# Appendix X

# Water Usage Minimization Study

# WATER MINIMIZATION STUDY

| Rev | Date | Revision Description | By | Chkd | Apprvd |
|---|---|---|---|---|---|
| 0 | 03-Jan-08 | Initial Issue | S. Tamura | P. Johnston | G. Sims |
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# 1. EXECUTIVE SUMMARY

The purpose of this study to is to report the water usage impact with respect to the Power Block's Steam Turbine Generator's (STG) Heat Sink. Typically a Water Cooled Condenser (WCC) with a Wet Cooling Tower is a very effective method of condensing the STG exhaust. However, water is scarce in the proposed area and this study explores of sharing the condensing duty with an Air Cooled Condenser (ACC) and replacing the WCC with an ACC. The main objectives of this study are as follows:

1. Compare the water usage, performance impact, and provide a Rough Order of Magnitude (ROM) cost differences for 100% Water Cooled Condenser (WCC), 100% Air Cooled Condenser (ACC), and Parallel Cooling System (PCS).
2. Compare the water usage and provide a ROM cost difference for using brackish water versus fresh water in a 100% WCC system.

The tables below summarize the results of this study. Note: The PCS values represented in the tables below will vary with the amount of makeup water available to the Plant. The amount of makeup water required can be reduced by adding more ACC surface area.

**Table 1: Fresh Water Usage Summary at Summer Design Conditions (102 °F / 16% RH)**

| Design | WCC | PCS | ACC |
|---|---|---|---|
| Output Effect | BASE | (16.3 MW) | (27.4 MW) |
| Cycles of Concentration | 5 | 5 | 5 |
| Total Plant Makeup Water | 5,130 GPM | 3,820 GPM | 2,350 GPM |
| Makeup Water Savings | BASE | 1,240 GPM | 2,710 GPM |

**Table 2: Fresh Water Usage Summary at Average Ambient Conditions (65 °F / 60% RH)**

| Design | WCC | PCS | ACC |
|---|---|---|---|
| Output Effect | BASE | (6.8 MW) | (8.4 MW) |
| Cycles of Concentration | 5 | 5 | 5 |
| Total Plant Makeup Water | 3,210 GPM | 2,320 GPM | 1,480 GPM |
| Makeup Water Savings | BASE | 890 GPM | 1,730 GPM |

**Table 3: ROM Cost and Plot Space Impact**

| Design | WCC | PCS | ACC |
|---|---|---|---|
| Cost Delta | BASE | ~ +$25 mm | ~ +$37 mm |
| Total Required Plot Space | 1.5 acre | 2.0 acre | 2.4 acre |

**Table 4: Fresh Water versus Brackish Water Makeup, Power Block Cooling Tower Only**

| | Fresh Water CT | Brackish Water CT | Difference |
|---|---|---|---|
| Cycles | 5 | 3 | |
| CT Makeup at Summer Design | 2,710 GPM | 3,250 GPM | 540 GPM |
| CT Makeup at Average Ambient | 1,730 GPM | 2,080 GPM | 350 GPM |
| Cost Delta | BASE | | ~ +$5 mm |

Note: The numbers represented in Table 4, does not include cooling duty for the Power Block's auxiliary load cooling.

## 2. CONCLUSIONS AND RECOMMENDATIONS

Results show that the WCC system is the recommended approach for the Project. WCC will have the lowest starting capital investment, highest plant output, and smallest plot space requirement. If the availability of fresh water is limiting, then the recommended path forward would be to use brackish water for the cooling tower makeup or supplement the fresh water with brackish water. The cost impact to the heat sink is relatively minor and the plot plan impact is small. Use of brackish water for cooling tower makeup would increase the $PM_{10}$ emissions relative to a fresh water cycle.

If the availability of makeup water (fresh or brackish) is still limiting, then the recommended path forward would be to (1) proceed with the PCS and/or (2) install a cooling tower makeup water storage tank/pond to level out the summer demands. This report documents the cost and plot impact of the PCS. In addition, adding an Air Cooled Condenser to the plant will have a major impact on the plot layout since the Air Cooled Condenser must be installed near the STG.

