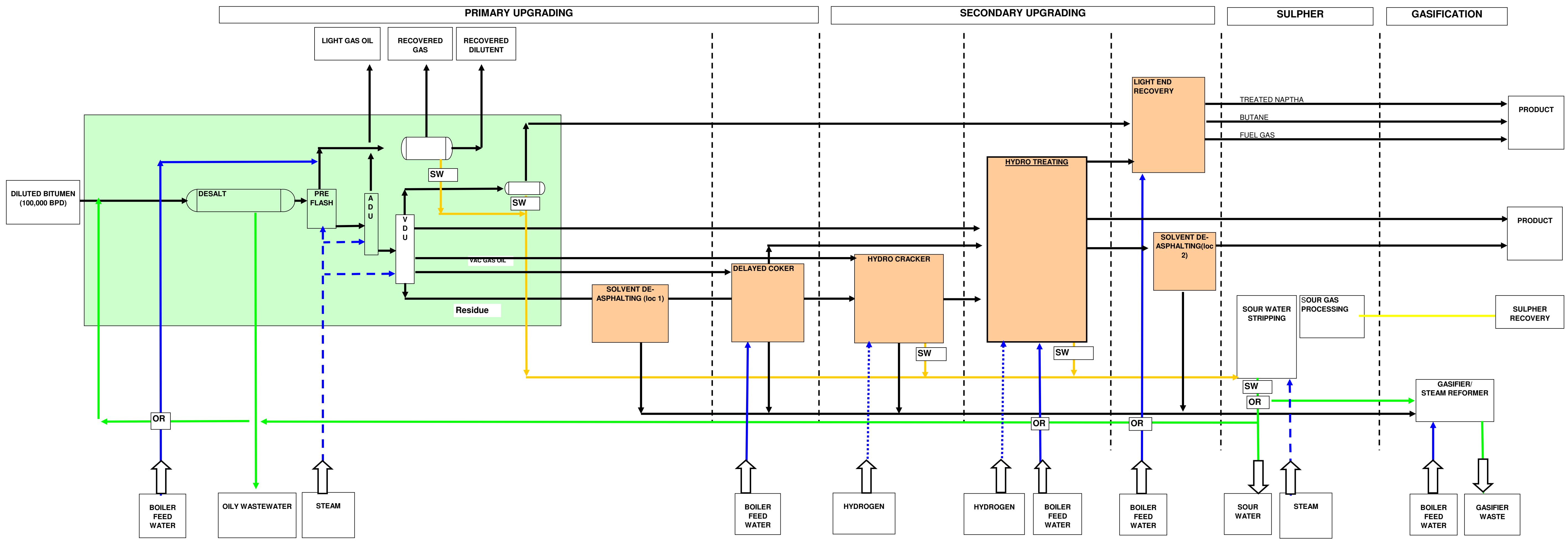
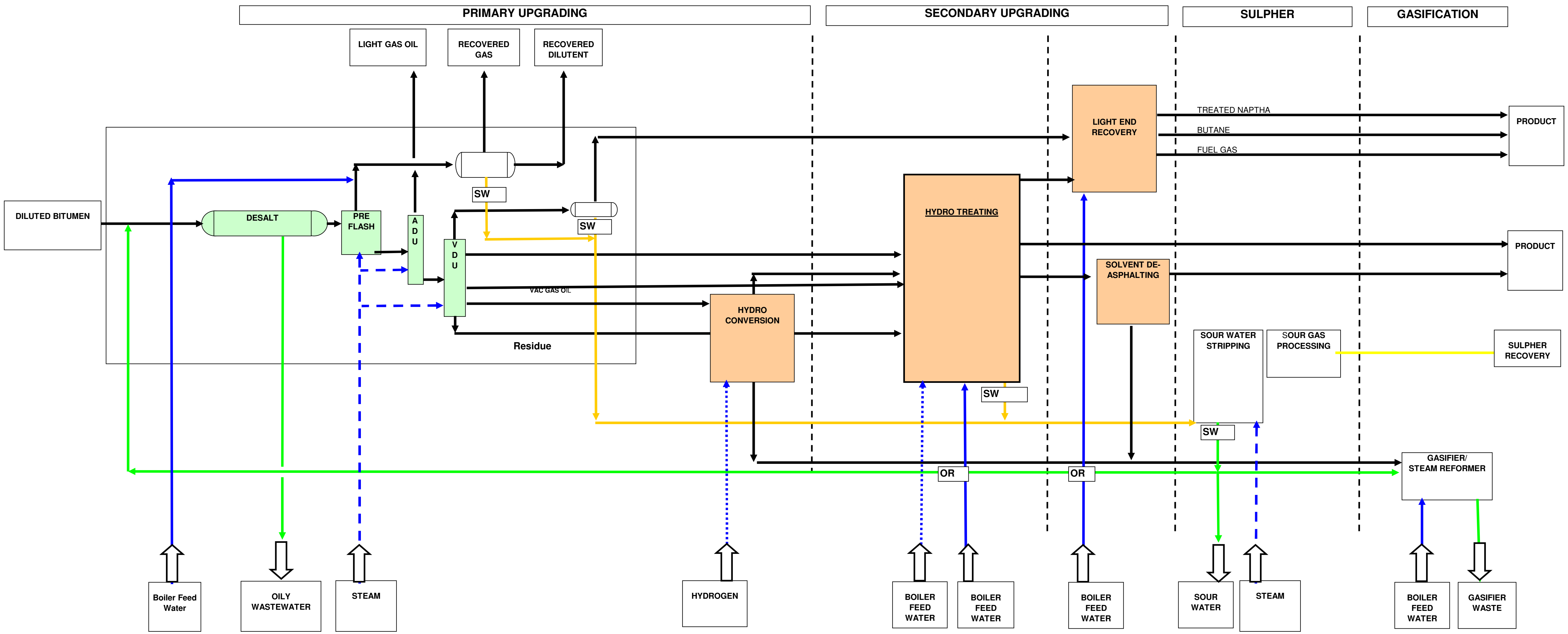


Figure 2 Upgrading with HydroConversion

File: 02.02.010.CAL.01 v.01

AENV - Upgrader Project

Rev			Date		By	Comments
0			21-Oct-07		CJG	Original



APPENDIX B

COMPUTER MODEL

Model Inputs and Outputs

AENV Upgrader

MODEL INPUTS

						Units
Upgrader Capacity					100,000	BPD
					15,898	m^3/day
		RANGE OF VALUES	UNITS	SELECTED VALUE	FLOW	
Is there a Desalter?						
	- Desalter Water In	3-7%	% BB	0%	0	m^3/hr
Is there a Gasifier?						
	- Feed Water Input	35-65%	% BB	0%	0	m^3/hr
	- Steam Input	3-20%	% BB	0%	0	m^3/hr
	- Wastewater Outlet	5-10%	% BB	0%	0	m^3/hr
	- Stream Produced	25-40%	% BB	0%	0	m^3/hr
Steam						
	Steam required by the process	35-50%	% BB	40%	6,359	m^3/hr
	% of Produced steam recaptured as Condensate	70-80%	% Steam Input	75%	11,924	m^3/hr
Boiler Feed Water						
	Boiler feed water sent directly to the process	8-15%	% BB	13%	2,067	m^3/hr
Cooling Tower						
	Evaporation Loss	35-50	% BB	40%	6,359	m^3/hr
	Windage Loss	2-3%	% BB	2%	318	m^3/hr
	% Blowdown	20-25%	% Evap. Loss	20%	3,180	m^3/hr
Water Treatment						
	RO Reject	15-30%	% Inlet to RO	15%	2,385	m^3/hr
	IX Waste	1-3%	% Inlet to IX	1%	159	m^3/hr
	Water Content of Disposed Sludge	5-15%	% BB	0.3%	41	m^3/hr
Bioreactors						
	Water Content of Disposed Sludge	2%	%Inlet To Bio	2.0%	9969%	m^3/hr
Utility Water						
	- Utility Water	0.02	% BB	0.02	31796%	m^3/hr

