# Water-Energy Nexus Insight:

# Optimization of Source Waters for DBP Control

by

Jacelyn Rice

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Graduate Supervisory Committee:

Paul Westerhoff, Chair
Peter Fox
Kiril Hristovski

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# ABSTRACT

Local municipalities in the Phoenix Metropolitan Area have voiced an interest in purchasing alternate source water with lower DBP precursors. Along the primary source is a hydroelectric dam in which water will be diverted from. This project is an assessment of optimizing the potential blends of source water to a water treatment plant in an effort to enable them to more readily meet DBP regulations. To perform this analysis existing water treatment models were used in conjunction with historic water quality sampling data to predict chemical usage necessary to meet DBP regulations. A retrospective analysis was performed for the summer months of 2007 regarding potential for the WTP to reduce cost through optimizing the source water by an average of 30% over the four-month period, accumulating to overall treatment savings of $154 per MG ($82 per AF).

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## Chapter 1

## INTRODUCTION

### 1.1. Disinfection By-Products.

DBPs are formed when chlorine is added to drinking water to kill or inactivate harmful organisms that cause various diseases. Chlorine is a very active substance and it reacts with naturally occurring substances to form DBPs. As a result of this, DBPs are more likely to form in water systems with higher levels of organics, such as surface waters. The different species and concentrations of DBPs are influenced by the types of organic and inorganic matter in the source water, chlorine dosing at the drinking water disinfection stage, the time since dosing, pH and temperature of the water. Due to the fact that temperature is positively correlated to DBPs, increased temperatures during summer months raise the difficulty in meeting DBP regulations. The USEPA regulates levels of two classes of disinfection by-products (DBPs). Maximum contaminant levels are set to 80 μg/l for total trihalomethanes (TTHMs) and 60 μg/l for haloacetic acids (HAAs). The amount of organic matter in the source water is measured by the quantity of dissolved organic carbon (DOC); which is present within the source water because it serves as a carbon source that supports biological activities within aquatic communities. Other indexes used to measure quantity of natural organic matter (NOM) present are Ultraviolet Absorbance (UVA) and Specific Ultraviolet Absorbance (SUVA).

## 1.2.Water-Energy Nexus.

The water-energy nexus has received increased attention for the managing of both resources in order to maintain reliable and sustainable supplies towards the future. It is believed that current rates of population growth, expected thermoelectric capacity additions by electric utilities, and increasing prevalence of droughts could induce possible water shortages in some areas of the United States (Sovacool and Sovacool, 2009). In an effort to sustain energy production and a dependable water supply, the U.S. must gain an in depth understanding of the interdependencies to reduce water use and loss. Sovacool et.al reaffirms the notion that many electric utilities have virtually ignored water concerns, they state that those within the electricity industry often downplay the importance of water management techniques for minimizing thermoelectric water consumption, and those in water management rarely promote electricity conservation as a water resource tool.

Hydropower dams have been noted to have several affects on the flow regime and sediment transport, with downstream geomorphic downstream changes (Simons and Senturk, 1997). Commonalities have been found worldwide regarding the effects of dams (Petts 1984; Stanford et al. 1996; Wirth 1997; Schmidt et al. 1998). These changes can be generalized into three main categories, habitat diversity, native diversity and water quality. The habitat diversity is substantially reduced. Flow and sediment regimes are drastically affected, this alters the fluvial dynamics that create heterogeneous channel and floodplain habitat (Lamouroux, 2006). Native diversity downstream of the dam decreases while exotic species propagate (Goodwin et al., 2006). Water quality is also altered downstream of the dam, due to changes in the temperature and increases in fine organic material. Majority of these changes are often anticipated during project design, but in many cases the severity of the problem is often underestimated (d'Anglejan, 1994).

### 1.3.Life Cycle Assessment.

A life cycle assessment (LCA) is a normalized method for the environmental assessment of industrial systems from "cradle-to-grave". The "cradle to grave" approach encompasses the extraction of raw materials from the earth, product development and manufacturing, and ends when all materials are returned to earth. LCA evaluates the environmental aspects of a product or service through all of its life cycle phases, allowing coherent comparison between different schemes providing the same service or function (UTEP/SECTAC, 2005). Its application to potable water production provides an adequate instrument for environmental decision support (Crettaz, 1999). With this being said, there are few papers published on the LCA of potable water production alternatives.