The ROM cost of a storage tank/pond and forwarding pumps are expected to be less than the PCS option. The size of a makeup water storage tank/pond will depend on the design criteria, but the capacity would need to be in the order of magnitude of a few days to significantly reduce the peak water demand. The Storage Tank/Pond option is expected to require a significant amount of plot space, but it can be located anywhere and will have a small effect on layout.

## 3. BACKGROUND

The scope of this study is limited to the effects on the Power Block. This study concentrates on the Power Block's Heat Sink (Cooling Tower, Surface Condenser, Air Cooled Condenser, Cooling Water Pumps, and the back end of the Steam Turbine). In areas where water is scarce, substituting a few or all cells of the Cooling Tower for an Air Cooled Condenser is a viable option for a power plant. The study evaluates the following three common Heat Sinks:

1. A 100% Water Cooled Condenser (WCC) system consists of a Water Cooled Condenser, a Wet Cooling Tower, Cooling Water Pumps, and 40 inch Last Stage Bucket on the STG. For this location, this is the most effective Heat Sink, but it will require the largest amount of makeup water.

2. In a 100% Air Cooled Condenser (ACC) system, the STG exhaust is directly ducted to a large air cooler where the ambient air is used as the heat sink. Although this configuration is common in power plants, it is costly, requires a larger plot space than the WCC, and the STG output is decreased, especially during warmer days. Due to the higher STG exhaust pressure, a 30 inch STG Last Stage Bucket is used.

3. A Parallel Cooling System (PCS) combines the WCC and the ACC to condense the STG exhaust. For this study, the duty on an average ambient day is split 50/50 between the WCC and the ACC. This increases the output versus a 100% ACC system and lowers the makeup water demand versus the 100% WCC system. The STG for the PCS option also

uses a 30 inch Last Stage Bucket. Note that the PCS cooling duty can be divided between WCC and the ACC systems in any number of ways depending on the amount of makeup water available.

The Power Block's auxiliary cooling load is relatively small compared to the rest of the Plant and was not included as part of this study. This cooling load can be integrated with the Process Cooling Tower or with the Air Cooled Condenser.

Heat and material balances from the Phase 3 Pre-Feed Package were used as a basis. There are slight changes to the site conditions between Phase 3 and this study. However, the indicated cost and water demand deltas should be accurate enough to support project decision making.

In general Kern County is a very dusty area due to the vast desert/farm lands and high winds which will present problems with the Wet Cooling Tower fill material. The dust in the air will tend to foul up the fill and mud will collect in the basin, therefore a high efficiency film fill is not recommended for the area. A less efficient film fill with larger openings is better suited for this dusty environment for both fresh water and brackish water makeup. Fouling tolerant fill material is recommended particularly if produced water or "grey water" is used for cooling tower makeup.

Much of the information in this report is derived from Thermoflex, a power cycle simulator developed by Thermoflow Inc. This software solves the heat and material balance, calculates performance and estimates equipment pricing. This information was used in developing the delta installed costs provided in this report.

# 4. POWER BLOCK MAKEUP WATER REQUIREMENT

The major makeup water consumers are the Cooling Towers, Gas Turbine Evaporative Cooler, and the Slurry/Slag process. Table 5 shows the expected evaporation rates and the process user requirements. Although Table 5 does not show the total amount of Plant makeup water required, the makeup water requirement can be calculated with this information based on the water quality and the required Cycles of Concentration at the Cooling Towers and the Gas Turbine Evaporative Cooler.

**Table 5: Evaporation and Process Water Consumption Rates**

| **Ambient Condition** | | 102 °F / 16% RH | 65 °F / 60% RH | 36 °F / 65%RH |
|---|---|---|---|---|
| **Wet Cooling Tower Duties** | | | | |
| Power Block (STG) | mmBtu/hr | 898 | 891 | 888 |
| Power Block (Auxiliary) | mmBtu/hr | 36 | 36 | 36 |
| ASU | mmBtu/hr | 269 | 269 | 269 |
| Process | mmBtu/hr | 405 | 405 | 405 |
| | | | | |
| **Wet Cooling Tower Evaporation Rates (WCC System)** | | | | |
| Power Block (STG) | GPM | 2,227 | 1,383 | 1,019 |
| Power Block (Auxiliary) | GPM | 89 | 55 | 41 |
| ASU | GPM | 666 | 417 | 308 |
| Process | GPM | 1,004 | 628 | 464 |
| Total Evap from CT's | GPM | **3,986** | **2,483** | **1,832** |
| | | | | |
| **Power Block (STG) Wet Cooling Tower Evap Rate for the PCS** | GPM | **1175** | **671** | **277** |
| | | | | |
| **Gas Turbine Evap Cooler Evaporation Rate** | GPM | **45** | **11** | **0** |
| | | | | |
| **Other Process Water Users** | | | | |
| Process Water to Slurry/Slag | GPM | 72 | 72 | 72 |
| Plant Water Requirement | GPM | 23 | 23 | 23 |
| Total Process Water | GPM | **95** | **95** | **95** |