Recycle Flows

	Value			
% Combined Bioreactor Recycle to Primary	0%	% Bio Eff.	-	m^3/hr
% Combined Bioreactor to Chem Precipitation	0%	% Bio Eff.	-	m^3/hr
Excess Stripped Sour Water to Cooling	0%	% SS Bio Inlet	-	m^3/hr
Recycle RO % reject	0%	% RO inlet	-	m^3/hr
% HTDS Waste to Evap/Deep Well	0%	% HTDS waste	-	m^3/hr
% HTDS Waste to Evap	0%	% HTDS waste	-	m^3/hr
% HTDS Waste t o DeepWell	0%	% HTDS waste	-	m^3/hr

MODEL OUTPUTS

	Value			
Source Water Flow	32%	% BB	5,026	m^3/hr
Oily Wastewater	0%	% BB	-	m^3/hr
Excess Stripped Sour Water	23%	% BB	3,657	m^3/hr
To River	31%	% BB	4,984	m^3/hr
To Evaporation	0%	% BB	-	m^3/hr
To Deep Well	0%	% BB	-	m^3/hr

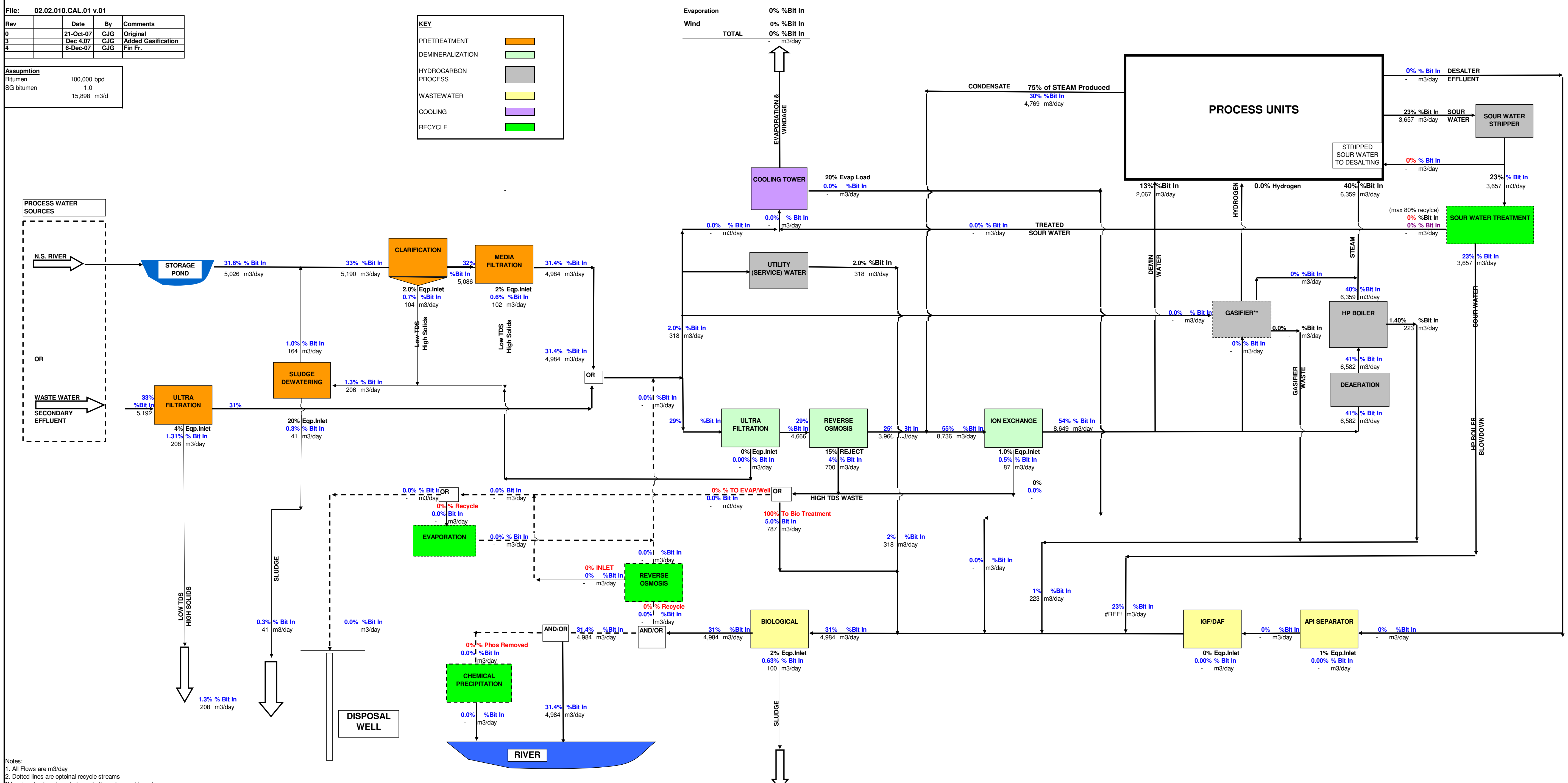
Example PFD

Water Process

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

APPENDIX C

DETAILED BATEA SUMMARY

APPENDIX C - Detailed BATEA Cost Comparison

A RELATIVE COMPARISON OF COSTING

Assumptions:

Bitumen Flow:	
Barrels/day	100,000
m3/day	15,898
Discount Rate	15%

ALTERNATIVE ANALYSIS

A - No Desalting

Senario #1 — Activated Sludge-BNR w/ Clarification and No Recycle Streams

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	85.35%	40.4%	CAPEX	9%	13%		0%	0%		40%	53%		0.0%	0%	0.0%	0%	66%
			OPEX		6%			0%			28%			0%		0%	34%
			TOTAL		19%			0%			81%			0%		0%	100%

Scenario #2 — Activated Sludge BNR w/ ultrafiltration

	RAW/WASTE		ECONOMIC	WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ UF (MBR)	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	85.35%	40.4%	CAPEX	9%		17%	0%		0%	40%		71%	0.0%	-	0%	-	88%
			OPEX			7%			0%			31%		$0	0%	$0	37%
			TOTAL			24%			0%			102%		$0	0%	$0	126%

Scenario #3 — Activated Sludge BNR w/ Clarification and SSW Recycle to Cooling

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	62.35%	17.4%	CAPEX	9%	13%		0%	0%		17%	53%		0.0%	0%	0.0%	$0	66%
			OPEX		6%			0%			28%			0%		$0	34%
			TOTAL		19%			0%			81%			0%		$0	100%