A study completed by F. Vince et al set out to perform an LCA of the water treatment process in an effort to reveal the environmental weak points of the water treatment process. The studied water treatment process was dedicated to bacteria removal of surface water with high organic content and low hardness. The steps that were responsible for most of the greenhouse gas (GHG) emissions throughout the water treatment process life cycle are the chemicals production for coagulation and remineralization. The second highest source is the electricity required by these treatment steps. In the study the steps that carried the highest environmental burdens were coagulant production (more than 30% of all impacts), electricity production for water treatment process operation (25% for most of the impacts) as well as chemicals production for remineralization (20% for most of the impacts) (Vince, 2008). Large doses of coagulant, lime, CO2 and soda were needed to reach potable water quality requirements. The production of these chemicals is responsible for more than 50% of impacts generated during the water treatment process life cycle. This impact is primarily due to the energy requirements of the chemicals production process and to gaseous emissions during chemicals production.

### 1.4. Objective.

The aim of this study is to assess the feasibility for purchasing a premium water quality source. Accomplished through a case study in central Arizona, involving two watersheds, one with hydropower and one without, which have different DBP precursor levels. Models were developed to predict treatment chemical use, DBP formation, offset lost hydropower cost and changes in the LCA. The outcome demonstrates that under certain conditions purchasing a premium source water can prove to be beneficial to all parties involved.

Chapter 2

# METHODOLOGY

## 2.1. Case-Study.

The setting for the study is Phoenix, Arizona. Phoenix is the fifth largest U.S. city and is located in the center of a rapidly urbanizing arid region within central Arizona. The Phoenix Metropolitan area has four main sources of water these include three surface water sources (Salt River, Verde River and Central Arizona Project (CAP)), a groundwater and reclaimed water source. Salt River Project (SRP) provides its customers with source water from the Salt and Verde watersheds. During summer months water is drawn from the Salt River to capitalize on energy production through the 13,000 kW hydroelectric generating unit. This region experiences challenges meeting DBP regulatory levels from July through October caused by increased temperatures and DOC content within source waters. Due to this, several cities have expressed interest in paying for the more preferable water (Verde River) during the summer months in hopes of enabling them to more readily meet regulations.

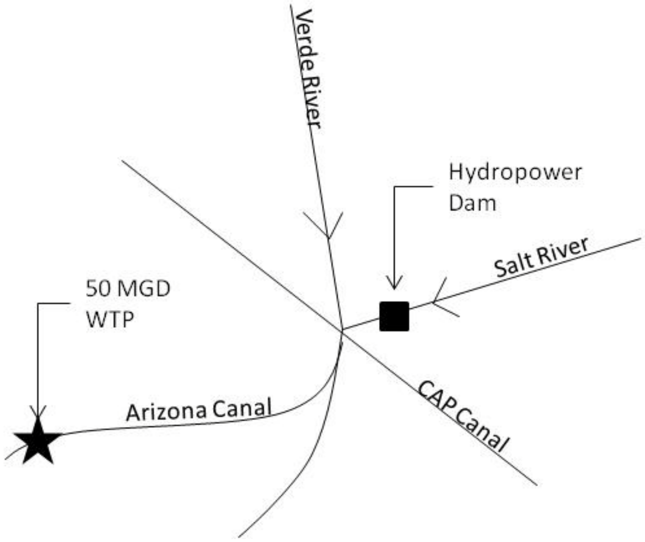

Figure 2.1 Case Study Schematic

### 2.2. Application of Model.

In an effort to achieve the objectives of the study a model was developed to predict DBP formation and total embedded cost to the WTP resulting from different source waters. The user identifies the mixture of source water that the WTP will utilize, the model then predicts the effluent water quality, end tap DBP concentrations, and total embedded cost. The models water treatment process was developed based upon the USEPA WTP Model Version 2.0. The WTP Model was utilized for its underlying assumptions and equations used in the calculations of the removal of NOM, disinfectant decay, and formation of DBPs. Figure 2.2 depicts the overall model structure. Underlying data of the model was attained from several sources. Delivery cost for the source waters were obtained from the supplier’s websites. Chemical costs were averaged bulk prices from three commercial wholesale providers in the Phoenix Area. Water quality data was obtained from an ongoing regional monitoring study of the areas surface water quality. Carbon equivalents in the form of kg of CO2 per kg of material were found for each chemical using the SimaPro Program and Ecoinvent database.

