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# Estimation and Comparison of Thermoelectric and PV Solar Water Usage in the Colorado River Basin States

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# ESTIMATION AND COMPARISON OF THERMOELECTRIC AND PV SOLAR WATER USAGE IN THE COLORADO RIVER BASIN STATES

By

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ABSTRACT

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With the continual expansion of populations in the arid Southwest, energy demands will continue to rise. On the other hand, depleting water levels in reservoirs of the Colorado River Basin is expected to continue as more intense and frequent drought events persist in addition to the rapid development in the region. Currently, the three largest water-use categories in the United States are thermoelectric energy, irrigation, and municipal water, which cumulatively account for 90 percent of the national water use. In the Southwest, most of the total electricity generated is still through thermoelectric means. That is, massive amounts of water are used to boil into steam to move the turbine to generate electricity. With such high dependency on water, higher energy demand in the future will lead to further rise in water demand. Therefore, more energy-specific water usage research is needed to determine the success of water resource management for future sustainability. The objective of this study seeks to estimate and compare the water usage in thermoelectricity generation (i.e. natural gas, coal), and solar energy, in five southwest Colorado River Basin states. The term “water use” includes both water withdrawal and consumption from a water body. While solar energy in general includes both thermal solar (Concentrated Solar Power; CSP) and non-thermal solar (Photovoltaic; PV), CSP is also

considered a type of thermoelectricity since it utilizes water intensive steam turbines. Thus CSP was not emphasized as the main focus of this study for the comparison of renewable energy alternative to fossil fuels. Results from the first stage of the study, which was based just on the state of Nevada, showed that with PV solar generating 2.84% electricity of the state total in 2014, Nevada saved approximately 56 million gallons of water. To further investigate other southwest areas and their potentials in solar energy, this study expanded the scope from the first stage study to examine four additional Colorado Basin states that have experienced the most droughts in recent years: Utah, New Mexico, Arizona, and California.

This study was conducted in two main parts: 1) estimation of the amount of water consumption and withdrawal for utility scale thermoelectricity generation and PV Solar energy for the past ten years, and 2) projection and comparison of future water demand in the basin states, based on each state's renewable energy portfolio standards (RPS). To accomplish the research objectives, estimations of operational and pre-operational water usage was determined as a function of the thermal fuel sources, cooling systems, and generator types used by power plants combined with established water coefficients per unit of electricity generated. Operational water use refers to the water withdrawal and consumption throughout the process of generating electricity. Preoperational water use refers to the water used to acquire and prepare the fuel sources. The same calculation was applied to calculate the water use for PV solar electricity generation.

This study utilizes the system dynamics (SD) model developed from the first stage study to evaluate the interrelationship of thermoelectricity responses from PV Solar energy on water use and their potential for water savings. A model that runs different simulations based on each state's optimal Renewable Portfolio Standards (RPS). Three case scenarios were simulated to

examine the projected energy outlooks by 2032. The first scenario examined projections with the present state of conditions on electricity generation by fuel distributions. The second scenario explored the projections based on the optimized expectation of each state's current RPS while the third scenario explored the projections on a modified hypothetical RPS expectation. A sub-scenario was created as a reference case to examine how much water were saved from the current trend of electricity production by renewable sources.

Results from the past water usage estimation show that although electricity demand has been a slow and steady decline for the past decade, energy demand for the future will continue to increase, but at a less intense rate than population growth. Although each state had set RPS goals to advocate for more future electricity production from renewable energy, and corresponding actions have been taken to build more renewable energy based power plants, statistics showed that they are currently still, and will be in the near future, highly dependent on burning fossil fuels. For example, while California holds the lowest percentage of coal-fueled electricity production (0.4%), it shows an increasingly higher dependency on natural gas over the past decade (from 49% in 2005 to 61% in 2014). Results from the model simulation indicate that with each state's current RPS goals, approximately 600 million to 1.3 billion gallons of water can be saved annually. Three out of five study states showed significant water savings with projections on a modified hypothetical RPS that will increase the PV solar energy production amounts while decreasing coal. Improvement on RPS goals would be beneficial for Arizona, Nevada, and Utah, while continual compliance to the current RPS goals would be sufficient for California and New Mexico. This study is reproducible so that it can be replicated using other renewable energy sources to test the potential for water efficient energy fuel replacement. Findings from this study will shed light on water resource management involving the utility scale

energy sector. Millions of gallons of water are used every day to produce energy. It is important to better explore energy alternatives in the hope of preventing further water shortage in the Southwest. Policy makers may reconsider whether to develop a more aggressive approach that depends on water conservation from the general public or to redesign current water conservation strategies that target the electric sector.

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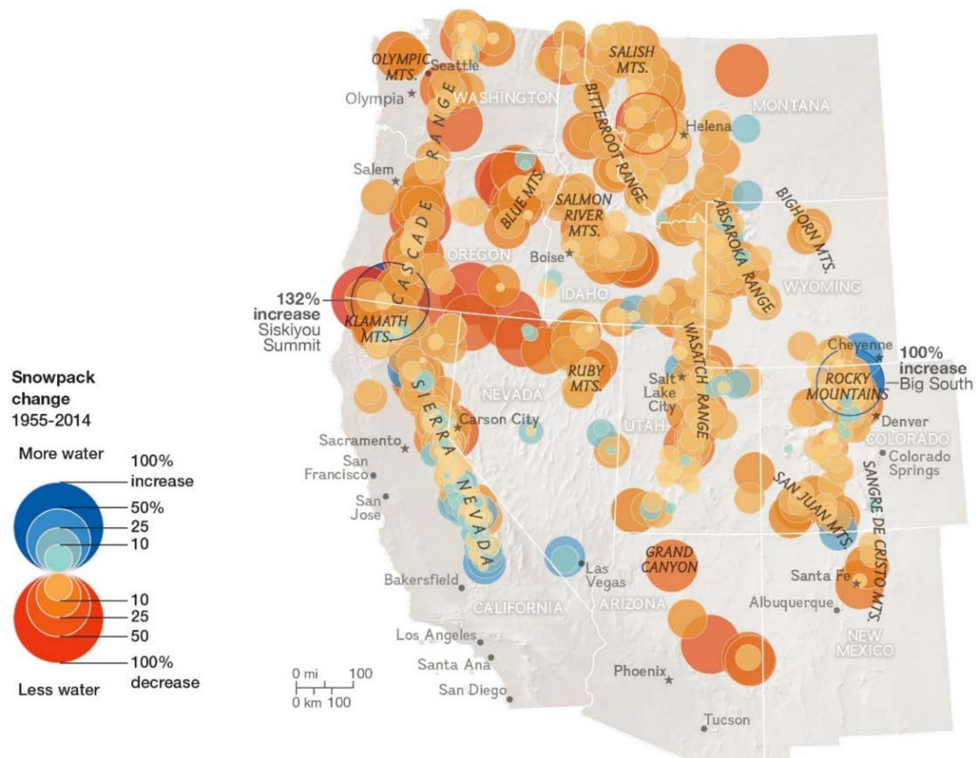
# CHAPTER ONE - INTRODUCTION

## 1.1 Background

Water plays a significant role in supplying urban development as well as in sustaining ecological activities. In the southwestern United States, the Colorado River is the primary water source for parts of seven southwestern states in the U.S. and two northern states in Mexico. With a total drainage of approximately 243,000 square miles, the Colorado River offers water supply for more than 33 million people and thousands of native plant and animal species. The majority of the flow in the basin come from Rocky Mountain snowmelt, yet most of the water usage occurs in the semi-arid and desert regions of the lower basin for irrigation and thermoelectricity (Benke and Cushing, 2005; Maupin *et al.*, 2010). Water usage is common for domestic and industrial purposes, such as irrigation, power generation, aquaculture, and mining. The term "water usage" includes both water withdrawal and water consumption from a water body. Water withdrawal refers to the amount of water removed from a water body, but some of that water can be returned to its source. Whereas water consumption refers to the amount of water removed that cannot be returned to its source. For the last 59 years, the relationship between precipitation and water demand has been inversely proportional as shown in *Figures 1.1* and *1.2*. The amount of snow precipitation has not been keeping up with the speed of snowmelt. Changes in this crucial aspect have imposed intensifying effects on many dependent variables that rely on the availability of snowmelt, such as soil moisture, streamflow, the onset of wildfire, or flooding events (EPA, 2016). In recent years, due to below average river flows, continual decrease in water levels were observed in reservoirs along the river. For example, Lake Powell is just 3,600 feet above sea level, the fall of water levels has dropped the reservoir capacity to less than 50%, which is its lowest levels since its filling in 1980 (USBR, 2015). Further water stringency is also seen in downstream areas. In summer 2014, water levels in Lake Mead dropped to the lowest

since the reservoir was filled in the 1930s, at just 1,080 feet above sea level. The reservoir capacity has dropped to less than 40%, which is more than 130 feet below capacity (USA Today, 2014). Diminishing discharges throughout the river basin have led to increased numbers of endangered or threatened species (Benke and Cushing, 2005). More than 20 species of fish, reptiles, birds, and mammals along the Colorado River in the Grand Canyon are federally recognized as endangered or threatened (NPS, 2015). The management of how we can balance viable water resources for urban development in the desert ecosystems is a demanding task.




VIRGINIA W. MASON AND KELSEY NOWAKOWSKI, NGM STAFF. SOURCES: NATURAL RESOURCES CONSERVATION SERVICE; CALIFORNIA DEPARTMENT OF WATER RESOURCES; DARRIN SHARP AND PHILIP MOTE, OREGON STATE UNIVERSITY

*Figure 1.1.* Nijhuis, M. (2014). *Historic snowpack changes from 1955-2014* [Map]. Retrieved from http://www.nationalgeographic.com/west-snow-fail/.