Scenario #4 — Activated Sludge BNR w/ clarification and Bioreactor Recycle to Primary w/ Zero Discharge

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ UF (MBR)	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	45.00%	0.0%	CAPEX	9%	13%		0%	0%		40%	53%		8.1%	41%	40.4%	25%	123%
			OPEX		6%			0%			28%			14%		42%	76%
			TOTAL		19%			0%			81%			55%		67%	199%

Scenario #5 — Gasification

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	110.40%	44.4%	CAPEX	9%	13%		0%	0%		44%	59%		0.0%	0%	0.0%	0%	72%
			OPEX		6%			0%			30%			0%		0%	37%
			TOTAL		19%			0%			89%			0%		0%	108%

Scenario #6 — Aereal Cooling

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	31.35%	31.4%	CAPEX	0%	0%		0%	0%		31%	41%		0.0%	0%	0.0%	0%	41%
			OPEX		0%			0%			21%			0%		0%	21%
			TOTAL		0%			0%			63%			0%		0%	63%

B w/ DeSalting

Senario #1B

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	85.35%	40.4%	CAPEX	9%	13%		7%	23%		37%	44%		0.0%	0%	0.0%	0%	80%
			OPEX		6%			5%			23%			0%		0%	34%
			TOTAL		19%			28%			67%			0%		0%	114%

Scenario #2B

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ UF (MBR)	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	85.35%	40.4%	CAPEX	9%		17%	7%		19%	37%		59%	0.0%	0%	0.0%	0%	95%
			OPEX			7%			6%			25%		0%		0%	38%
			TOTAL			24%			25%			84%		0%		0%	133%

Scenario #3B

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	69.35%	24.4%	CAPEX	9%	13%		7%	23%		17%	44%		0.0%	0%	0.0%	0%	80%
			OPEX		6%			5%			23%			0%		0%	34%
			TOTAL		19%			28%			67%			0%		0%	114%

Scenario #4B

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ UF (MBR)	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	45.00%	0.0%	CAPEX	9%	13%		7%	23%		33%	44%		8.1%	41%	40.4%	17%	137%
			OPEX		6%			5%			23%			14%		28%	76%
			TOTAL		19%			28%			67%			55%		44%	214%

C -Zero Discharge

Scenario #3C

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	45.00%	0.0%	CAPEX	9%	13%		0%	23%		17%	44%		3.5%	25%	17.4%	10%	115%
			OPEX		6%			5%			23%			9%		17%	60%
			TOTAL		19%			28%			67%			33%		27%	174%

Scenario #4C

	RAW/WASTE FLOWS			WASTEWATERS GENERATED													
	Raw Water	WW to Env.		Cooling Water Blowdown			Oily WW Train			SSW Train			High TDS (Evaporator)		Biological Recycle w/ RO		TOTALS
ACTIVATED SLUDGE BNR w/ CLARIFICATION	% Bit	% Bit		% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	BNR w/ UF	% Bit	BNR w/ Clarification	% Bit	$	$
	45.00%	0.0%	CAPEX	9%	12%		0%	23%		17%	37%		3.5%	69%	17.4%	14%	156%
			OPEX		6%			5%			19%			24%		24%	79%
			TOTAL		18%			29%			56%			94%		38%	235%

APPENDIX D

MODEL RUNS

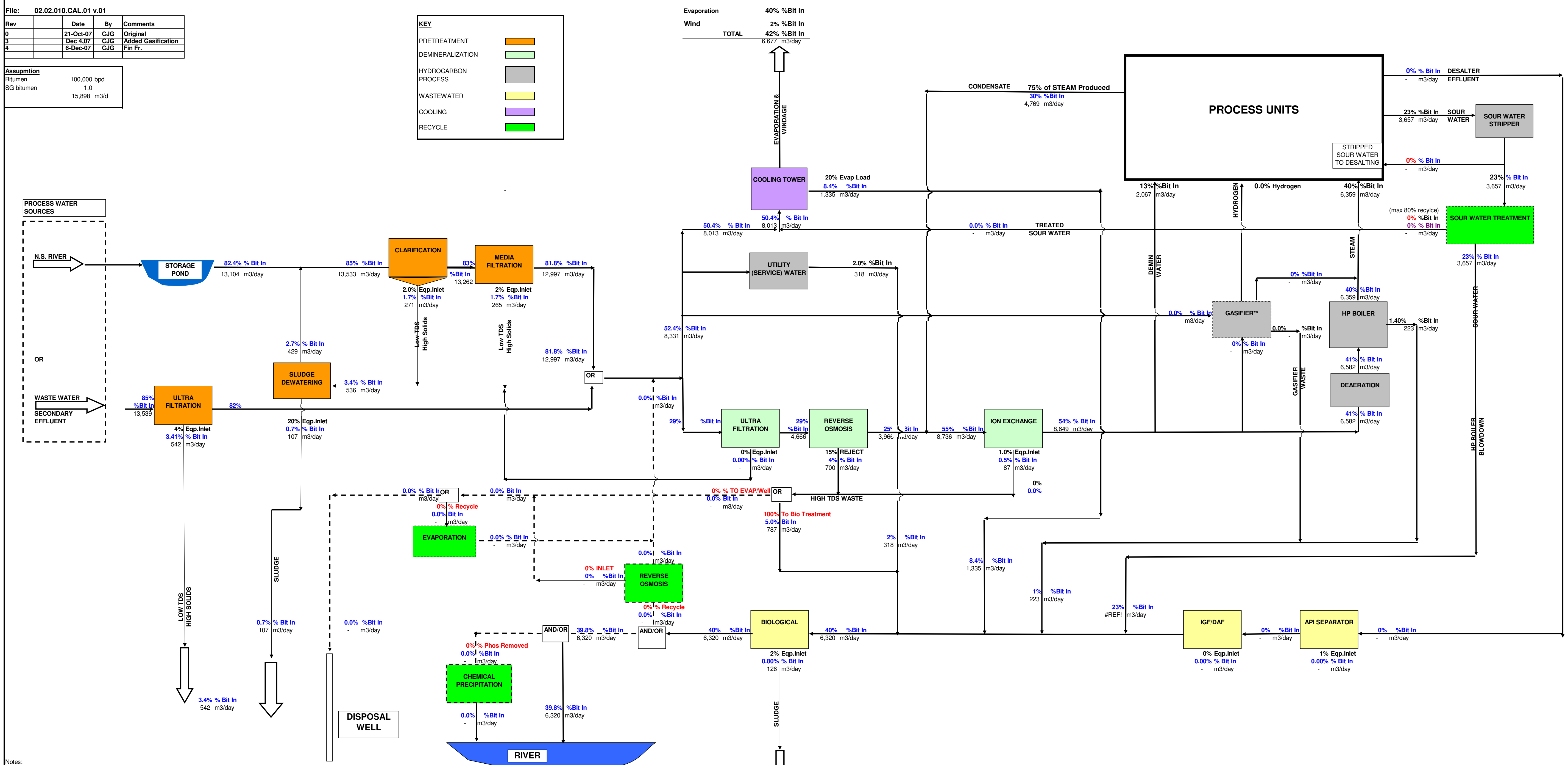
Scenario 1A - Base Scenario

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assupmtion		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