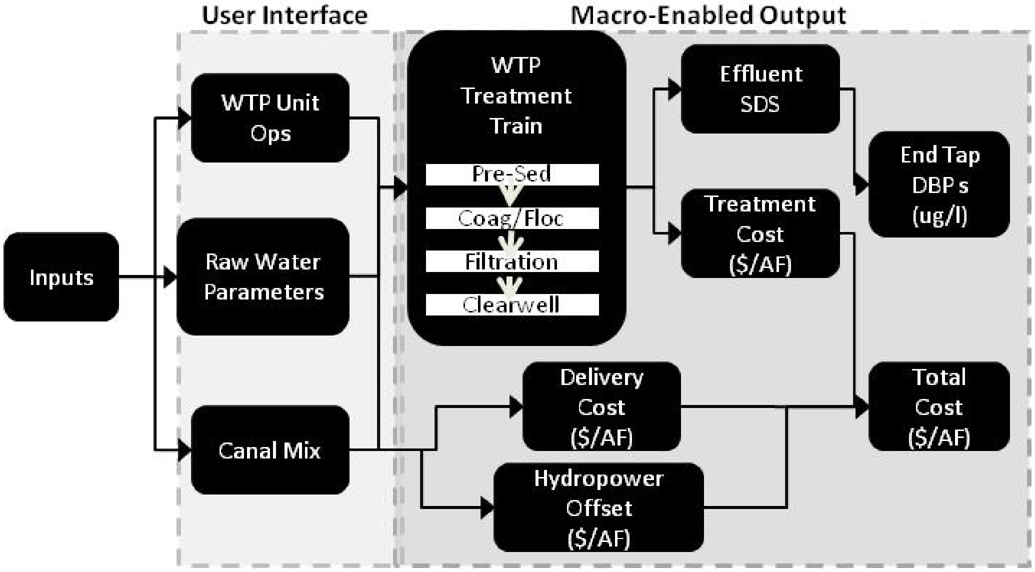

Figure 2.2 Overall Model Structure

## 2.3. Assessment of Embedded Cost of Water.

The total embedded costs to the WTP are made up of three sets of costs. These include the treatment costs incurred to meet the TTHM goal, the delivery costs of the water, and the offset hydropower costs. Treatment costs include chemical and sludge handling costs. Delivery costs are set annually and are displayed in Figure 2.3 for the source waters, alongside the actual mix of source waters in the Arizona Canal during 2007-2009.