The Power Block's Wet Cooling Tower's evaporation rate accounts for a substantial amount of the makeup water demand. Reducing the size of the Power Block's Wet Cooling Tower can have a significant reduction of the makeup water requirement. The total makeup water will depend on the water quality of the available makeup water and how many cycles of concentration the Cooling Towers and Gas Turbine Evaporative Cooler can tolerate. The makeup water to the Cooling Towers and Gas Turbine Evaporative Cooler is calculated using the following equation:

**Equation 1: MU = Evap x C ÷ (C – 1)**

| | |
|---|---|
| MU | = Makeup Water Rate |
| EVAP | = Evaporation Rate |
| C | = Cycles of Concentration |

Sample Calculation (102 °F ambient and 5 cycles of concentration):
From Table 5, above, at 102 °F ambient, we get the following data:

| | |
|---|---|
| Total Evaporation rate from the Cooling Towers: | 3986 GPM |
| Evaporation from the Gas Turbine Evap Cooler: | 45 GPM |

Using 5 cycles of concentration and Equation 1, we can calculate the Cooling Towers and Gas Turbine Evaporative Cooler makeup water rate as follows:

Cooling Tower: MU(CT) = 3986 GPM x 5 ÷ (5 – 1)
MU(CT) = 4983 GPM

GT Evap Clr: MU(GT) = 45 GPM x 5 ÷ (5 – 1)
MU(GT) = 56 GPM

The total process makeup water required by the Plant is as follows:

| | | |
|---|---|---|
| Cooling Towers | 4,983 GPM | |
| Gas Turbine EC | 56 GPM | |
| Other Process Water Users: | 95 GPM | |
| TOTAL | 5,134 GPM | or round to 5,130 GPM |

By repeating the Sample Calculation above, Figures 1 thru 5 were generated on the following pages to compare the different heat sink technologies. Figures 1 thru 3 show the total plant makeup water rates as a function of cycles of concentration and ambient temperatures for each heat sink technology. Figures 4 and 5 shows the water savings relative to the WCC.