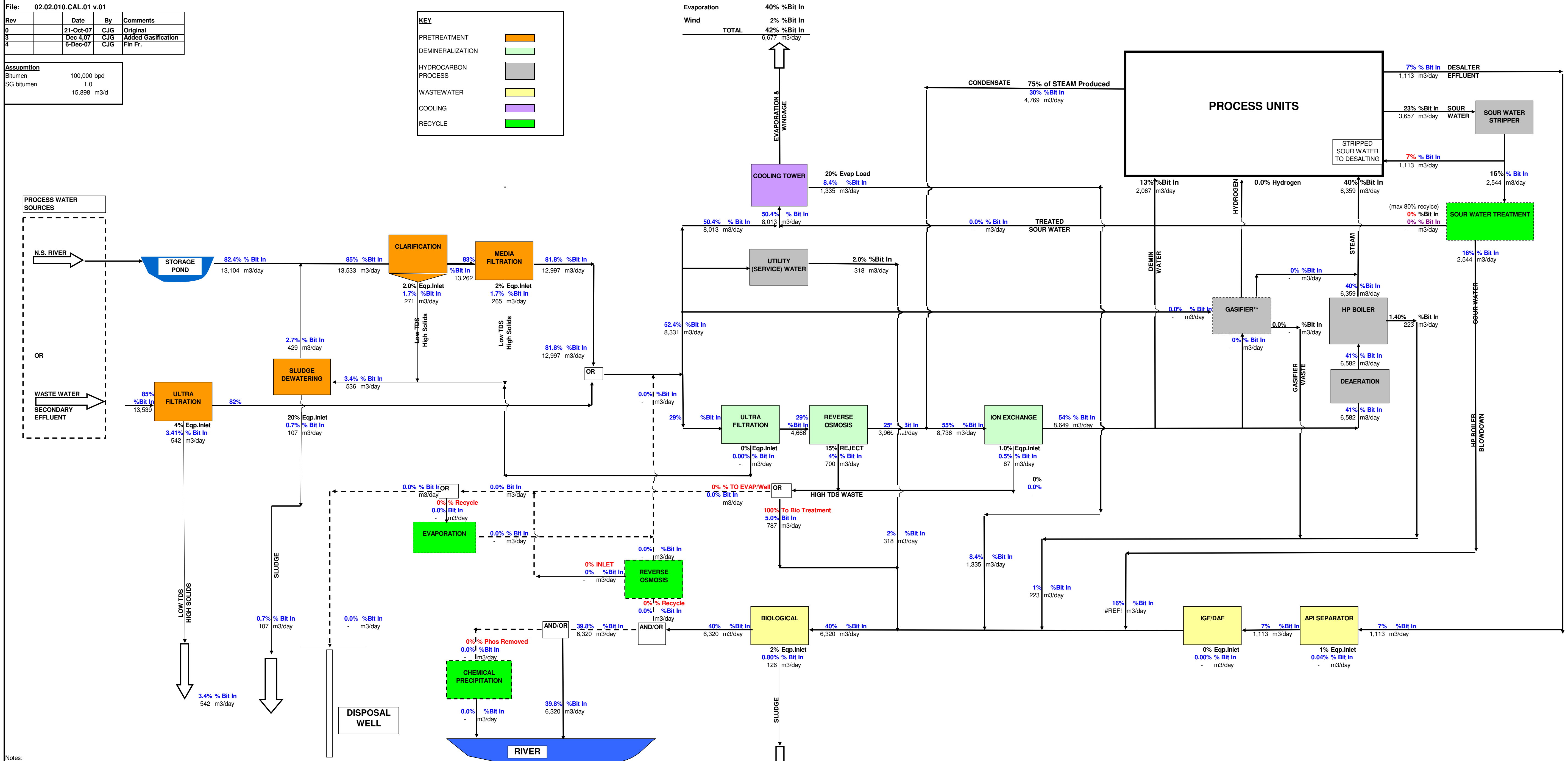
Scenario 1B - Base w/ DeSalting

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

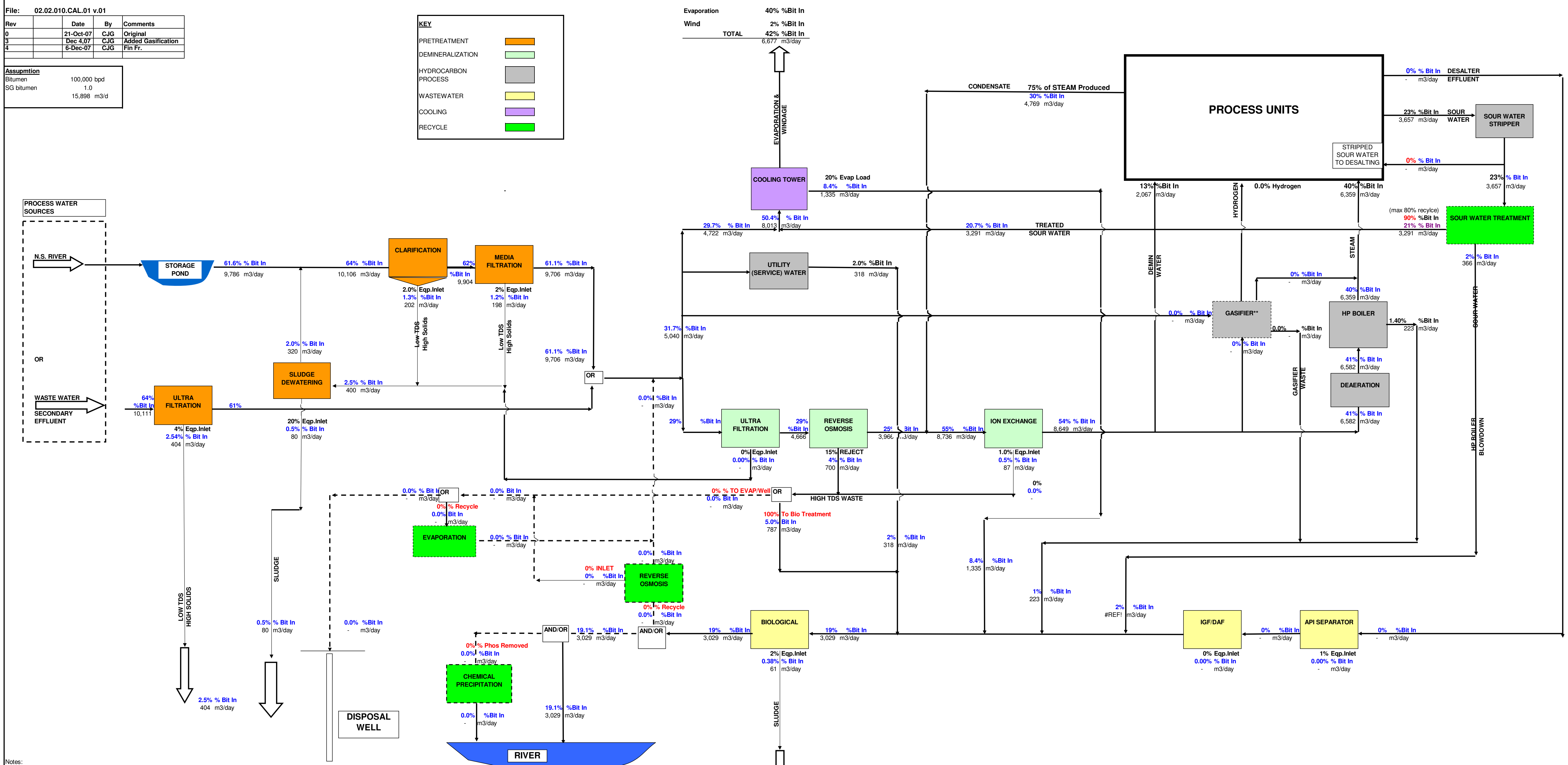
Scenario 3A - SSW Recycle to Cooling - No Desalting