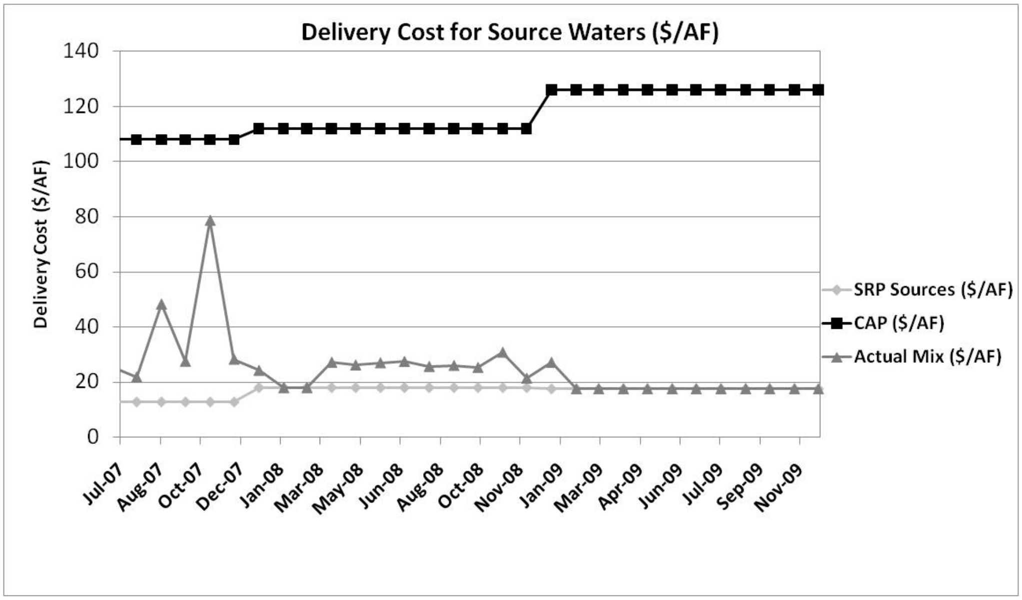

Figure 2.3 Delivery Cost

The cost of not using Salt River water when hydropower is generated, but instead using Verde River water where hydro is not produced was determined. The costs involve lost revenue of not producing hydropower, plus cost taken on by the power provider to purchase from the grid at an equal amount of power to meet utility demands. The offset cost for using Verde instead of Salt ranges from 35$/AF to 101$/AF for the summer months of 2007-2009. In discussions with the power provider monthly averages provided were relatively insensitive to hourly and daily hydropower generation between the months of July and October. Additional benefit to the water provider lies in available water for hydropower during other parts of the year.

Chapter 3

# RESULTS AND DISCUSSION

## 3.1. Comparison of DBP Formation and Chemical Use.

The case study WTP treatment train includes powder activated carbon (PAC) pre-sedimentation, Alum coagulation/flocculation, filtration and chlorine disinfection. DBP goal is set to 64 ug/l, 80% of the MCL. The WTP Model was validated for 2007 data based on chemical use, DOC, UVA and DBP levels. Model runs were completed for 3 consecutive years (2007-2009), which experienced differing DBP precursor levels in the primary source waters. These variances can be viewed in Figure 3.1.1. Verde River DOC values held 74, 56, 60 and 63 negative percent change when compared to Salt River for July through October respectively. Values for UVA were on average 25% lower for Verde when compared to Salt.

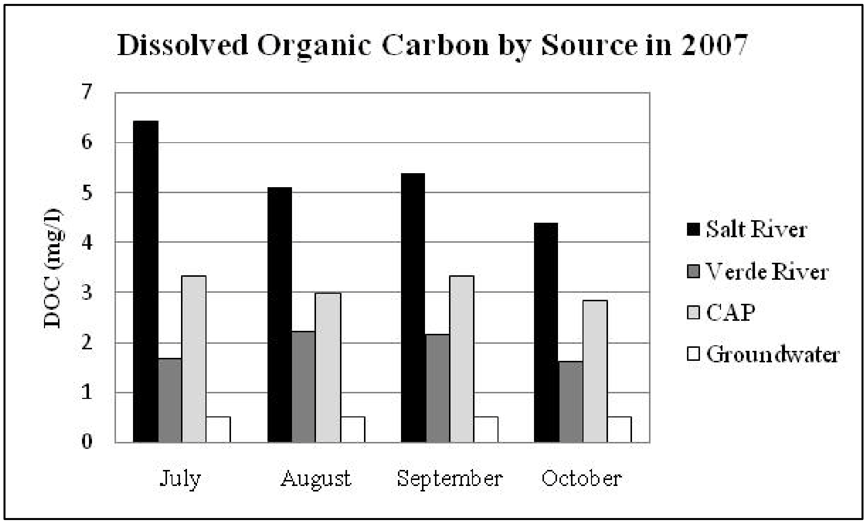

Figure 3.1.1 Dissolved Organic Carbon by Source in 2007

There was an underlying assumption in this study that when Verde water is supplied to the WTP in place of Salt water fewer TTHMs (at the max tap) would form as a result of lower DBP precursors. Further analysis was performed in an effort to verify this assumption and to quantify the magnitude of reduction treatment plants could expect. The dosage values were 15 mg/l of powder activated carbon (PAC), 55 mg/l of aluminum sulfate (alum) and 10 mg/l of sulfuric acid. These values are heightened doses, commonly used during summer months and were supplied from by the case study WTP. Maintaining similar treatment costs (i.e. same chemical usage), resulted in 38% lower DBP formation in Verde when compared to Salt River water during July-October, 2007. Figure 3.1.2 is a representation of TTHM formation along the treatment train for the above scenario.