**Figure 1 - Plant Makeup Water for a Water Cooled Condenser Design**

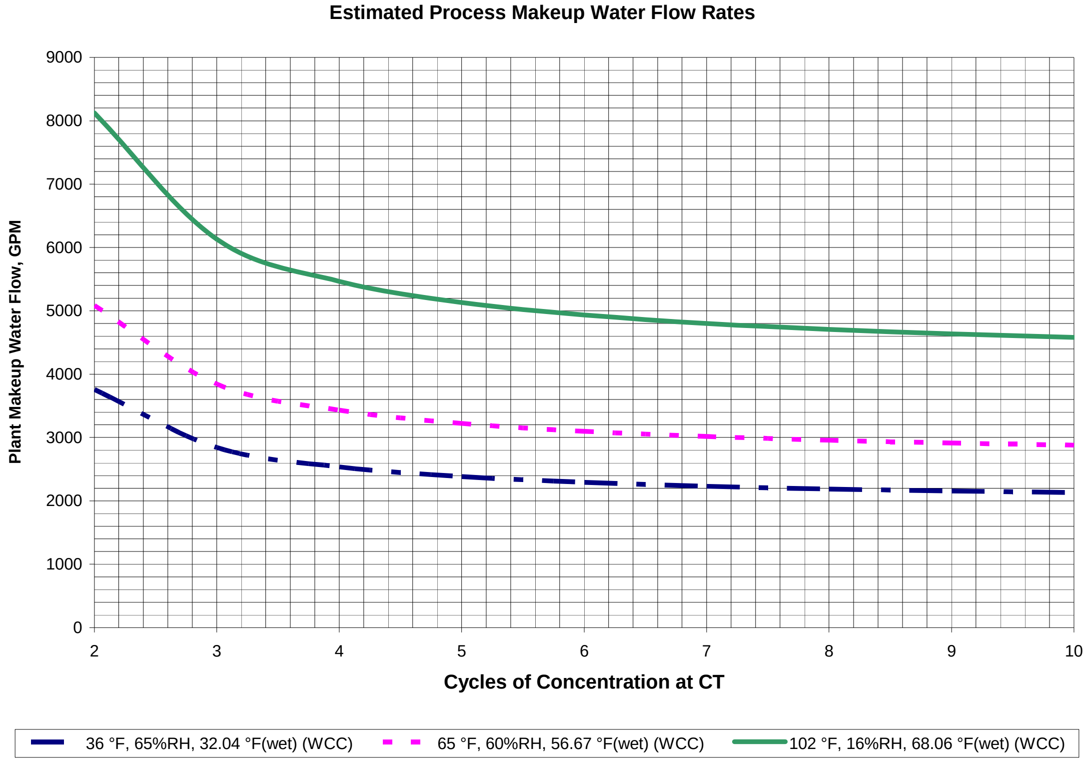
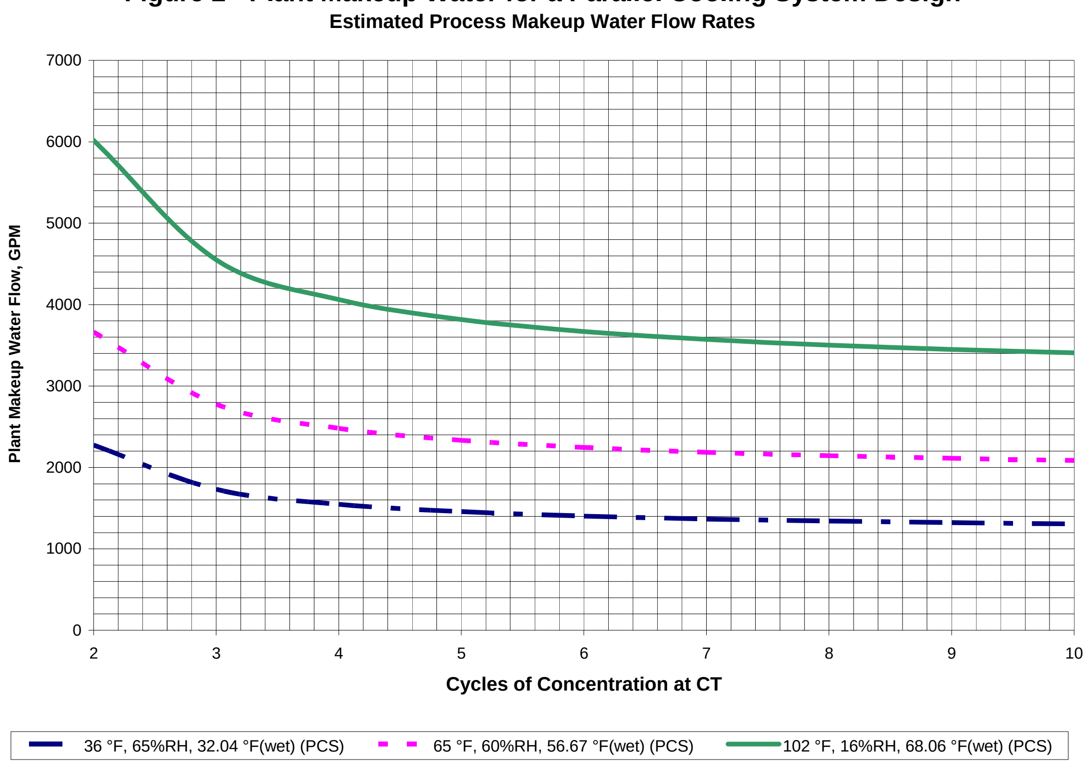