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optional recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

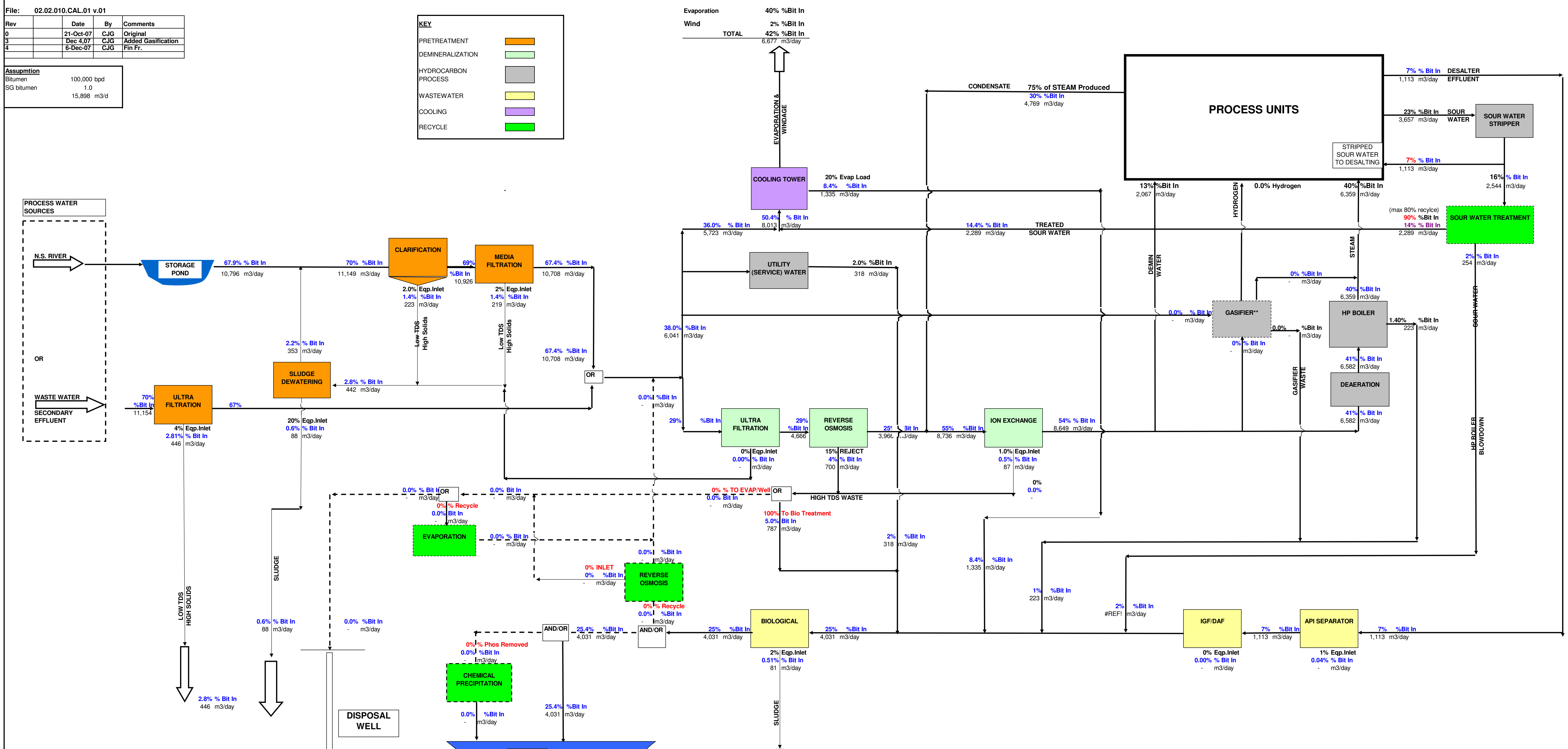
Scenario 3B - SSW Recycle to Cooling - Desalting

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption	
Bitumen	100,000 bpd
SG bitumen	1.0
	15,898 m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

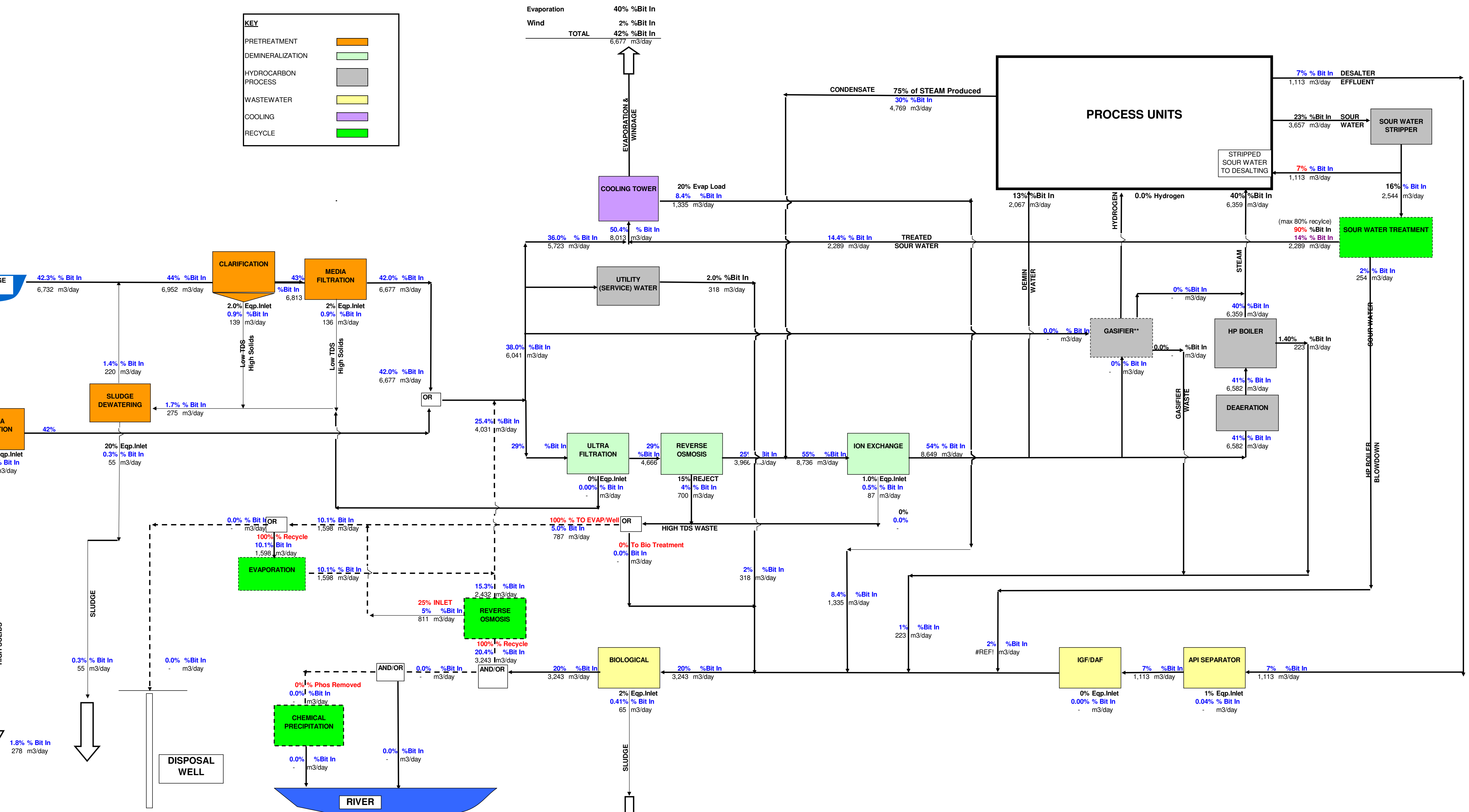
Scenario 3C - SSW Recycle to Cooling - No Desalting Zero Discharge