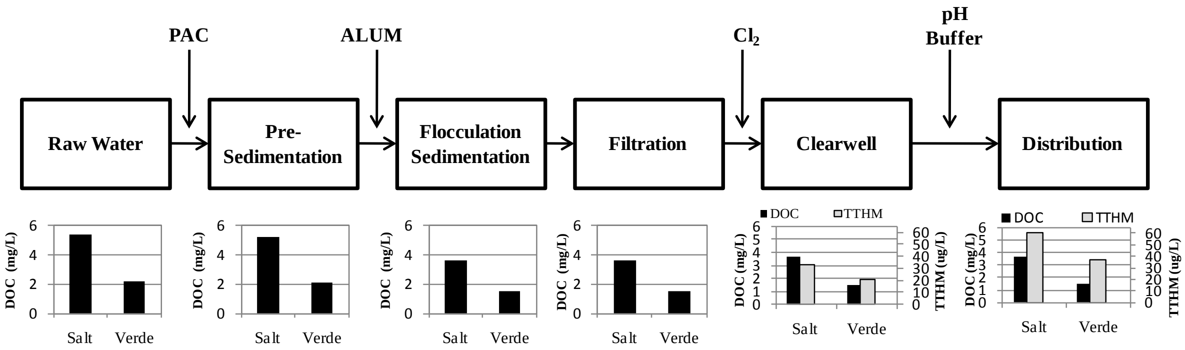

Figure 3.1.2 WTP Treatment Train with DBP Formation

Further analysis was performed to assess if using Verde River water could be used to achieve the TTHM goal with a considerably lower chemical dose. Dosage consisted of 15 mg/l of PAC, 35 mg/l of alum and 10 mg/l of sulfuric acid. During July 2007 if the water treatment plant was using 100% Salt River water they would have been endanger of not meeting USEPA regulations and far above the TTHM goal, the resulting TTHM concentration was 74 ug/l. Increasing the mix ratio to 50% Salt River and 50% Verde River would have enabled the treatment plant to meet the TTHM goal without increasing the chemical costs. This analysis shows it is possible to meet 64 ug/l during the summer months by increasing the ratio of Verde River water and not increasing the treatment cost.

### 3.2. Water-Energy Nexus Cost Comparison.

Analysis was completed to quantify the “value” of Verde River as source water. Numerous simulations were ran for the July through October 2007 time period. For each month the selected ratios of Salt to Verde River water simulations were ran. For this analysis the chemical dosage was tailored for each run, to meet the TTHM regulations. The author used the model in conjunction with local knowledge of the manner in which chemicals are added to raw water to attain treatment goals, and to determine the total embedded costs (of the WTP) for each scenario.