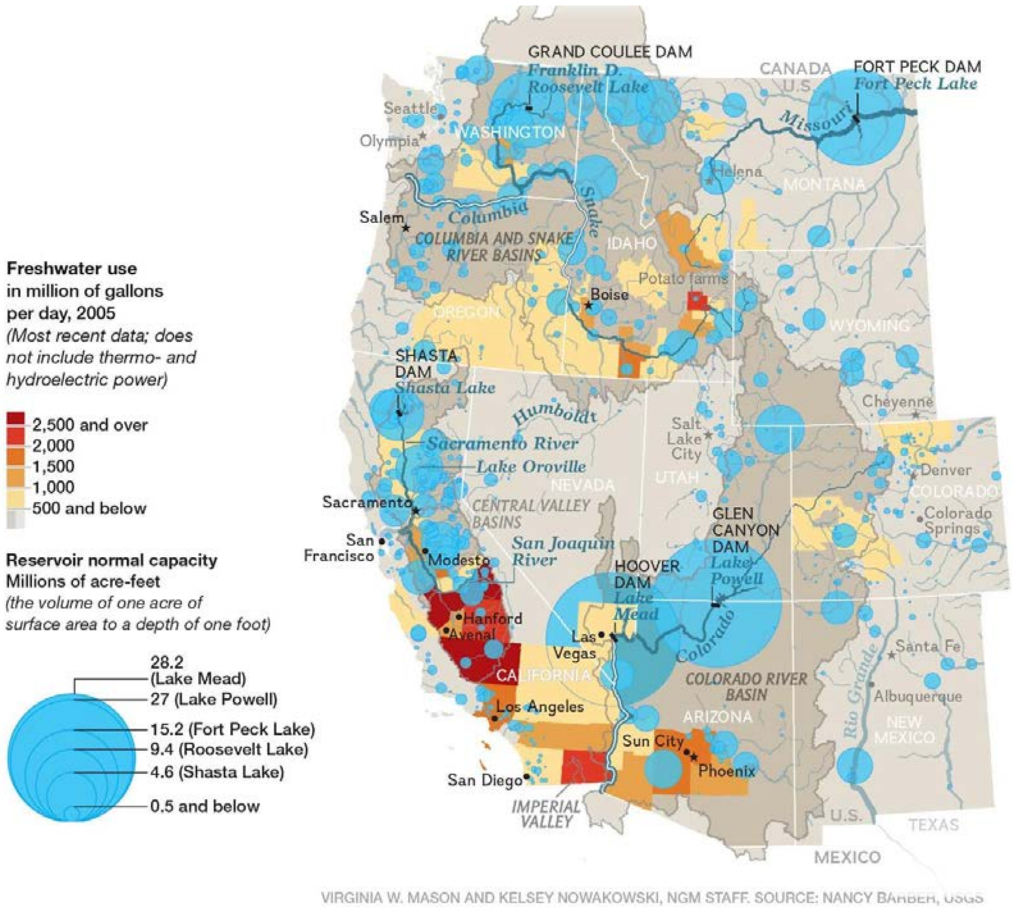



*Figure 1.2.*Nijhuis, M. (2014). *Freshwater usage in million gallons per day* [Map]. Retrieved from http://www.nationalgeographic.com/west-snow-fail/.

## 1.2 Droughts in the Southwest

Currently, abnormally dry conditions have been lingering in the Southwest, leaving much of the lands parched, especially seen in California as shown in *Figure 1.3*. A majority of the Southwest long-term cumulative drought conditions were considered extreme droughts or worse. According to the U.S Drought Monitor Center (USDM, 2015) and the National Oceanic and Atmospheric Administration (NOAA, 2015), approximately two-thirds (65%) of the rangeland and pastures in California were rated with poor to very poor conditions. California is also ranked highest in poor topsoil and subsoil moisture with an estimated 90% land being short or very short of moisture, as shown in *Figure 1.4*. (USDM, 2015; NOAA, 2015). Furthermore, significant

water-supply shortages due to the multi-year drought are seen in Arizona, California, Nevada, and New Mexico.  Long-term drought conditions have impacted on farms in the Southwest, this led the U.S Agriculture Department to declare numerous counties in California, Arizona, Nevada, and Utah natural disaster areas in 2015 (USDA, 2015).  Occurrences of severe droughts and extreme droughts are expected to increase toward the end of the twenty-first century, particularly in the Colorado River Basin (Cayan et al., 2010; MacDonald, 2010).  The increased drought severity will amplify wildfire frequencies in arid regions and the bordering regions (Williams *et al.*, 2014). Currently, wildfires are most severe in California, Nevada, Arizona, and Texas.  Increased fire sizes were also observed as more wildfire events have occurred in the Southwest, specifically an increase of approximately seven large wildfires (fires that have burned an area of more than 405 hectares) each year (Dennison *et al.*, 2014). Losses because of wildfires include not only wildlife habitats and their associated ecological activities, but also billions of dollars for fire management and damage control (Kearney *et al.*, 2014).  The increased risks of more frequent and mega-droughts in the Southwest indicates a need for reevaluation of past water conservation plans and the need to prevent further water shortages.

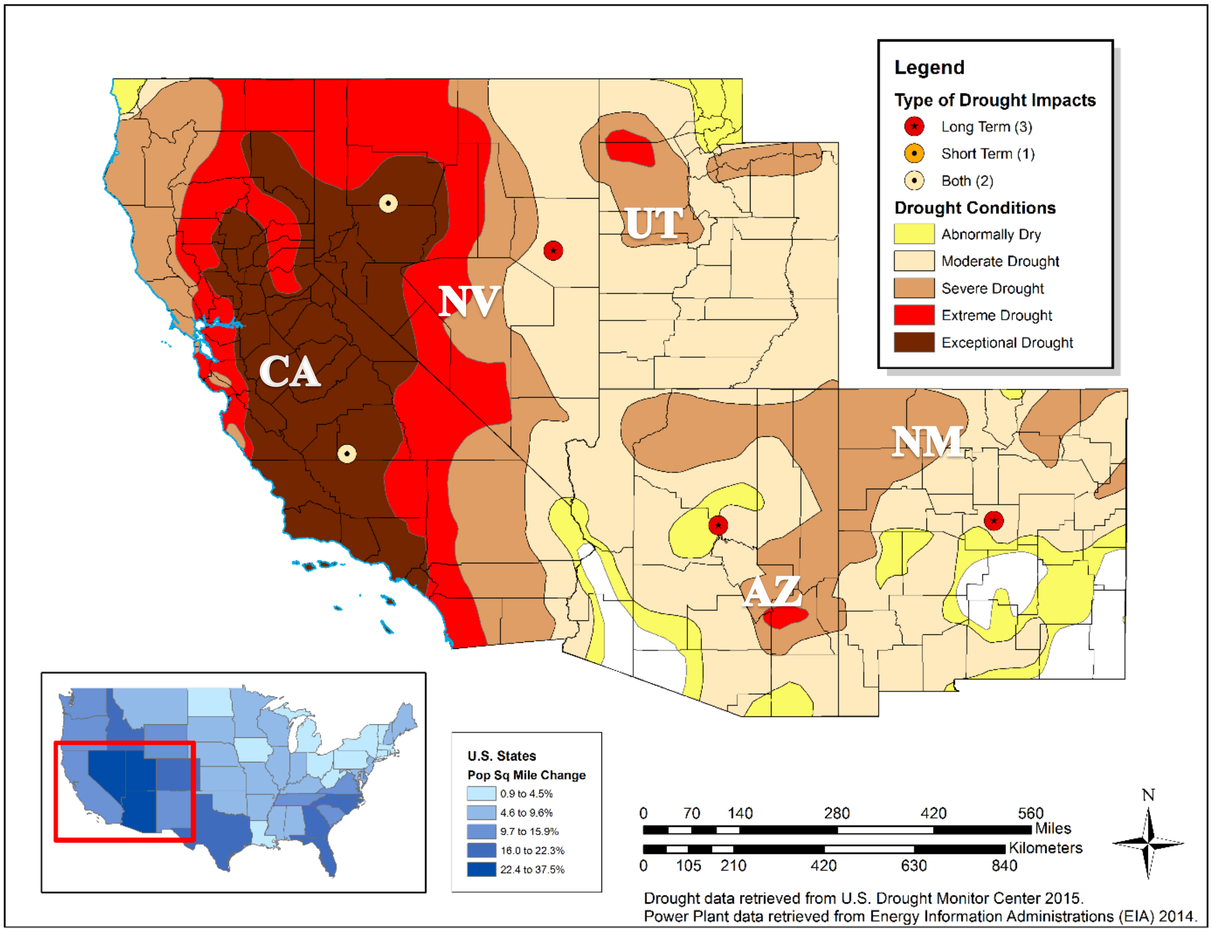



*Figure 1.3.* Drought conditions in the five chosen Basin States as of October 2015.

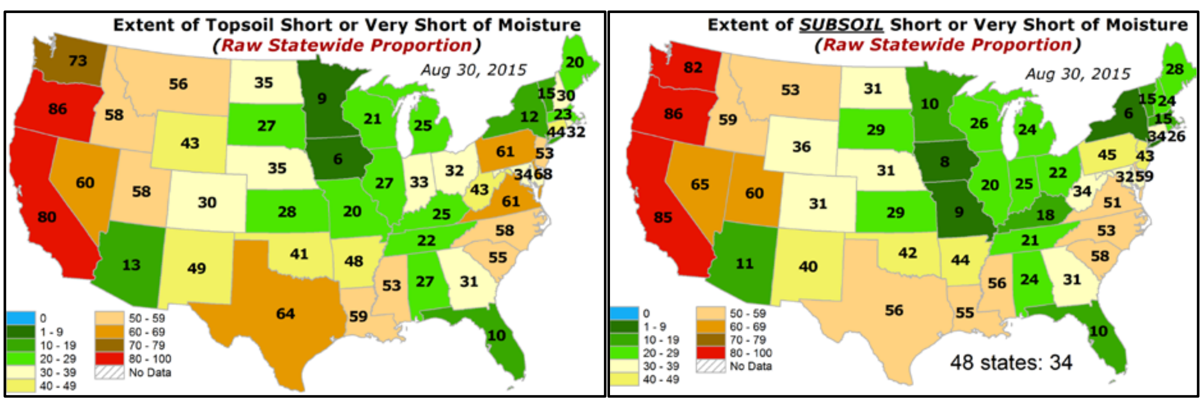



*Figure 1.4.*Topsoil and subsoil condition in the contiguous U.S. (adapted from NOAA, 2015).

## 1.3 Growth in the Southwest

Along with climate change, rapid urban development in the Southwest can also contribute to the water crisis. Based on the 2014 U.S. Census estimates, four out of the top ten fastest-growing states in the nation are from the Southwest, ranked from highest to lowest; these states are Nevada, Colorado, Arizona, and Utah (U.S. Census, 2014). The population in these states have increased at least 15 percent from 2005 to 2015. The population in Nevada increased more than 30 percent between 2000 and 2010, and it is expected to increase from the 2014 estimate of 2.8 million to 3.3 million by 2033 (NV Demographer, 2014). The same trend is also observed in the other fastest growing states. Population in Arizona and Colorado is expected to increase from the 2014 estimates of 6.8 and 5.4 million, respectively, to 2033 forecasts of 8.9 and 7.3 million, respectively. Utah will have a 31 percent population increase from the 2014 estimate of 2.9 million to 3.9 million by 2030 (UT Governor's Office, 2012). Rapid population growth in the Southwest results in water resource competition across different sectors. Agricultural irrigation withdrawals account for 37 percent of the total freshwater withdrawals in the nation. Irrigation in the Southwest accounts for more than 40 percent of total irrigation withdrawals in the United States (USGS, 2014) while California irrigation alone uses approximately 19 percent of the total irrigation withdrawals. However, on a national level, for the past several decades, the largest portion of water withdrawal was for thermoelectric power production, followed by irrigation then public supply as shown in Table 1. In years prior to 2010, water withdrawal for thermoelectricity production was 161 billion gallons per day, which accounted for well over 45% of the national total (Maupin *et al*, 2010). The historic loss of reservoir storage has resulted in hydroelectric production losses and decreased energy supplies (MacDonald, 2010). Hoover Dam's electricity production capacity has been reduced by about 25

percent, whereas Glen Canyon Dam's power production experiences an 8 percent annual drop based on the 2013-14 expectation (Thiel, 2013; Capehart, 2015). Within California's four continuous dry years, Lake Shasta has dropped to half of its capacity, which has caused a cutback of approximately one third of the dam's electricity production. Many dams across California face the same circumstance and some are down to less than 20 percent of their normal production. These reduced hydroelectricity productions would have to be compensated by other energy source, such as natural gas (Xia, 2015). As populations in the Southwest continue to grow at the current pace, public demand for electricity will accelerate. This increased burden on the already stressed water resources will result in increased energy costs per household. Balancing water supply for different users will be even more challenging in the future.