**Figure 2 - Plant Makeup Water for a Parallel Cooling System Design**



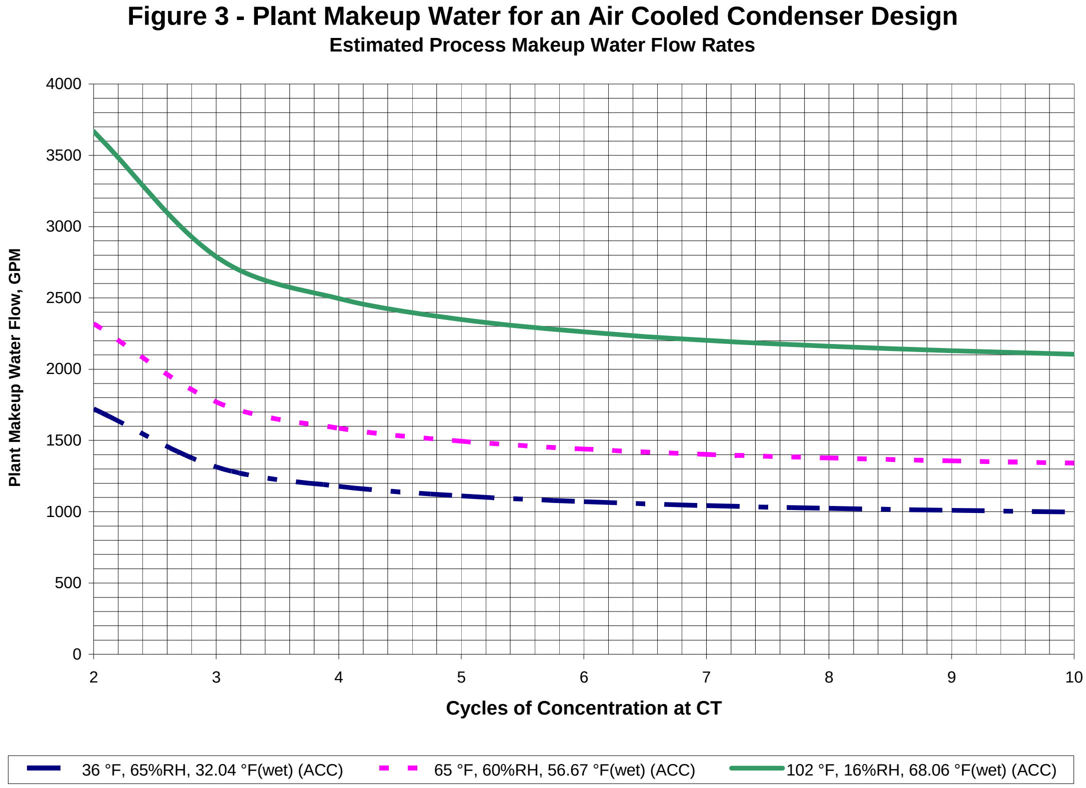


Figure 3 - Plant Makeup Water for an Air Cooled Condenser Design
Estimated Process Makeup Water Flow Rates
Plant Makeup Water Flow, GPM
4000
3500
3000
2500
2000
1500
1000
500
0
2
3
4
5
6
7
8
9
10
Cycles of Concentration at CT
36 °F, 65%RH, 32.04 °F(wet) (ACC)
65 °F, 60%RH, 56.67 °F(wet) (ACC)
102 °F, 16%RH, 68.06 °F(wet) (ACC)