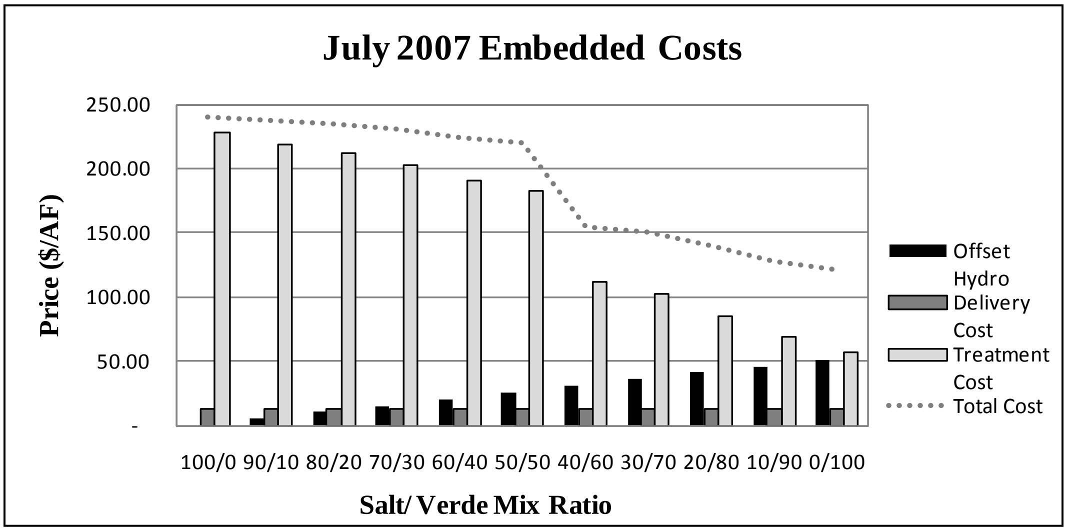

Figure 3.2 July 2007 Embedded Costs

Figure 3.2 displays a breakdown of the embedded costs to the treatment plant for July 2007. The total cost (depicted by the dotted line) decreases with increased Verde River ratios. The actual mix in the canal for this time period was a 70/30 ratio. According to the graph, from the standpoint of the WTP, the most preferred solution in an effort to minimize total costs would be to obtain 100% Verde influent. The supply constraints of Verde will inhibit its ability to meet this newfound high demand. The optimal mix is therefore constrained to 30/70.
The rate at which the treatment costs are decreased by the introduction of more Verde water is greater than the off-set hydropower cost associated with using it as the primary source. Therefore, the change has the potential to award the WTP with a savings of $73.08/AF. Very similar results were concluded for the remaining summer months of 2007. For the months of August, September, and October the decrease in embedded costs are 49.9, 25.6 and 14.7% respectively.

The inherent value of Verde water is highly dependent upon the natural organic matter present in both water sources, as well as the difference in quantity between them. Scenarios were run to get a better feel for the volatility of the potential savings. The first scenario forecasts the event of having a year that produces high concentrations of DOC in both water sources. Over the past ten years the highest DOC value for the Salt River was present in June 2005, DOC values for Salt and Verde were 8.76 and 4.63 mg/l respectively. For this scenario the savings in treatment cost did not off-set the additional embedded costs. The DOC level in Verde is too high to make a difference in the treatment costs to the WTP when it is added to the already high in DOC Salt water. Several simulations displayed that the window of opportunity for savings in treatment costs resides when DOC values for the Salt River are 4-7 mg/l and 2-3.5 mg/l for the Verde River. In addition, Verde water must be at least 50% less than Salt water. Looking at the 1999-2009 time periods this would have been viable for 4 out of the 10 summers.

### 3.5. $CO_2$ Equivalent Analysis.

For the year 2007 the mixing and optimization of source waters could have led to significant decreases in carbon emissions contributed from chemical production. The largest potential decreases were from July-September; this corresponds to the absence of powder activated carbon in the optimal mix. PAC has the highest carbon equivalent, therefore a source water influent with DOC concentrations that are low enough to not warrant the use of PAC will lead to the largest decreases in carbon emissions. The average over the four month period is a decrease of 44%. Overall savings related to the chemical decrease in depicted in Figure 3.5.1.