Table 1
*National water uses by categories from 1990 to 2010. Information based on USGS five-year Water Census Compilation Report series (USGS, 2010).*

| | Thermoelectric Power | Irrigation | Domestic | Public Supply | Industrial | Mining | Aquaculture | Livestock |
|---|---|---|---|---|---|---|---|---|
| 2010 | 45% | 33% | 1% | 12% | 4% | 1% | 3% | 1% |
| 2005 | 49% | 31% | 1% | 11% | 4% | 1% | 2% | <1% |
| 2000 | 48% | 34% | <1% | 11% | 5% | <1% | <1% | <1% |
| 1995 | 47% | 33% | <1% | 11% | 6% | <1% | N/A | 1.4% |
| 1990 | 48% | 34% | <1% | 10% | 6% | 1% | N/A | 1.1% |

## 1.4 Energy and Water

In recent years, various water conservation programs were implemented throughout the Southwest, which mainly targeted on regulating public and domestic water usage. Such programs include usage of reclaimed water on golf courses, offer incentives to promote adaptation to less water intensive landscapes, and reinforce community-based watering schedules (SWCD, 2015). However, few were aimed towards the utility scale energy sectors. The process of thermal energy production is highly dependent on water. Conventional methods of electricity

generation are based on burning fossil fuels, such as coal or natural gas, commonly referred to as *thermoelectricity* generation. Steam-run and combustion turbines are the two most commonly used thermoelectric technologies throughout the southwest. In typical steam-run generating units, water is needed for a boiler to create steam to rotate the turbine blades, which drives the compressor to create energy. In combustion turbines, high-temperature gasses pass through a combustion chamber to achieve the same reactions, but a considerable drop in pressure is expected throughout the process. In order to capture potential heat loss, some power plants have heat recovery systems that boil water to drive a secondary steam turbine. Other water uses are needed in the operational phase, such as flue gas cleaning to reduce air pollution, removal of mineral build-up in cooling towers to increase cooling efficiency, and the cooling agent for various types of cooling systems. Furthermore, pre-operational procedures such as fuel processing, transportation, and disposal can also contribute significantly to the total water withdrawal and consumption. On the contrary, electricity generation from renewable energy sources, such as solar, biomass, and geothermal energy can reduce the dependency of water in the generation process only if the power plant uses the most efficient cooling systems. Although some renewable energy sources use less water than conventional nonrenewable thermoelectric systems, any type of thermal energy that employs steam turbine technology and cooling systems will consume significant amount of water. For example, a plant that uses geothermal energy with a dry-cooling system can consume up to 1,800 gallons of water per MWh (Macknick et al., 2011). Whereas non-thermal renewable technologies that transform energy from the direct source uses essentially no water. The use of renewable energy such as solar and wind also alleviates the concern that fuel sources might eventually run out in the future. The maximum water consumption rate for a PV solar, utility-scale power plant is 33 gallons per MWh, which is

100 times less water consumed per MWh than consumed by natural gas. Factors such as reduced cost, innovative financing, and the abundance of sunlight in the Southwest have increased the popularity and demand for PV solar energy. A majority of the thermoelectric water withdrawal in the Southwest comes from scarce surface waters in the reservoirs of the Colorado River basin and neighboring groundwater wells. Nevada currently has 20 out of 63 power facilities that use nonrenewable fossil fuels for energy generation. More than a third of these facilities still employ steam technologies that consume a massive amount of water each day (EIA, 2015a). The same trends are seen in the neighboring Basin States, 37 out of 61 power facilities in Arizona, 28 out of 46 power facilities in New Mexico, and 32 out of 45 power facilities in Utah use natural gas, coal, and petroleum products for electricity generation. Current rates of implementing renewable electricity production and water conservation strategies to preserve water resources are not keeping up with the burgeoning urban development and water shortages in the southwest. Estimation of water usage in renewable solar powered technologies should be done to measure the change in potential water savings in cases of energy source replacements.

### 1.5 Initial Study

A small-scale first stage study for the state of Nevada was carried out in October 2015. The study developed the calculation methods to estimate total water usage and simulations of future water savings in different scenarios of thermoelectricity technology and photovoltaic (PV) solar energy in the state of Nevada. This previous study examined the state of Nevada to compare water usage between coal, natural gas, and PV solar energy from 2004 to 2014. Currently, thermoelectric power plants in Nevada withdraw an average of 33,000 million gallons of operational water per year and consume approximately 6,300 million gallons of operational water per year. In 2014, approximately 2.84 percent of energy was generated using PV solar as a

renewable energy source. The 2014 estimated water savings by using PV solar to generate electricity was 56 million gallons of water. Even if the percentage of PV solar generation is kept at only three percent, the amount of water saved increases as the demand for electricity increases. Results from the study also showed that Nevada has an estimated 10 percent operational water savings (566 million gallons) if PV solar energy can increase its electricity generation, from the current 2.84% to 7% of the state's total electricity productions by the year 2032.

### 1.6 Hypothesis and Objectives

The overall scope of this study is an expansion of the previous study. The expanded scope includes four additional Basin States. The objective of this study was to estimate the water used for coal and natural gas fueled thermoelectricity in the Basin States that have experienced the most droughts in the lower Colorado River Basin in recent years. To highlight the imminent water issues in the Southwest for the past decade, the four additional Basin States were chosen as shown in *Figure 1.3*: Arizona, California, New Mexico, and Utah. The study goals were to place the electricity water usage from the past decade into the context of the future ten to twenty years to determine how electricity water usage in the Southwest is likely to change from its past patterns in the future. To achieve this objective, the study tested the hypothesis that more water could be saved if coal was to be replaced by solar energy than from the replacement of natural gas. Solar energy in general includes both thermal solar (Concentrated Solar Power, CSP) and non-thermal solar (PV). While CSP is considered a type of thermoelectricity that utilizes water intensive steam turbines, photovoltaic systems have the ability to convert sunlight directly into electricity without the need of boiling water. Therefore, CSP is not considered to be the main focus of this study for the comparison of renewable energy alternative to fossil fuels. The hypothesis was tested quantitatively, but each state's renewable portfolio standards (RPS) were

also evaluated to underline the larger aim of the hypothesis: to explore the relationship between current energy trend and future governmental incentives on the issue. This study addresses two key questions: 1) how much water is being used for thermo-electricity production and 2) how much water can be saved if power plants replace fossil fuel energy sources with PV solar energy. Considering the strong correlations between electricity demand and water demand, findings from this study can implicate prospects of future renewable portfolio standards and water resource management policies in each state.

### 1.7 Significance

This study is significant to the understanding of energy water usage in the southwest region and to fill in gaps of the previous study. Currently, what little water data exists for power plants that are publicly accessible is not focused on the total water usage throughout the electricity production process. Past studies on the water usage per unit of electricity generated were done (Macknick et al., 2001; Fthenakis and Kim, 2010), but they were fragmented to only parts of the energy generation process. Accurate estimation of the water used in energy production can offer insights for water resource management in the lower Colorado River Basin. In addition, topics on efficient energy are highly publicized, yet the impact that electricity generation has on water resources are oftentimes overlooked. This study seeks to estimate water savings if electricity generation can be shared between thermal and renewable energy by linking the scattered data from previous studies to produce an integrated estimation of total water usage in electricity production. A more coalesced estimation that focuses on the water concern can provide data for future studies in the water-energy nexus. Estimation and projection of the total water usage and water savings between different energy fuels can help improve potential water conservation outlooks in future power supply developments. The future development of the

energy sector should consider water-efficiency as an important aspect in choosing energy production technologies.  Policy makers can find results from this study informative, and reconsider whether to develop more aggressive new water conservation regulations or to re-design current water conservation strategies that target the energy sector.

### 1.8 Study Approach

This study mainly entails calculation and analytical work focused on the management, control, and schema manipulation applications of publicly available water-energy data. Calculations for water usage were based on the 1,300 operating generators from power plants in the five Basin States that have a reported geolocation.  In this study, all energy data involved were converted to express in units that are based on the unit Kilowatt-hour (KWh), which includes Megawatt-hour (MWh, equaling to one thousand KWh), Gigawatt-hour (GWh, equaling to one thousand MWh), and Terawatt-hour (TWh, equaling to one thousand GWh).  The KWh is a commonly used unit of energy transmitted or sustained for one hour delivered by electric utilities.  All water data involved were converted to express in units that are based on the unit gallons of water (gal) over a period of time. These include million gallons (Mgal) and billion gallons (Bgal).  The Mgal is a commonly used unit of water-usage in the U.S., which is equivalent to approximately twenty thousand home baths (USGS, 2016).  If one were to attempt to fill up a standard size football field to the highest point of the goal post, which is a total of 30 feet tall, the relative amount of water needed would be approximately 4.3 million gallons.

This study employed analytical techniques for data modification such as using standard query language (SQL) to manage relational data for all power plants such as types of fuel, cooling systems, and technologies.  The modified data was used to adopt the appropriate operational and pre-operational water rates (gallons/MWh) per unit of electricity produced

(MWh) by each generator to deduce the total water withdrawal and consumption in million gallons. Projections of each state's population growth, electric sales data, and calculated water usage were used to estimate future electricity and water demand. Projected values and calculated total water withdrawal and consumption from different energy sources in each state were used as inputs to determine the estimated water saved from substituting different types of renewable energy sources to a portion of the conventional thermo-energy source. Different substitution scenarios of renewable energy sources were calculated to compare potential water saving rates (i.e., Substituting different percentages of PV solar to portions of coal). To further address the water management aspect of the study, this study implements each state's RPS into the model simulation. As a combination of these analyses, a brief discussion is presented based on the comparison and evaluation of each state's RPS program effectiveness in water resources management.

## 1.9 Renewable Portfolio Standards

Since the energy bill "American Clean Energy and Security Act" was passed on 2009, many states in the U.S. increasingly adapted regulatory policies to ensure the production of renewable energy were being promoted in each state (H.R. 2454, 2009). These mandated regulations are collectively called Renewable Portfolio Standard (RPS). The initiative for developing RPS goals in each state was to promote the production of energy other than by conventional means. Some common RPS regulation approaches are to increase renewable energy sources such as wind, solar, and other alternatives while progressively decreasing the dependency on non-renewable fossil fuel electric generation. Currently 38 states and the District of Columbia have adopted RPS in the U.S. Although RPS were mandated on the federal level to encourage renewable energy share, different states can issue different expectations on the minimum quantity of

Renewable Energy to be included in the policies. For example, Maine's RPS goal was to increase its overall renewable energy generation to 40% by 2017, whereas West Virginia's original RPS goal was to increase overall renewable energy generation to 25% by 2025, but the entire program was later repealed in 2015 (Durkay, 2016).