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

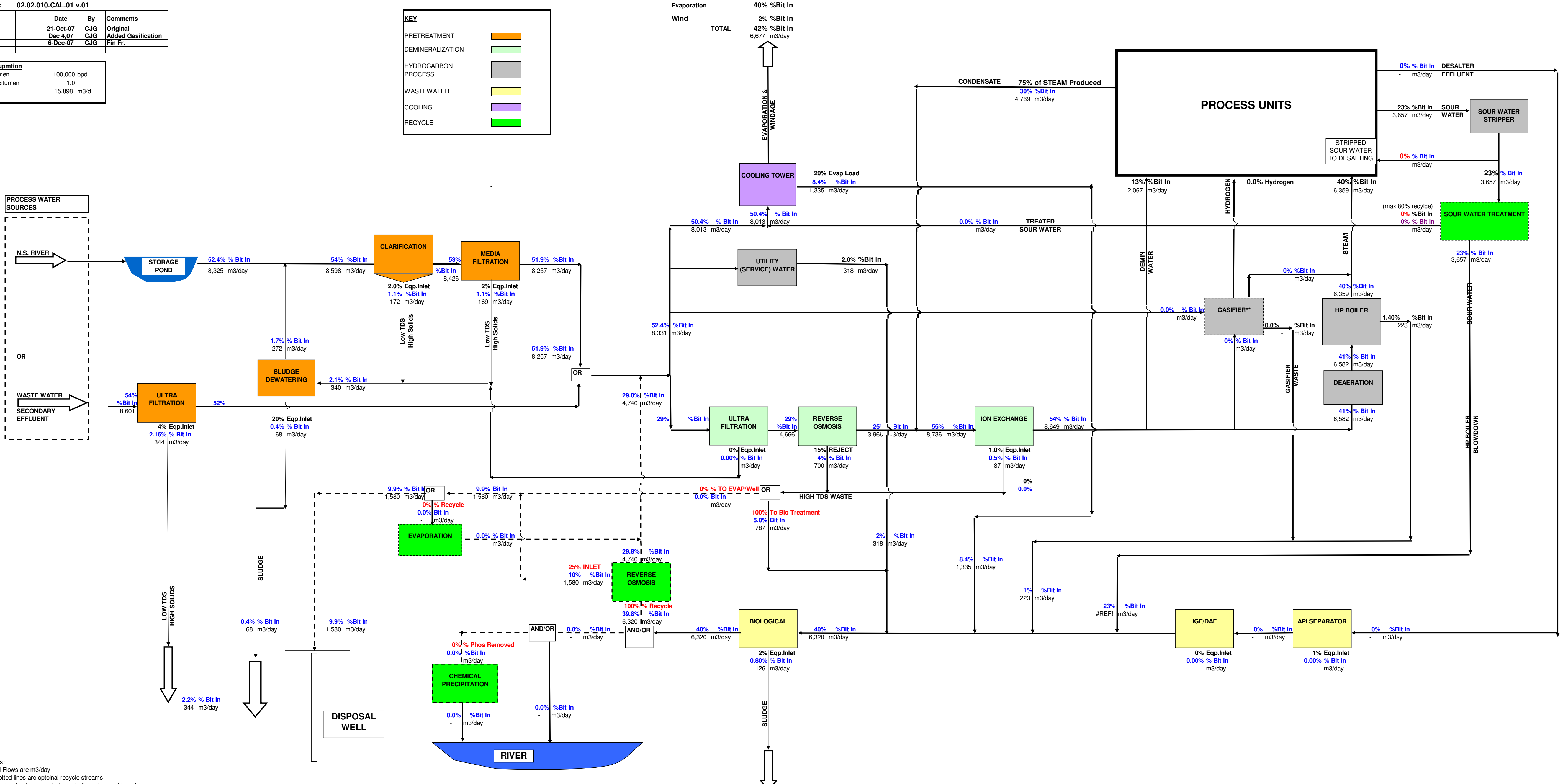
Scenario 4A - Combined Recycle to Cooling & No Desalting

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

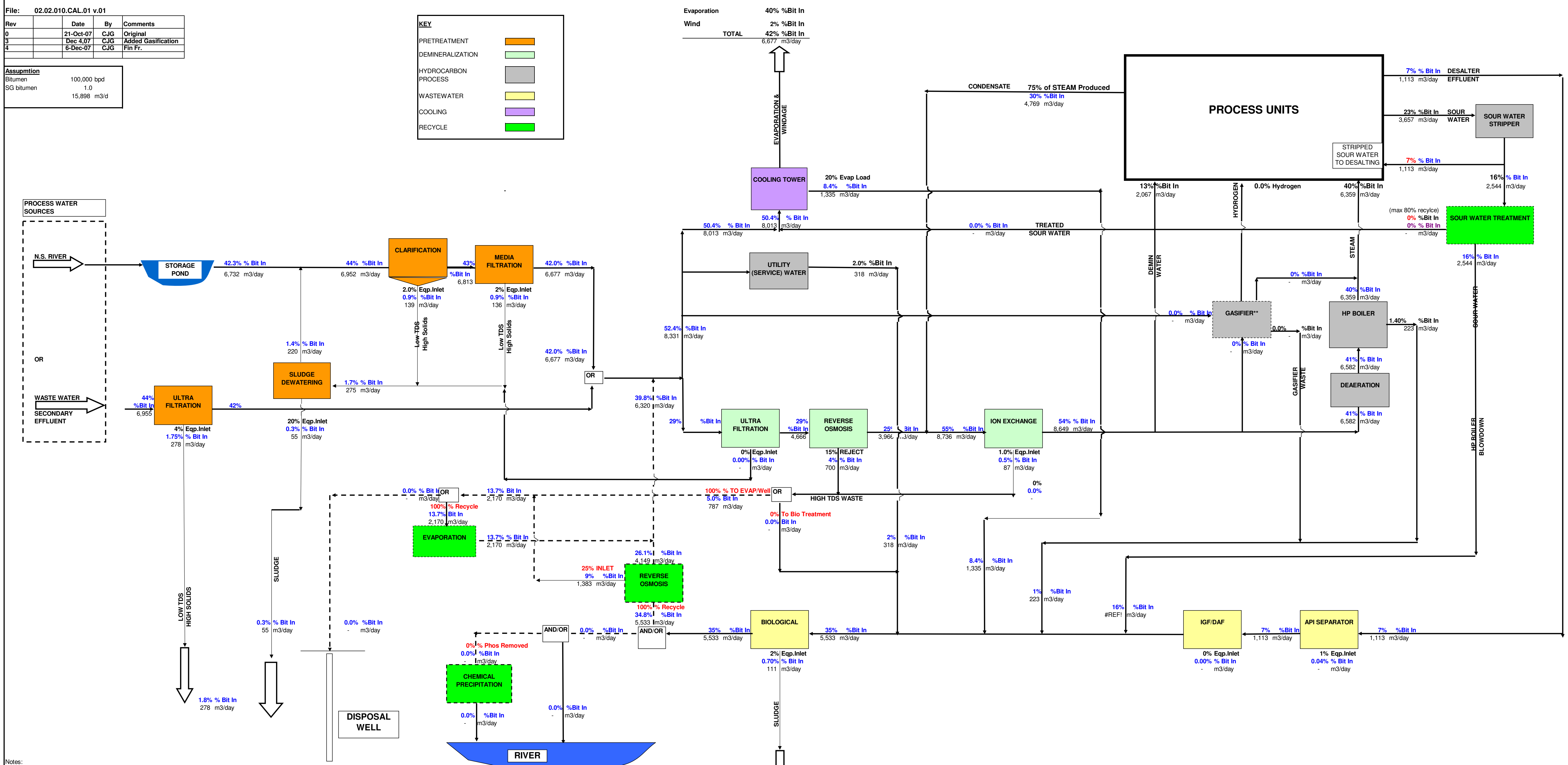
Scenario 4B - Combined Bioreactor Recycle & Desalting