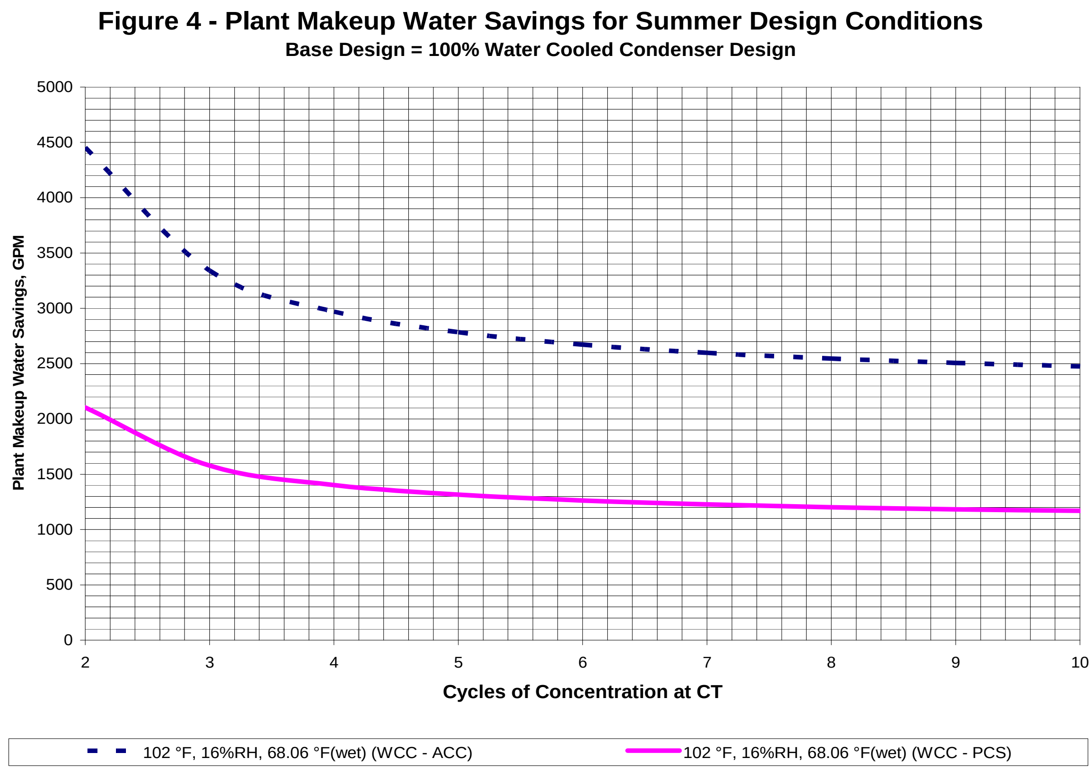
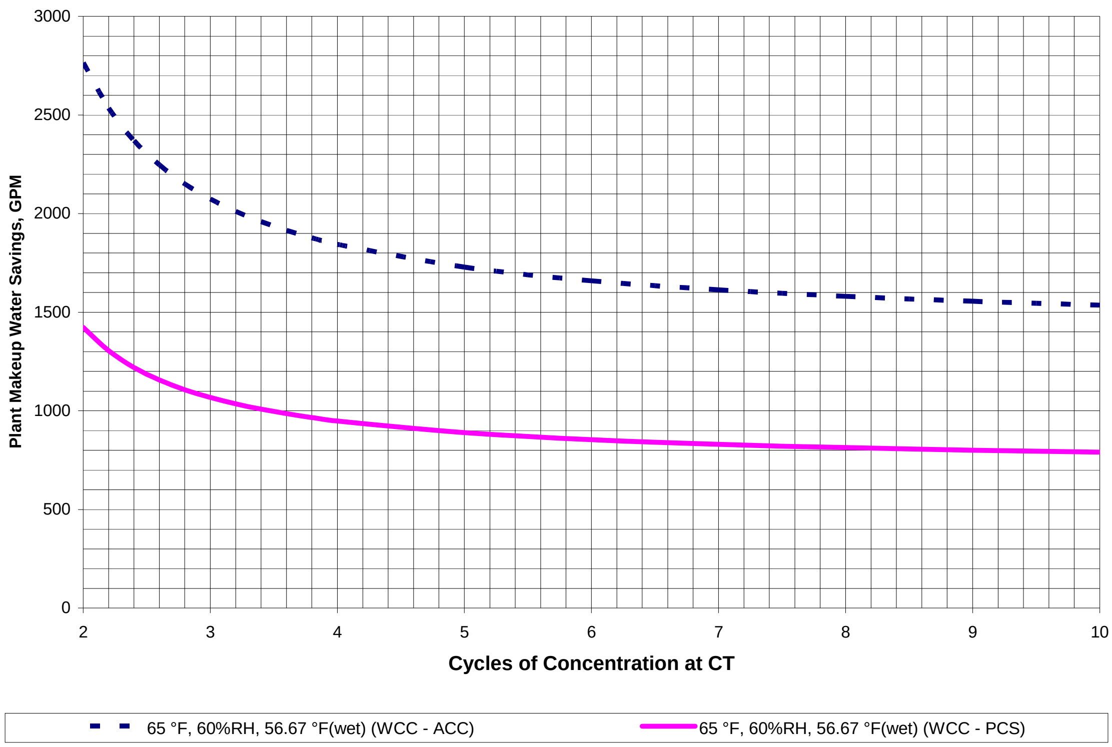