# CHAPTER TWO - ESTIMATION OF WATER USAGE

## 2.1. Data Collection

All electric data used in this study was based on publicly available, utility scale power facilities' data collected from the Energy Information Administration (EIA) by the U.S. Department of Energy for years 2005 to 2015. Collected data were compiled to construct an analogous measure based on energy generation rather than capacity for each power plant. Data prior to years 2007 were less suitable as variables since the EIA modified the survey contents. Collected compilation information was sorted based on each electricity-generating units in each power plant.

### 2.1.1. Electricity Data

Data for the total net electricity generated by power plants were collected mainly from the EIA Forms 923 and 860 (Power Plant Operations and Annual Electric Generator Report Database). These publicly available electricity data were self-reported to the EIA by power plants that met two criteria:

1) Power plants that have a nameplate capacity of one megawatt (MW) or greater, and;

2) Power plants that have generators connected to the local or regional electric power grid and can draw or deliver power to the grid (EIA, 2015b).

The four types of cooling systems commonly used by conventional thermoelectric power plants are once-through systems, recirculating systems, dry-cooling systems, and cooling ponds. Information on power plant characteristics from EIA Form 860, such as cooling system types, plant location, and the prime mover types were manually updated based on literature research. For example, public records of the Edward W. Clark Generating Station facility located in Las Vegas, Nevada, indicated that the plant used a cooling pond. The plant's cooling system was changed to a once-through system from 2010 to 2012, and then changed again to a recirculating system from 2013 to 2014 according to the EIA. Moreover, public records of the Harbor Generating Station located in Wilmington, California, indicated that the power plant location coordinates are at 33.770477, -118.265614, whereas such information was missing from the EIA surveyed data. Plants that did not report any specified cooling characteristics were assumed to have the same cooling systems that were found in the company's public records (EIA, 2015b). For example, no cooling system types were specified on EIA Form 860 for Black Mountain Cogeneration Plant, but a recirculating system with cooling ponds was indicated in the public records (NDEP, 2007). The analysis assumes that all generating units within the same power plant and employ the same fuel type would also use the same cooling system. For example, generating units that were marked to a retired cooling system but had designated wet-cooling technologies were assumed to have the same cooling systems as other operative units in a power plant that used the same fuel source.

Across the five study states, there are 1,954 generating units from the 1,508 utility scale power plants. Of these surveyed generating units, 194 generating units do not have a geolocation. There are about 22 generating units that were labeled with the EIA Utility code "9999", which contain data that represent generating units that do not have a geolocation. Data

inspections were done for other plant operational details to ensure data accuracy. About 232 generating units' geolocation, cooling systems, and the prime mover type were manually inputted to update the correct value throughout the ten-year duration. *Figure 2.1* shows the stacked three-dimensional distribution of the total generating units sorted by state per year. The huge difference in scale between California and the other Basin States is due to it having the largest population amongst other states which results in needing the highest number of power plants (almost 13 times more than the others) to support growth. The number of thermoelectricity generator units by state per year are, ranked from the most to the least number of units in 2015; California (663), Arizona (99), Utah (68), Nevada (65), and New Mexico (51).

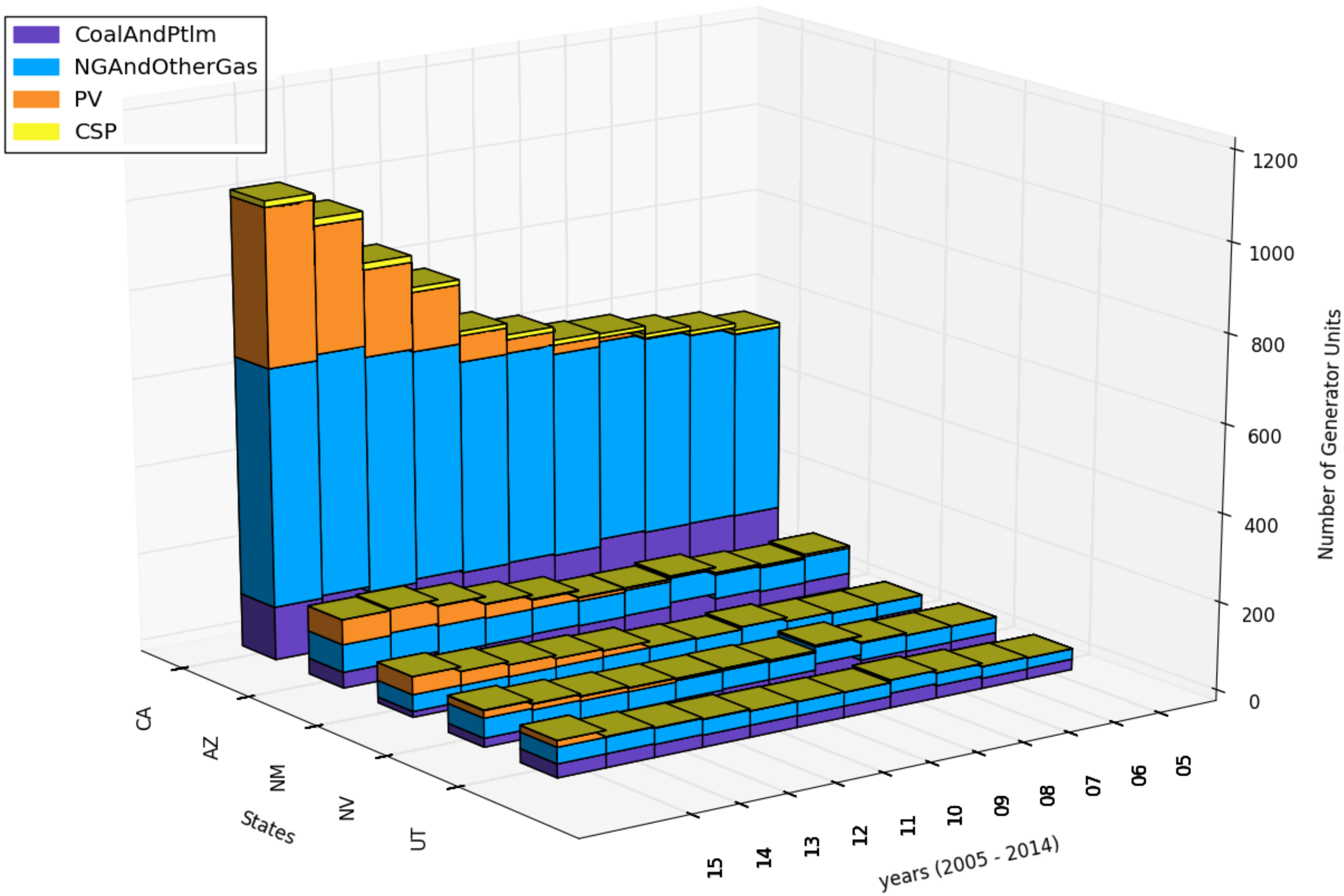



*Figure 2.1.* Distribution graph on the number of generator units per state per year. (Based on data obtained from EIA form 923)

### 2.1.2. Water Use Coefficients

Water use coefficients have a direct connection with energy generation in the calculation process. Various established pre-operational and operational water coefficients from past studies by the U.S. Geologic Survey (USGS) and/or the National Renewable Energy Laboratory (NREL) were utilized for the calculation of the total water usage at each power plant (Diehl et al., 2013; Macknick et al., 2011; Klett et al., 2007). Water coefficients for the operational phase associated with power generation were retrieved from Macknick et al. (2011) while the pre-operational phase based on heat and water budgets are retrieved from Fthenakis and Kim (2010). In addition, other types of water consumption or withdrawal factors as retrieved from Diehl et al. (2013) were included in the calculation to produce a more accurate estimate. Other water withdrawal coefficients include processes like flue gas desulfurization and combustion turbine inlet cooling are included the table listing operational water withdrawal. Adjustments and modifications were done to update the published water coefficients to reduce estimation uncertainties. The modified operational water coefficients used in the calculation process are listed in Table 2.

Table 2
*Operational water withdrwal and consumption coefficients used for calculation (gal/MWh) (reproduced from macknick et al., 2011)*

| Fuel Type | Prime Mover | Cooling Type | Consumption Q | Withdrawal Q |
|---|---|---|---|---|
| Coal | Steam | Tower | 687 | 1005 |
| | | Pond | 545 | 12,225 |
| | | Dry Cooling | 42 | 1,277 |
| | Combustion | Generic | 471 | 586 |
| Natural Gas | Combustion | Tower | 378 | 253 |
| | | Once Through | 100 | 11,380 |
| | | Dry Cooling | 2 | 2 |
| | Combined Cycle | CHP | 2 | 2 |
| | | Dry Cooling | 2 | 2 |
| | | Once Through | 100 | 11,380 |
| | | Tower | 378 | 496 |
| | Steam | Dry Cooling | 340 | 2 |
| | | Once Through | 240 | 35,000 |
| | | Pond | 240 | 5,950 |
| Solar- CSP | Steam | Tower | 865 | 865 |
| Solar -PV | | N/A | 26 | 26 |

Q= coefficient in gal/MWh

Preoperational water usage refers to when water is being used to acquire and prepare the fuel sources. Factors such as fuel extraction and beneficiation and transportation processes were included in the coefficient to determine the preoperational water use (Fthenakis and Kim, 2010). Beneficiation is the process that removes unwanted minerals in an ore deposit to produce a higher grade product. In the fuel acquisition and preparation stage, water is used primarily for cleaning. Data on preoperational water withdrawal and consumption were adapted from the literature (Fthenakis and Kim, 2010). The preoperational water-use coefficient was calculated by taking the sum of different processes such as beneficiation, transportation, and construction and an averaged value for fuel mining and extraction in the unit of gallons per megawatt hours (gal/MWh). The same calculation was applied to calculate the preoperational water use for PV solar electricity generation. Preoperational water use was considered to be zero because PV

solar requires no water for fuel. Therefore, only the operational water use of current and future thermoelectric and PV solar energy projections were compared. Details on the calculated preoperational water-use coefficients are shown in Tables 3 and 4.