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

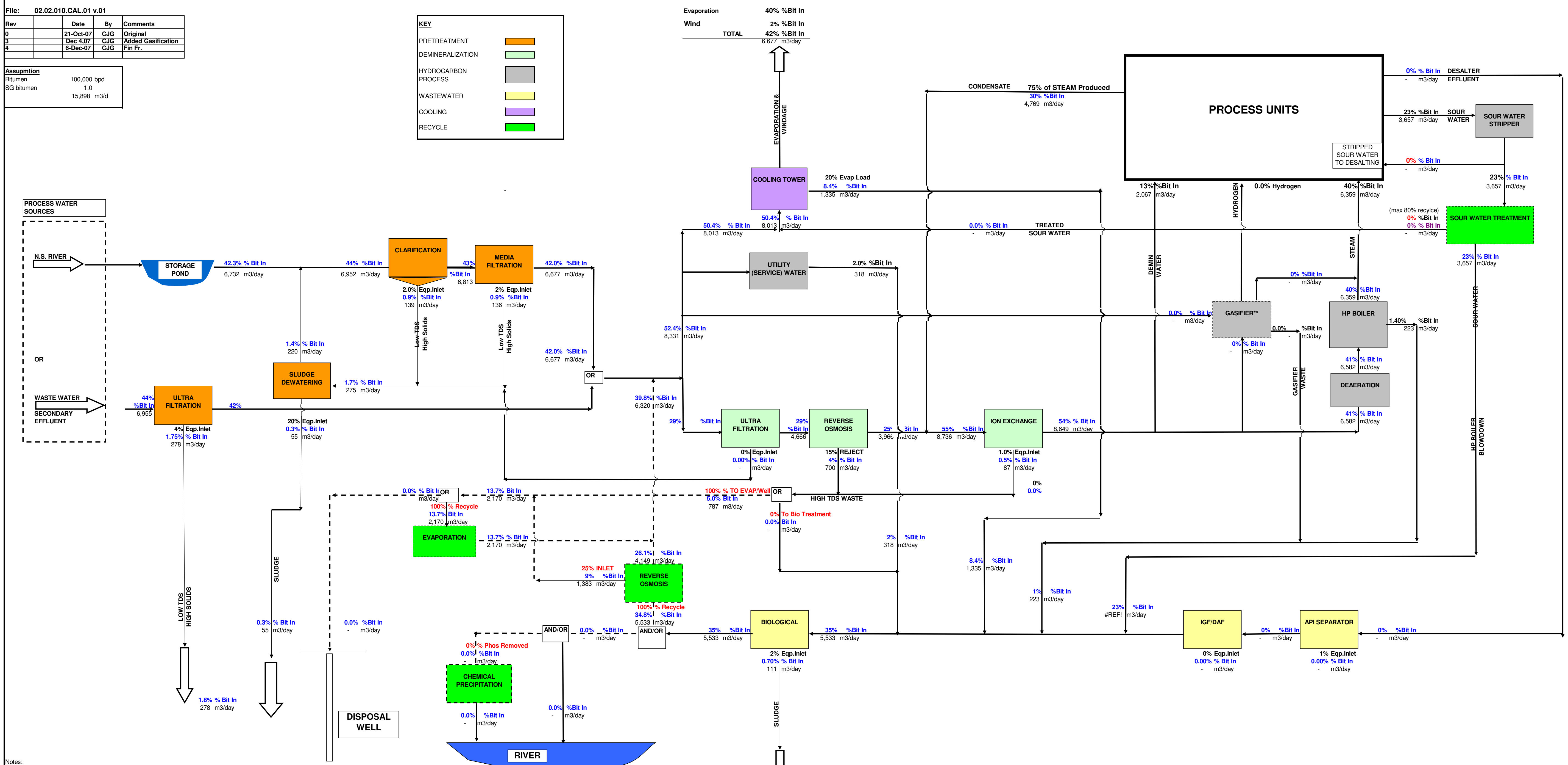
Scenario 4C - Combined Recycle to Cooling & No Desalting - Zero Discharge

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev	Date	By	Comments
0	21-Oct-07	CJG	Original
3	Dec 4,07	CJG	Added Gasification
4	6-Dec-07	CJG	Fin Fr.

Assumption	
Bitumen	100,000 bpd
SG bitumen	1.0
	15,898 m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