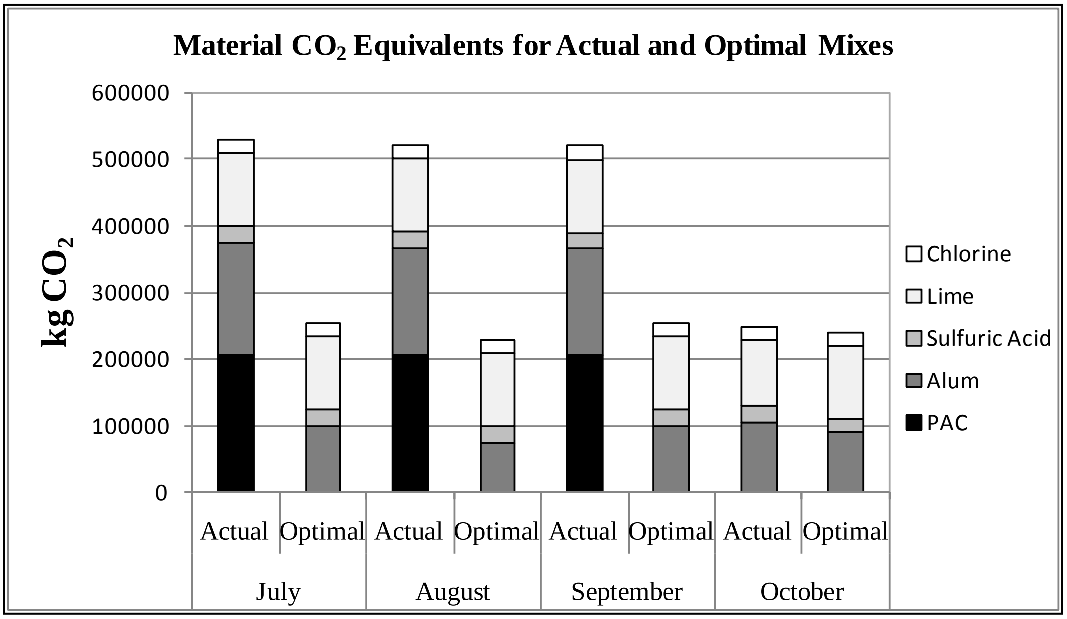

Figure 3.5.1 Material $CO_2$ Equivalents

The off-set hydropower must be accounted for when comparing the carbon footprint of the actual and optimal mixes. The energy that was generated during the hydropower dam will be replaced by the purchase of energy generated on the grid. Energy produced by coal, natural gas, and hydropower have 1041, 622 and 18 tons of carbon equivalents per Gigawatt-Hour respectively. Figure 3.5.2 depicts the changes in the carbon footprint based upon the type of energy supplanted. Once the offset energy is taken into account the optimal mix for the embedded costs has the potential to drastically increase, dependent upon the source of replacement energy. For this scenario, it is likely that the offset energy purchased from the grid will be coal generated which increases the carbon equivalents by magnitudes. The optimal solution from the environmental standpoint would be to replace the energy with power generated from an alternate hydropower dam. In the event that this is not possible, the savings in materials will be trumped by the increase in environmental impacts credited to power generation.

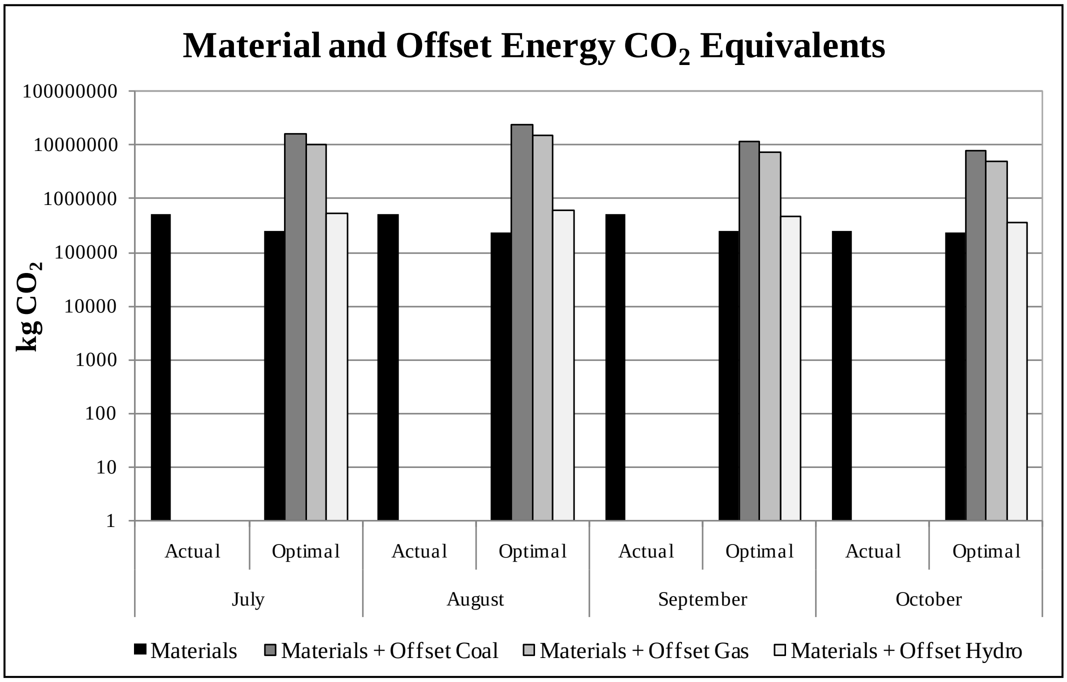

Figure 3.5.2 Material and Offset Energy $CO_2$ Equivalents

## Chapter 4

## CONCLUSION

This study attributes to knowledge on the meticulous relationship of the water-energy nexus through insight into the case study's water and energy savings. In this set of circumstances a balance was found between paying for alternative energy and obtaining costs savings through drawing upon alternate resources. These savings come with potentially high cost to environmental impacts. The author concludes that at this time there are limitations prohibiting employ of the preferred alternative. While several simulations displayed the potential savings to the WTP and to the environment through the aid of Verde River water, there are some limitations that hinder the models potential use for planning. The narrow range in the required values warrants the necessity for improvements in the ability to forecast seasonal DOC. Furthermore, unsteadiness in the energy market is a vital limitation for the models application. This study has provided the supplier with groundwork that enables them to identify circumstances that have prospect for costs and environmental savings.

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