Table 3
*Preoperational water withdrawal coefficients for coal, petroleum, and natural gas power plants (gal/MWh) (reproduced from Fthenakis and Kim, 2010 and Diehl et al., 2013).*

| **Fuel Type** | **Stage** | | **On-site** | **Upstream** | **Both** | **Ave./ process** | **Total per fuel cycle** |
|---|---|---|---|---|---|---|---|
| Coal | Mining | Eastern underground | 50 | 134 | 184 | 66 | 114 |
| | | Eastern surface | 10 | 39 | 39 | | |
| | | Western surface | N/A | 3 | 3 | | |
| | | U.S. coal | 28 | N/A | 28 | | |
| | Beneficiation | | 12 | 14 | 26 | 26 | |
| | Transportation | Train | N/A | 10 | 10 | 10 | |
| | Construction | Coal power plant | N/A | 12 | 12 | 12 | |
| Natural Gas | Extraction | Onshore | 34 | 79 | 114 | 57 | 323 |
| | | Offshore | 0.2 | 0.1 | 0.3 | | |
| | Purification | | 17 | N/A | 17 | 17 | |
| | Pipeline transportation | | 0.4 | 10 | 10 | 10 | |
| | Storage - underground | | N/A | 4 | 4 | 4 | |
| | Power plant environmental control | | N/A | 235 | 235 | 235 | |

N/A = Not available

Table 4
*Preoperational water consumption coefficients for coal, petroleum and natural gas power plants (gal/MWh) (reproduced from Fthenakis and Kim, 2010).*

| **Fuel Type** | **Stages** | | **Reported Max** | **Ave./ process** | **Total per fuel cycle** |
|---|---|---|---|---|---|
| Coal | Mining | Surface | 14 | 33 | 62 |
| | | Underground | 53 | | |
| | Washing | | 17 | 17 | |
| | Beneficiation | | 12 | 12 | |
| | Transportation | Train | N/A | N/A | |
| Natural Gas | Extraction | Onshore | NG | NG | 23 |
| | | Offshore | NG | NG | |
| | Purification | | 15 | 15 | |
| | Pipeline transportation | | 8 | 8 | |

N/A = Not available

NG = Negligible

## 2.2. Methods

The reported data from the EIA contain important information for analysis, such as the unit annual net electricity generation, plant annual gross electricity generation, cooling-system information, boiler-fuel data, generator data, and plant frame information. All acquired data for each of the thermoelectric generating units and the generating units in the PV solar energy plants (*Figure 2.1*) were filtered to include only the attributes needed for the calculation. Descriptions of how these general attributes were filtered are shown in the subsequent sections.

### 2.2.1. Equation Components

Energy-generation data collected from the EIA Form 923 only report the annual net energy generation instead of the annual total energy generation. However, data collected from EIA Form 860 contain the plant gross generation. Annual net energy generation is the total (gross) energy generation minus the electricity used to operate the power plant in megawatt hours. Since one power plant can have multiple generating units, the gross generation for each generating unit can be achieved by having each generation unit's net generation divided by the total net generation from all units of the same plant. The equation to calculate the gross generation for each generating unit is shown below:

$$\left[\frac{(Unit\ Net_{\ 1})}{(Unit\ Net_{1+2+3+\cdots n})}\right][Plant\ Gross\ Gen]=\text{Unit Gross Generation (MWh)} \qquad (1)$$

Any generating units that contained a net zero or negative electricity generation were excluded from the database. Generating units that were marked retired or nonoperational were also excluded from the dataset.

Once all electric data from EIA forms 923 and 860 were collected and corrected, Structured Query Language (SQL) is used to create relational algebraic queries to extract necessary record sets from the database. Query commands were utilized in Microsoft SQL Server® to sort, extract, and calculate the results. Different clauses of the SELECT command are commonly used in combination with case statements to filter records, columns, and grouping categories in this query. Specific variables were used to categorize each thermoelectric power plant, such as the prime generator type, primary fuel type, primary cooling technology, number of generators, the calculated annual gross electricity produced by each generating unit, and the gross annual electricity production by plant. Tables from different datasets that have a matching Plant ID were imported into a common database using the INNER JOIN command and CASE statements to create new result tables. These expressions work by grouping categories based on values that have the same fulfilling condition. For example, a generating unit that has its prime mover type listed as “combined-cycle combustion turbine part” will be grouped as the same category as prime movers that were listed as just “combustion turbine”. Once the query is completed, customized results such as to display only the total electricity generated and total water consumption per state per fuel can be done using the “SELECT” and the “GROUP BY” statements. Detailed equations are provided in Appendix A. The newly created result tables would contain grouped properties of generating unit type, fuel type, cooling system type for the ease of calculation later on. The major types of cooling systems that were grouped from data manipulation series were dry-cooling, once-through, cooling ponds, cooling towers, and no cooling. Detailed lists of categorization and description of the different generating unit type, primary fuel types, and primary cooling types used in the calculation are shown in Appendices B, C, and D.

Only the operational thermoelectric generating units for the 10-year duration was arrayed for computation. Retired or non-operational generating units that does not generate or consume any electricity were excluded from the database. Range in variation among number of operational generating units could be a result of old units being retired and/or new units being built. Once the electricity generation data were queried, the annual pre-operational and operational water-use coefficients are assigned. The total water withdrawal or consumption was extrapolated by multiplying the sum of all calculated average water use coefficients with the calculated gross generation, shown in the equations below.

$$\frac{(C_{op}+C_{pre}+C_{other})(MWh)}{10^6} = Total\ Water\ Consumption\ (Mgal) \quad (2)$$

$$\frac{(W_{op}+W_{pre}+W_{other})(MWh)}{10^6} = Total\ Water\ Withdrawal(Mgal) \quad (3)$$

Where

$$W_x = \frac{Gal}{MWh}, C_x = \frac{Gal}{MWh} \ (4)$$

Generating units that declare coal, natural gas, and petroleum products as primary fuel types would have a calculated preoperational water-use coefficient since these values only apply to fossil fuels. Therefore, the final calculated amounts of water withdrawal and consumption based on each generating unit should contain all the possible water-use phases throughout the energy generation process.

#### 2.2.2. Calculation Structure

The different combinations of generating unit types, fuel source, and the cooling system types are important variables in determining which water coefficients to use. The roles of these

variables are shown in *Figure 2.2*, which shows a schematic diagram of the simplified computational steps in the process.

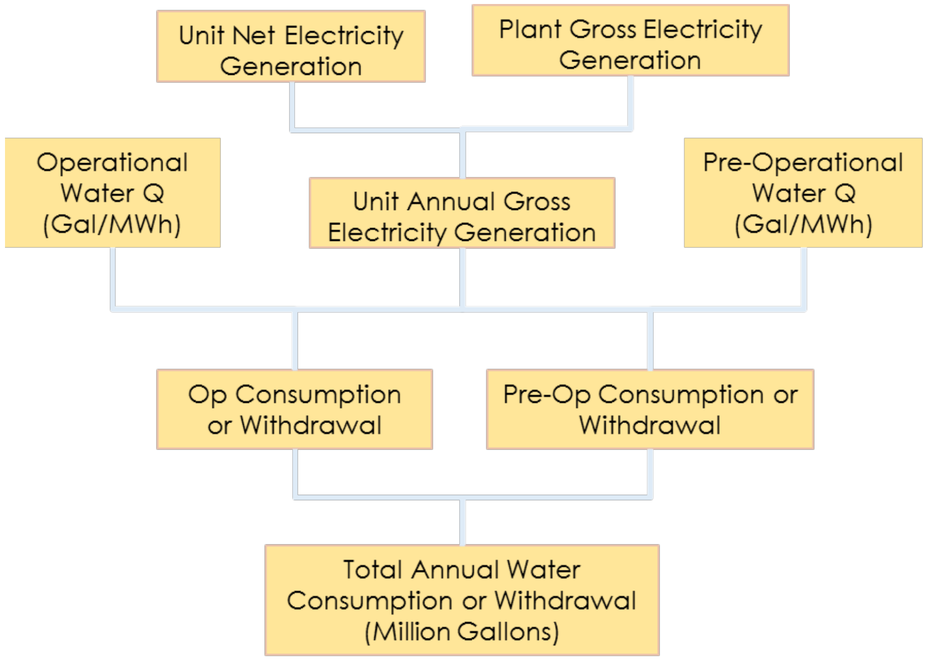



*Figure 2.2.* Flow Chart of the calculation process

As depicted in Figure 2.2, each generating unit's total net generation and the power plant's gross generation was used to calculate each generating unit's gross electricity generation. Operational and preoperational water consumption or withdrawal coefficient is then multiplied with the calculated gross to achieve the total annual water consumption or withdrawal in each generating unit. The process itself represents a small part of the reinforcing system. The more traditional and conventional the generating unit produces electricity at a higher rate, the higher value the water consumption and withdrawal, and the higher in water demand for these generating units.

Generic coal and natural gas power plants with steam turbines use huge amounts of water in cooling systems. The cooling system of a typical natural gas fueled thermoelectric unit consumes an average of 290 gallons of water per MWh. A coal-fueled unit can consume up to

three times more water than a natural gas fueled unit (Macknick *et al.*, 2011). Thermal-renewable energy sources such as concentrated solar power (CSP), biomass, and geothermal technologies generate energy via steam turbines similar to fossil fuel energy concepts. Regardless of the fuel source, steam production and cooling systems in any thermal energy production need water to proceed. For example, a plant that uses geothermal energy with a dry-cooling system can consume up to 1,800 gallons of water per MWh (Macknick et al., 2011). These types of renewable energy plant can use less water but only under the condition that the power plant uses the most efficient cooling systems. Moreover, non-thermal renewable fuels such as PV solar energy use essentially no water. It was assumed that PV solar plants do not require wet-cooling systems because they use water mainly for panel maintenance. Therefore, no cooling technologies were associated with PV solar energy in the calculations (Macknick et al., 2011). Generating units that use petroleum products were assumed to have the same coefficients as units that use coal as a fuel source. The amount of water withdrawn by PV solar energy was assumed to be equal to the amount of water consumed because electricity generation by PV solar energy does not require water for cooling. The maximum water consumption rate for a PV solar, utility-scale power plant is 33 gallons per MWh, which is 100 times less water consumption than natural gas. Over the years in the Southwest, factors such as reduced cost, innovative financing, and the abundance of sunlight in the Southwest have increased the popularity and demand for PV solar energy.

### 2.2.3. Statistical Analysis

Statistical analysis was done on calculated water consumption and water withdrawal for each state using JMP (Release 5.0.1.2, SAS Institute Inc.) with $p = 0.05$, corresponding to a 95% confidence level. Data for water usage was normalized with the annual population for each state

for the ten-year duration. The Tukey's range test was used to compare the means for all five states. Annual average water consumption and withdrawal per capita were compared between all five states from 2005 to 2015. Statistical analysis showed that the data were different indicating that water usage was affected by population.

## 2.3 Data Analysis Results

### 2.3.1. Electricity Generation

A majority of the total thermoelectricity generated comes from two main fossil fuel energy sources: coal and petroleum products (COL), and natural gas (NG). According to EIA's 2014 State Electricity Profile, an overall decrease in percentage of fossil fuel energy generation is seen in the past decade, but the reduction rate is somewhat discouraging. Electricity production from coal, petroleum, and natural gas fueled power facilities in each state still largely occupied more than 60 percent of the total industrial (utility-scale) electricity generation. Whereas for all five states, solar energy facilities (including CSP) produced less than six percent of the total electricity generation. A three-dimensional stacked bar graph showing electricity generation for fossil fuel and solar power for each state is provided in Figure 2.2.