Scenario 5A - Gasification & No Desalting

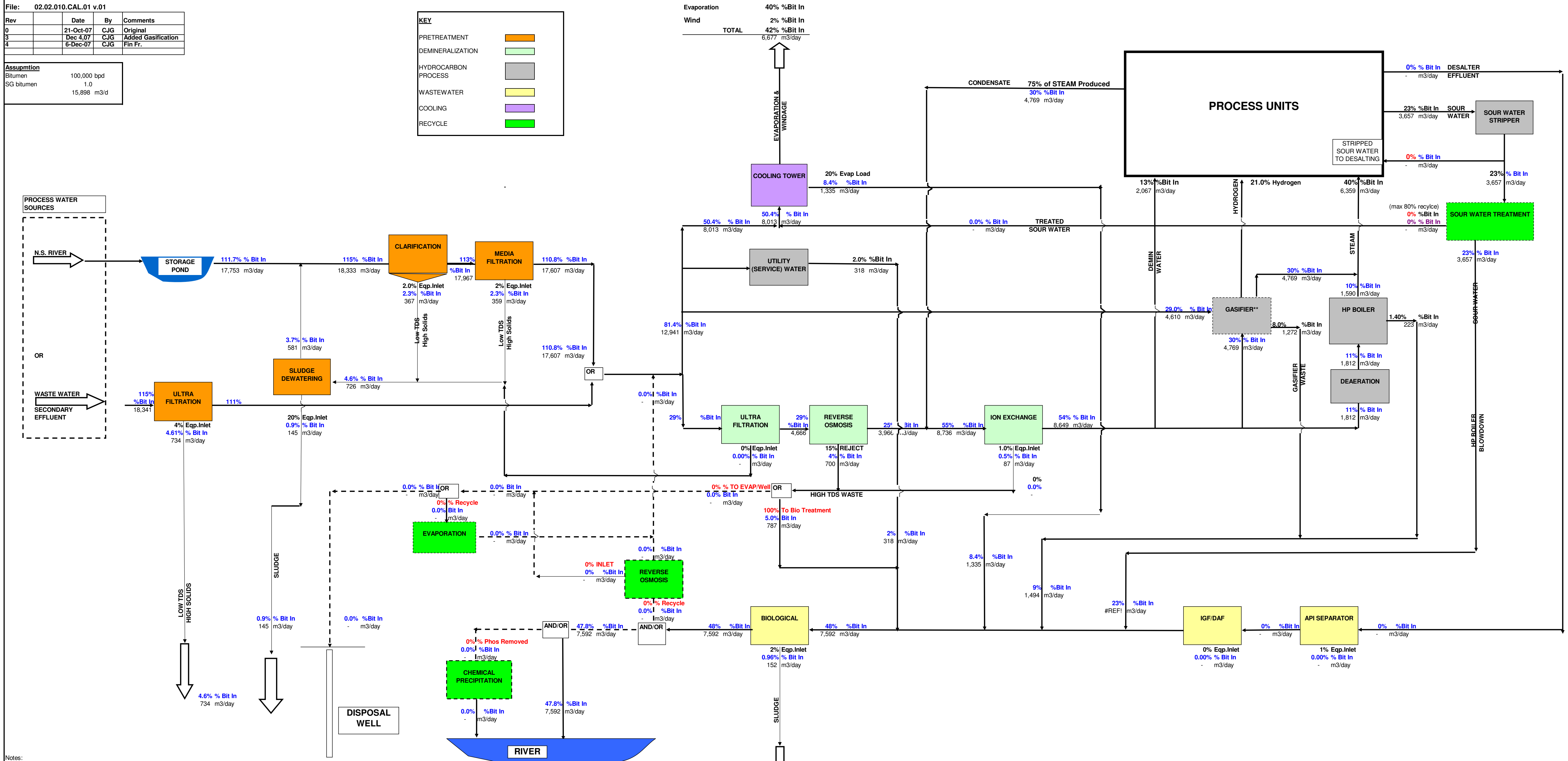
Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assupmtion

Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optoinal recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time

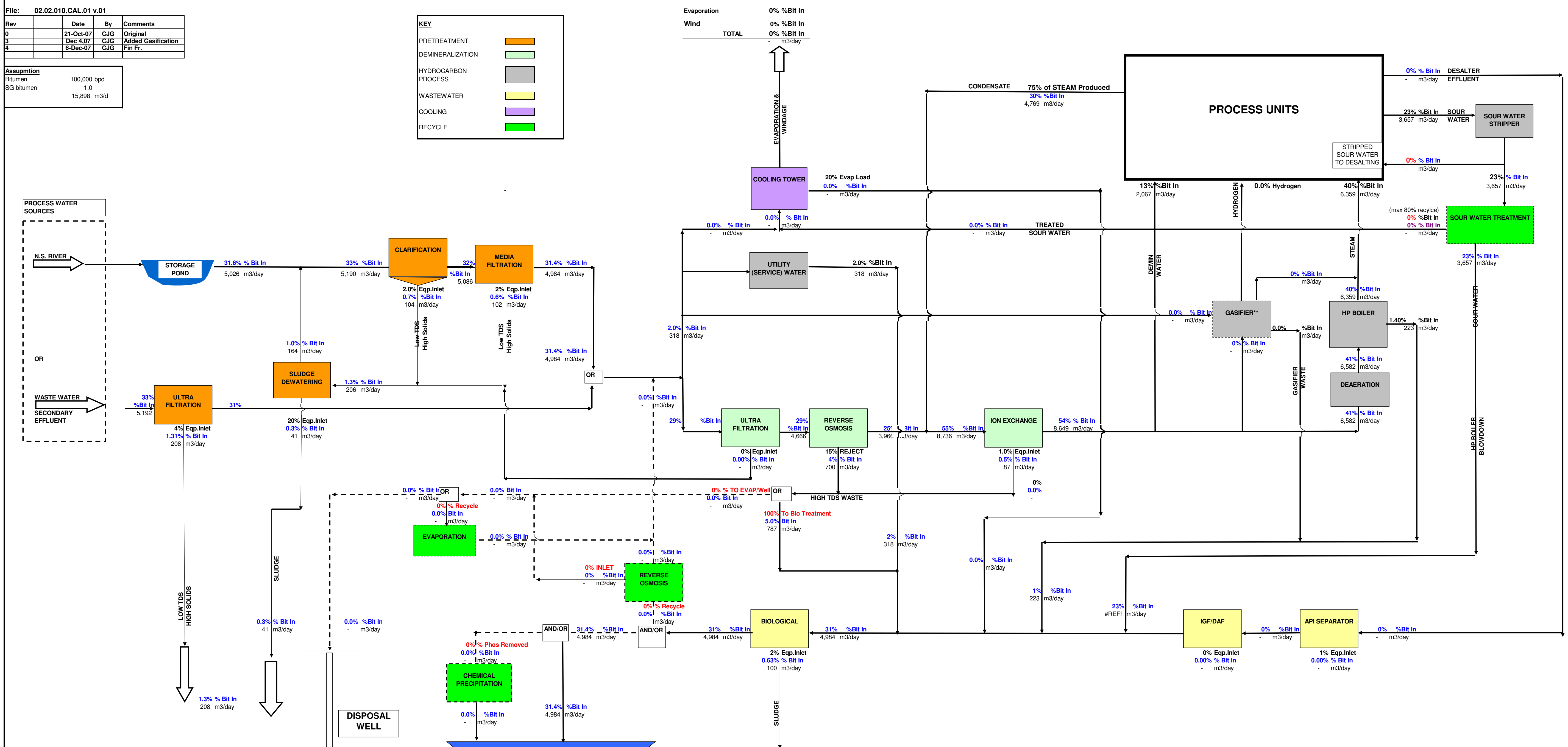
Scenario 6A - No Evaporative Cooling

Water Process - WORKING PDF

File: 02.02.010.CAL.01 v.01

Rev		Date	By	Comments
0		21-Oct-07	CJG	Original
3		Dec 4,07	CJG	Added Gasification
4		6-Dec-07	CJG	Fin Fr.

Assumption		
Bitumen	100,000	bpd
SG bitumen	1.0	
	15,898	m3/d



Notes:
1. All Flows are m3/day
2. Dotted lines are optional recycle streams
*User input values in red; don not alter values not in red
** Assumption that gasification will add roughly 10% to water demans. Due to resources allocated to report, gasification has not been examined in more detail at the present time