Figure 4 - Plant Makeup Water Savings for Summer Design Conditions
Base Design = 100% Water Cooled Condenser Design
Plant Makeup Water Savings, GPM
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2
3
4
5
6
7
8
9
10
Cycles of Concentration at CT
102 °F, 16%RH, 68.06 °F(wet) (WCC - ACC)
102 °F, 16%RH, 68.06 °F(wet) (WCC - PCS)

**Figure 5 - Plant Makeup Water Saving for Average Ambient Conditions**
**Base Design = 100% Water Cooled Condenser Design**




## 5. POWER BLOCK OUTPUT

The power output for the STG is highly dependent upon the temperature of the condenser's coolant. The ACC design will have the highest coolant temperature and therefore have the lowest STG output. By using the PCS heat sink, the output will fall in between the ACC and WCC designs, depending on the split.

**Table 6: Performance Impact (ΔMW)**

| Ambient Temperature | 36 °F | 65 °F | 102 °F |
|---|---|---|---|
| 100% WCC | BASE | BASE | BASE |
| 50%-50% PCS | (6.2 MW) | (6.8 MW) | (16.3 MW) |
| 100% ACC | (6.6 MW) | (8.4 MW) | (27.4 MW) |

# 6. ROM COST AND PLOT REQUIREMENT

Several variables account for the difference in cost. Table 7, below, shows the overall ROM cost differential between the three heat sink designs. Another cost variable pertinent to this study is the plot space requirement, see Table 8 below. The Air Cooled Condenser will have the largest plot space requirement and requires to be in close proximity to the STG.

Steam Turbine: The WCC design will have a more expensive Steam Turbine due to the higher output and larger Last Stage Bucket. The WCC design will support a 40” bucket while the ACC and PCS designs will support a smaller 30” bucket.

Condenser: The WCC requires a Water Cooled Condenser, a Cooling Tower, Cooling Water Pumps, and a large diameter cooling water line. This is less costly than the single Air Cooled Condenser or a Parallel Cooling System.

**Table 7: ROM Cost Differential**

| | |
|---|---|
| 100% WCC | BASE |
| 50%-50% PCS | ~ +$25 mm |
| 100% ACC | ~ +$37 mm |

**Table 8: ROM Plot Space Requirements (Power Block Only)**

| | Cooling Tower Dimensions (Equipment Only) | Air Cooled Condenser Dimensions (Equipment Only) | ROM Plot Space per Train (Note) |
|---|---|---|---|
| 100% WCC | 546 ft x 54 ft | | 1.5 acre |
| 50%-50% PCS | 168 ft x 54 ft | 215 ft x 85 ft | 2.0 acre |
| 100% ACC | | 301 ft x 127 ft | 2.4 acre |

Note: The “ROM Plot Space per Train” is the estimated total plot space required for the Cooling Tower, Air Cooled Condenser, Pump Pit, and maintenance accessibility.

# 7. POWER BLOCK FRESH WATER VS. BRACKISH WATER

Using brackish water is a viable option as makeup to the cooling tower. There are two major issues with using brackish water. First, there is a higher chance that brackish water will leave deposits on the cooling tower fill. Therefore, the cycles of concentration must be decreased to prevent the solids in the circulation water from precipitating out. A brackish water cooling tower can use an film-fill, equivalent to those used in a fresh water cooling tower. Second, the materials must be upgraded to counter the effects of the corrosive brackish water. Table 9, below, shows the major comparison between fresh water and brackish water makeup for the Power Block's Wet Cooling Tower. Third, use of brackish water for cooling tower makeup would increase the $PM_{10}$ emissions relative to a fresh water cycle.

**Table 9: Brackish Water Makeup to WCC Comparison**

| | Fresh Water | Brackish Water |
|---|---|---|
| Cycles of Concentration | 5 | 3 |
| Power Block CT Makeup Flow at Max Ambient | 2,780 GPM | 3,250 GPM |
| ΔMakeup Flow (Max Ambient) | BASE | +470 GPM |
| Power Block CT Makeup Flow at Average Ambient | 1,730 GPM | 2,080 GPM |
| ΔMakeup Flow (Ave. Ambient) | BASE | +350 GPM |
| Cost Delta | BASE | ~ $5 mm |