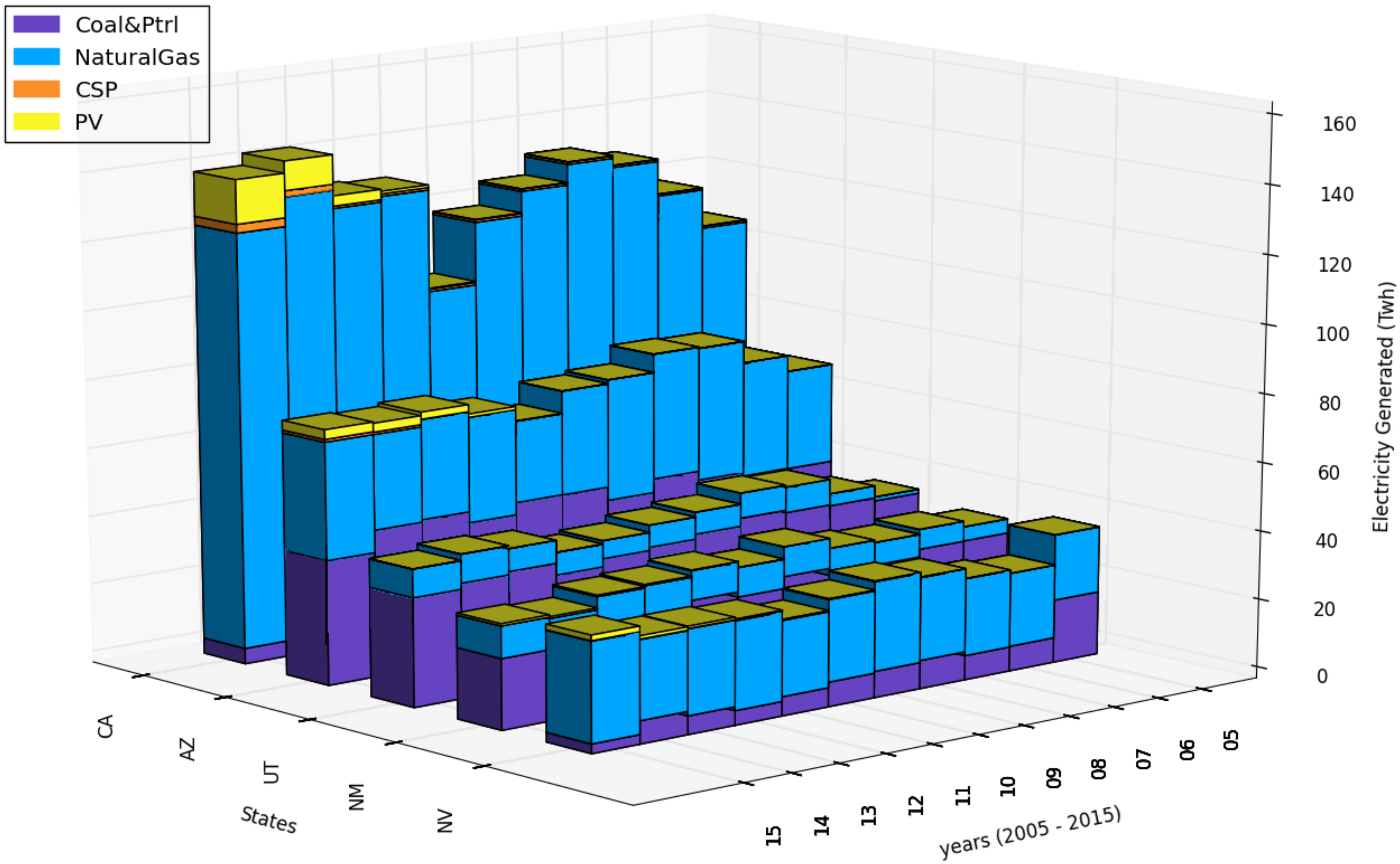



*Figure 2.2.* Types of electricity generation by state per year. (Based on data obtained from EIA form 923)

Due to the large population body, California has the highest total in both generating units and electricity production.  While California has the most aggressive path on promoting non-thermal renewable energy generation and eliminating the use of coal fuel at the same time, electricity generation in California is still highly dependent on burning fossil fuels.  This anomaly occurs due to the high dependency on natural gas.  In fact, California has actually increased its natural gas electricity generation by 14 percent since 2005 (49 percent of the total in 2005 increased to 61 percent of the total in 2014).

A current distribution of different types of energy generation for each state in 2014 is provided in *Figure 2.3*.  Arranged from most to least proactive on renewable energy adaptation, these basins states are ranked as the following: California, Arizona, Nevada, New Mexico, and Utah.  With more than 95 percent and 90 percent of the total electricity generation from coal and natural gas, respectively, Utah and New Mexico has the slowest adaptation to renewable energy compared to the other states.  As of 2014, Utah's electricity production from coal fuel is still at 76 percent of the state total.  Even historical data for Nevada and Arizona's coal dependency in 1990 (75 percent for Nevada and 51 percent for Arizona) showed that they had a lower percentage than Utah's current record.  Moreover, with an approximately 2.81 percent increase from 2005 to 2015, Nevada has the highest positive percent change over the last decade in adapting solar energy in general.  Although New Mexico adapted to solar energy at a later time than the other states, its 2015 records show that all solar energy produced in the state is from PV solar since CSP Solar facilities in New Mexico are still under development.  A more detailed description of the distributions of different types of generating units sorted by state per year is provided in Appendix E.

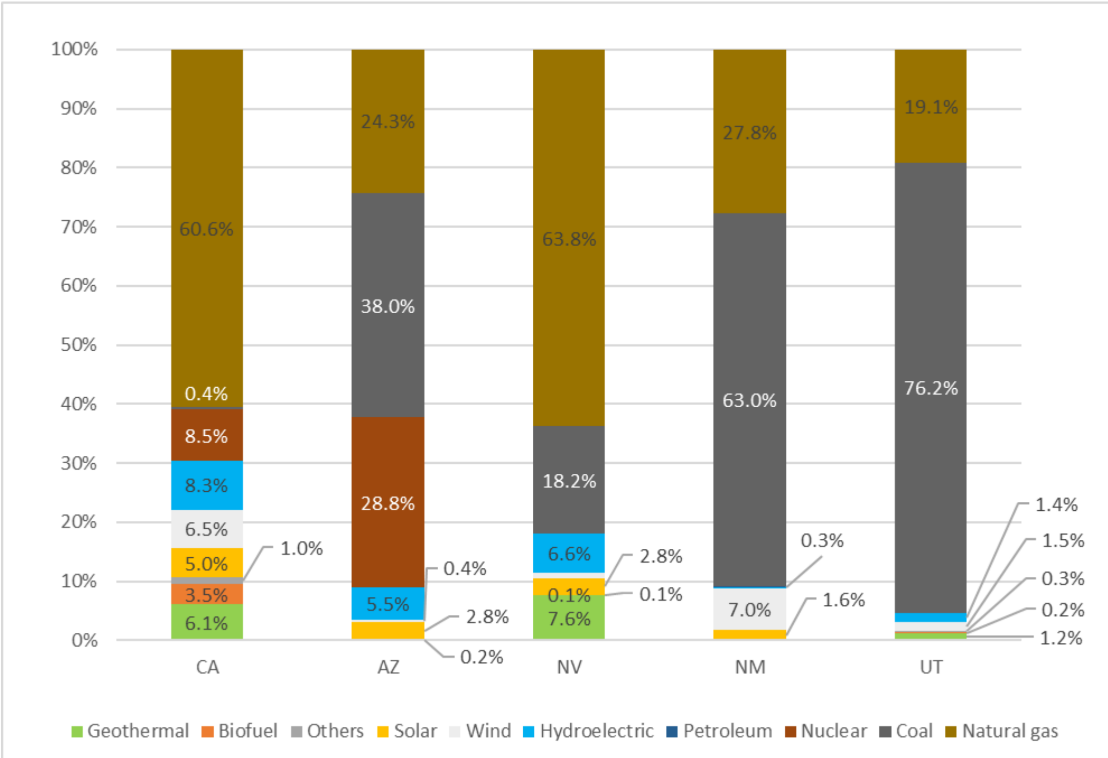



*Figure 2.3.* Percentage distribution of types of electricity generation for each state in 2014. (Based on data obtained from EIA form 923)

### 2.3.2. Cooling System Types

There are eight types of cooling systems identified by the EIA shown in Figure 2.4. “Cooling towers” and “No Cooling” were the two largest percentage categories in each state except “Air cooling” in Arizona. In most cases, power plants that were identified as hydroelectric, wind, and PV solar would have the cooling system type determined as “No Cooling”. Out of the total identified energy generating units for all five states in the 10-year duration, more than 50 percent of them used recirculating systems such as cooling towers. California has the highest percentage in generating energy that does not need cooling (i.e. PV Solar and Wind). Nevada has the highest percentage in hybrid cooling systems. New Mexico has a similar trend to Utah and California in producing energy that utilizes no cooling systems.

Arizona holds the highest percentage in utilizing cooling towers and the lowest percentage in utilizing hybrid-cooling systems.

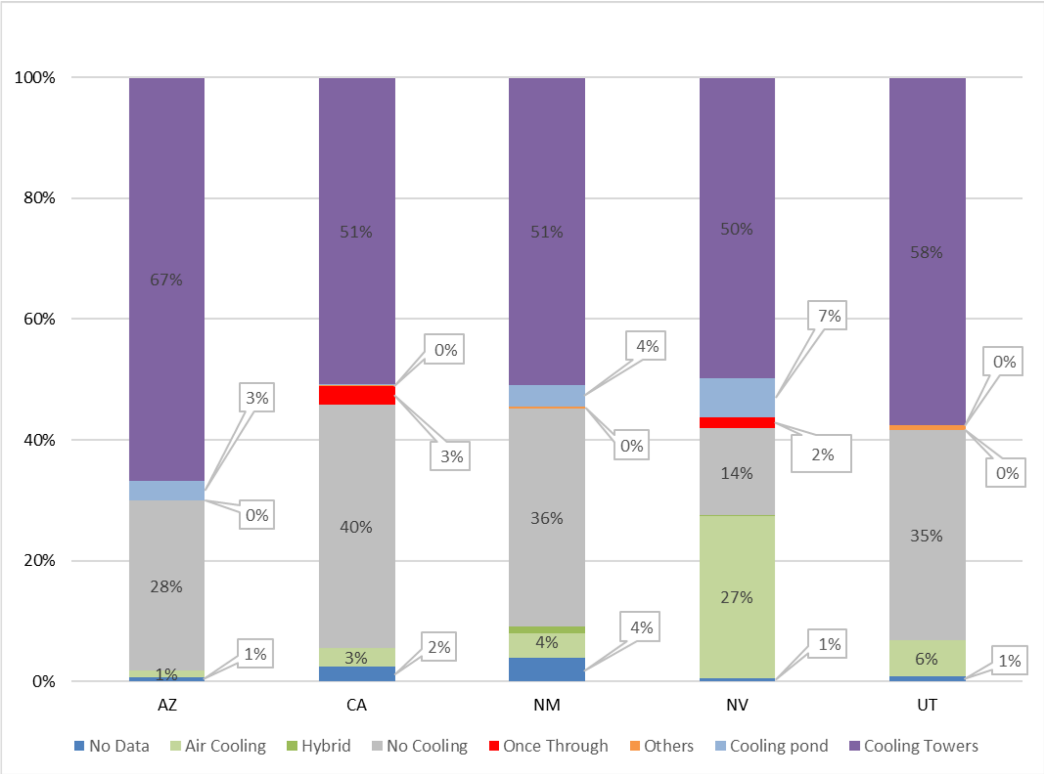



*Figure 2.4.* Average percent distribution of cooling systems utilized in each state. (Based on data obtained from EIA form 923)

Based on the EIA's electricity annual forecasted growth rates of 0.9 percent per year, the estimated amount of electricity used in the Southwest from 2015 to 2040 (Table 5) will increase as population increases, but in a substantially slower pace than that of 2000 to 2015. Effects of increased energy-efficiency housing units and other energy regulations are some of the suggested reasons to explain this slowed growth. However, the overall electricity demand will have a 24 percent growth by 2040 (EIA energy outlook, 2016).

Table 5
*Forecast of electricity demand based on EIA estimated annual growth rate.*

| Year | AZ | CA | NM | NV | UT |
|---|---|---|---|---|---|
| 2020 | 112,456 | 211,909 | 36,502 | 36,813 | 43,174 |
| 2025 | 112,478 | 211,951 | 36,509 | 36,820 | 43,183 |
| 2030 | 114,148 | 215,098 | 37,051 | 37,367 | 43,824 |
| 2035 | 115,262 | 217,197 | 37,412 | 37,731 | 44,252 |
| 2040 | 116,376 | 219,295 | 37,774 | 38,096 | 44,679 |

(Based on data obtained from EIA form 923. Units are expressed in GWh).

*Figure 2.5* shows the estimated forecasts of electricity demand for each state for every five-year increment from 2020. By 2020, the electricity demand for the Southwest was estimated to have a 0.9 percent increase per year. In general, the number of power plants and the amount of electricity generated in each state should correlate with the population trend in each state. It was assumed that the amount of electricity used would increase as each state's population increases. However, electricity demand projection (*Figure 2.5*) and population projection (*Figure 3.1*) showed that Utah has a relative higher electricity usage per capita than the other states.

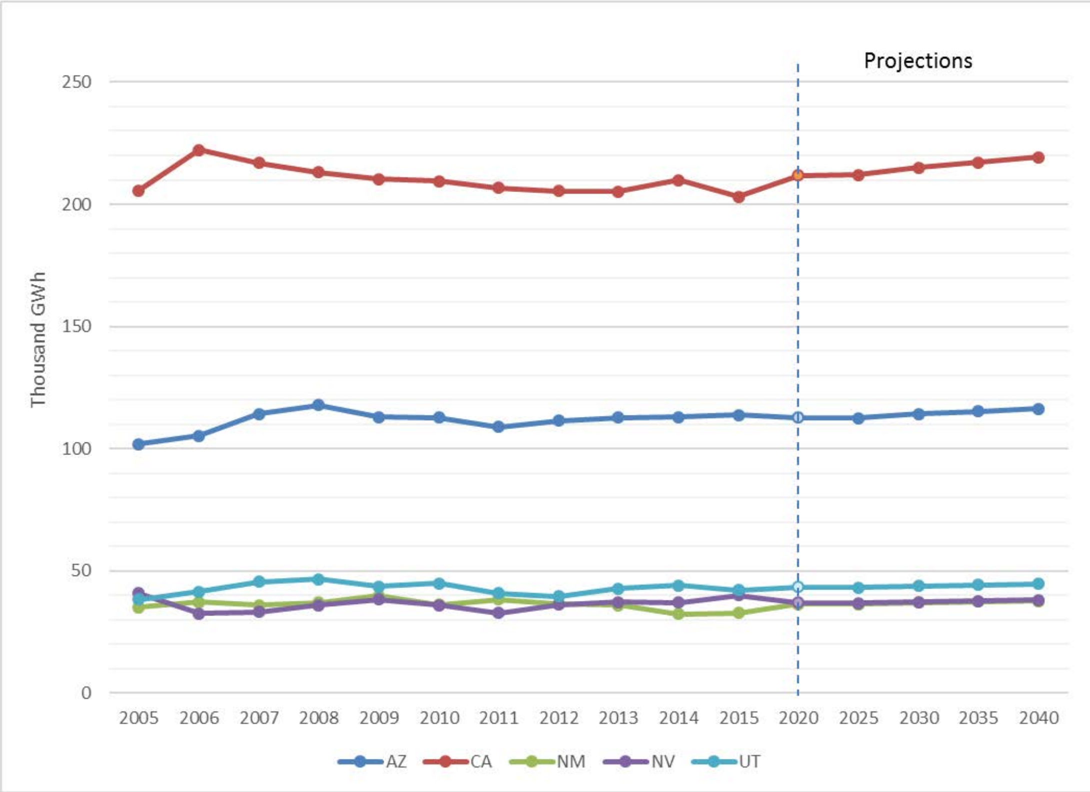



*Figure 2.5.* Annual electricity generated in each state.
(Based on data obtained from EIA form 923)

### 2.3.3. Water-Use Estimates

Utility-scale PV solar energy withdrawal and consumption coefficients in the basin states ranged from 0.009gal/kWh to 0.026 gal/kWh on average due to the difference in gross generation from each state. In general, utility scale PV solar energy uses approximately 89 percent less water per MWh (26 gal/MWh) than thermoelectric generating units (227.4 gal/MWh). Figures *2.6* and *2.7*showed the annual water consumption and withdrawal by conventional thermoelectric power plants versus solar energy from 2005 to 2015. Since California has the highest number in total population, gross generation, and the number of generating units, California also have the highest water consumption and withdrawal total amongst other states. The total water consumption in California correlates the total electricity

generated shown in Figure 2.2. Electricity generated in California from the selected fuel types (Figure 2.2) were on a decreasing trend for years 2005 to 2011, but showed a rapid increase the years after, which paralleled with the water consumption (Figure 2.6). One of the possible causes for this shift could be due to the newly commissioned 30 natural gas generating units in 2012, thus causing the water consumption to increase from 2011. However, the overall total water consumption by all identifiable fuel types was decreased, from 312 billion gallons in 2011 to 254 billion gallons in 2012. The decrease in total water withdrawal for coal, natural gas, and solar energy production in California (Figure 2.7) is most probably due to replacement of water intensive cooling systems and the shutdown of coal power plants over the years. A substantial decrease in water consumption for Nevada was observed in 2006. The cause for such steep decline was most likely due to the shutdown of the largest coal power plant, Mohave Generating Station, which led to the large reduction of overall electricity generated from coal (18 million MWh in 2005 to 7 million MWh in 2006, *Figure 2.2*). The decommissioning of the coal power plant saved 4.2 billion gallons of water annually from the Colorado River (Brean, 2009). In addition, some of the discrepancies may have been caused by the accuracy of available data. Also, power plant information such as cooling systems were limited for years prior to 2009.

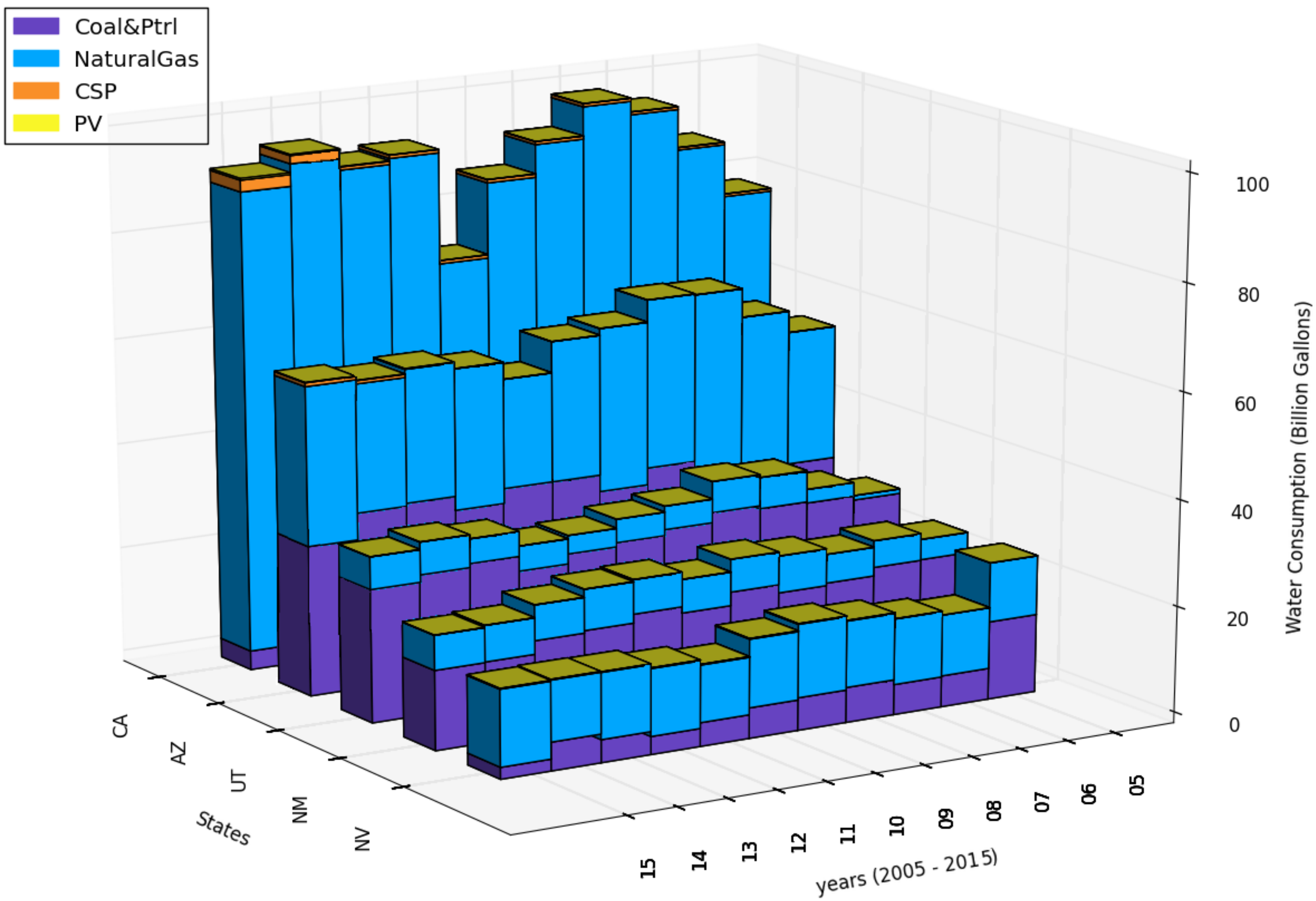



*Figure 2.6.* Total water consumption by fuel per state per year (Based on data obtained from EIA form 923).

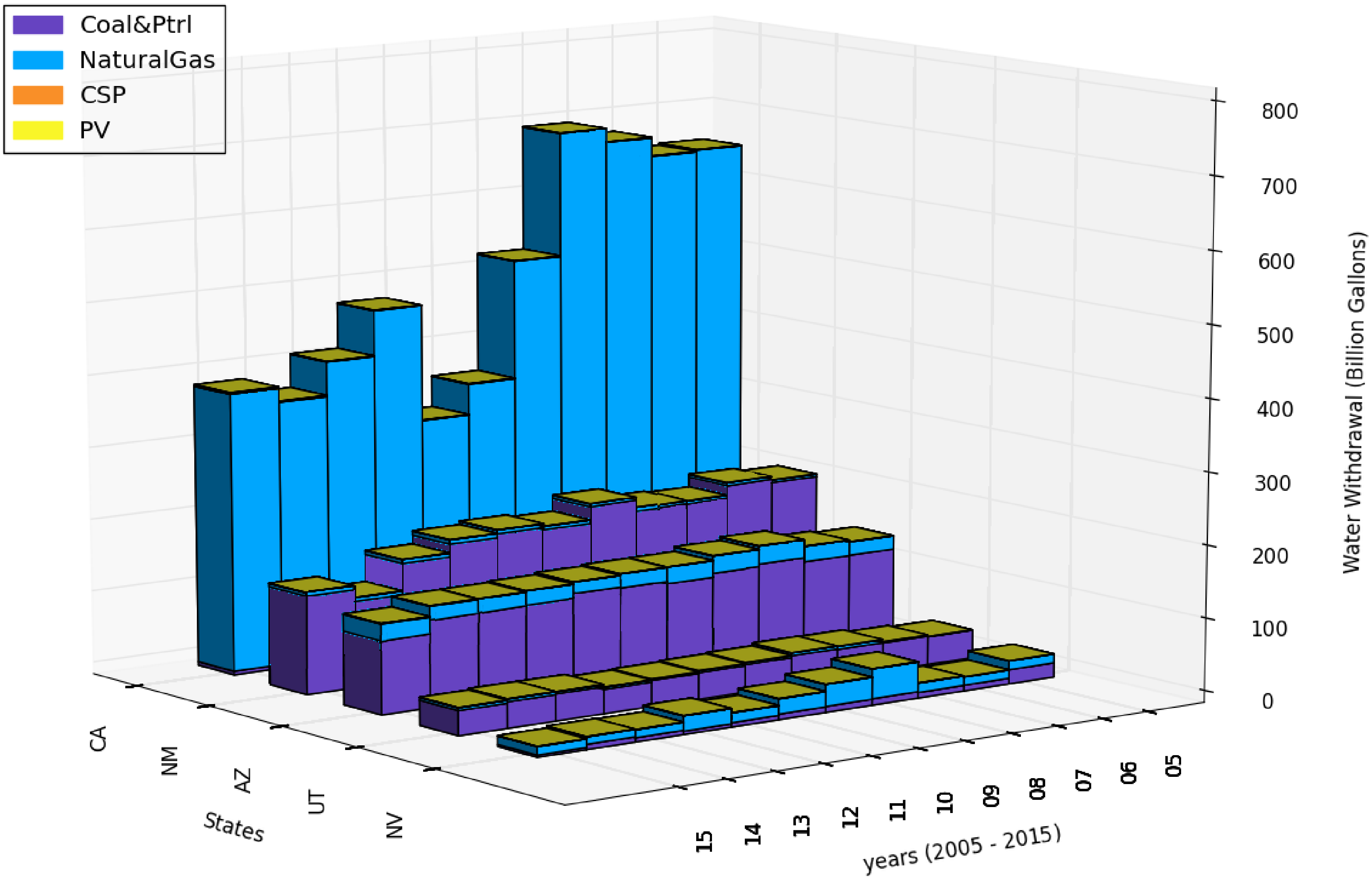



*Figure 2.7.* Total water withdrawal per state per year (Based on data obtained from EIA form 923).

However, due to the state's advantageous coastal location, and based on the population to household electric use ratio, California has the highest water efficiency in energy than the other states.  Normalized results from total state electric-water consumption and the total population show that California consumes an average of 2 thousand gallons of water per capita while the other states consumes an average of above 7 thousand gallons.  *Figures 2.8* and *2.9* show comparison of statistical means on water consumption and withdrawal for each state.  Letters above bars indicate statistical difference by Tukey–Kramer (p=0.05) with error bars showing as standard errors of mean.  Comparison for water consumption (*Figure 2.8*) shows statistically significant means among most states. New Mexico and Utah have similar water use per capita numbers. Arizona, California and Nevada are not only different from New Mexico and Utah but also among themselves. Over the ten-year period, California has the lowest consumption whereas New Mexico and Utah both have higher means than the other states.

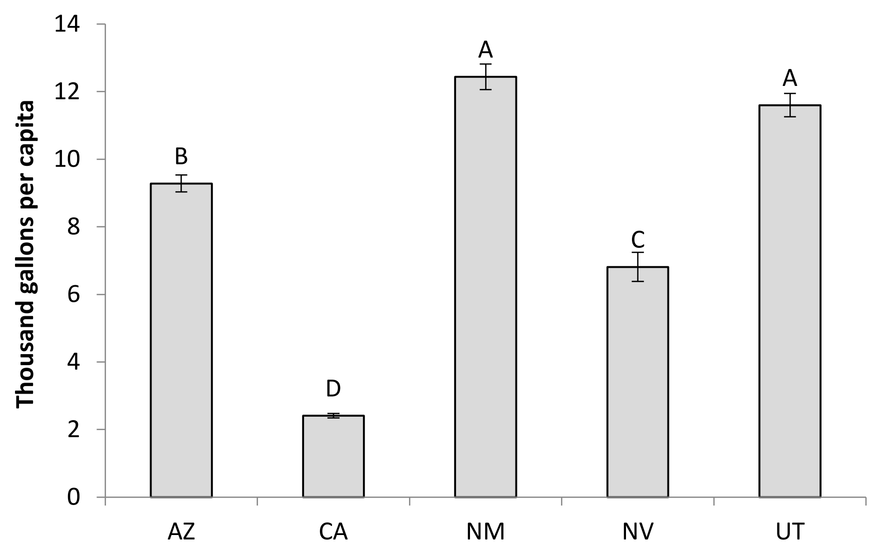



*Figure 2.8.* Water consumption statistic means comparison between five states. (Error bars display standard error of the data)

Despite differing in water use data, comparison for water withdrawal (*Figure 2.9*) shows less statistical significance for each state.  New Mexico, Arizona, and Nevada are significantly

different from each other, while California and Utah are not significantly different from Arizona or Nevada. The high error bar shown on New Mexico was possibly due to the overall 39 percent decrease for the ten-year duration.  In general, New Mexico has the highest average water withdrawal while Nevada has the lowest.

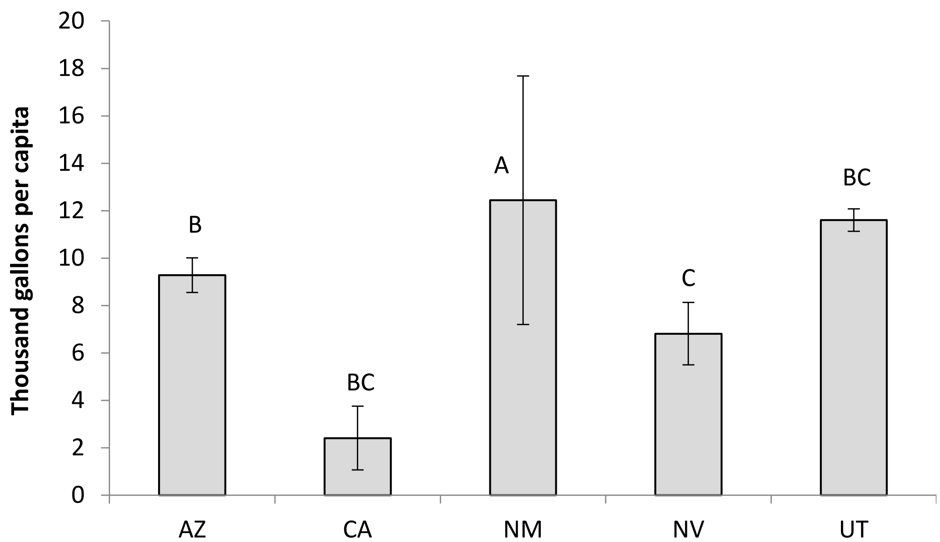



*Figure 2.9.* Water withdrawal statistic means comparison between five states. (Error bars display standard error of the data)

The calculated total electric water consumption in Arizona was only slightly less than that of California considering the population in Arizona is six times less than that of California.  On average, California has the most efficient annual household electric use at 6,444 kWh, whereas Arizona has the least efficient annual rate of 12,732 kWh (EIA, 2015c).  Furthermore, nearly all of California's water withdrawal for thermoelectricity purpose are from saline waters, which relieve the stress on freshwater availability (Maupin et al., 2010).  Calculated average water consumption is directly proportional to the amount of gross electricity generated in each state while withdrawal is not.  Coal water withdrawal rate ranged from 1.01 gal/kWh in Nevada to 6.29 gal/kWh in New Mexico, whereas water consumption rate ranged from 0.63 gal/kWh in

New Mexico to 0.70 in Nevada.  Natural gas water withdrawal rate ranged from 0.43 gal/kWh in Utah to 4.30 gal/kWh in California, whereas water consumption rate ranged from 0.23 gal/kWh in Nevada to 0.58 gal/kWh in Arizona.

# CHAPTER THREE - PROJECTION OF WATER USAGE

## 3.1. Data Collection

Estimated future electricity demand was based on the EIA forecasted growth rate of electricity sales in the residential and nonresidential sectors. The projection of electricity sales in the nonresidential sector was based on the past trend, and the electricity sales in the residential sector were based on the correlation between electric sales and the number of households in each state. The estimation method was chosen because of the weak correlation (with a $r^2$ value of 0.53) between population changes and total electricity use. Therefore, residential electricity sales were estimated assuming that the population and household increases directly reflect electricity use. However, nonresidential electricity sales were estimated assuming that the past trend is closely related to electricity use rather than the changes in population. Population and household estimates at every decade from 1950 to 2010 were obtained from the United States Census Bureau. The number of future households was calculated using the estimated future population based on the past correlation between the population and households. Finally, total electricity use was calculated by summing the increased electricity sales in nonresidential and residential sectors and the average electricity generated between 2005 and 2015.

### 3.1.1. Population Data

Two sets of population data were used in the simulation model. A set of two series (2000 and 2010 based) of state population and population forecast was collected from the U.S.Census Bureau while the other set of individual series of the state population data was collected from each state's demography office. Random sampling with replacement of a 95 percent confidence interval was used to calculate the estimated averages for these different population sets as the

state annual population data being used for the system dynamic projection. *Figure 3.1* shows the population projection for each state from 2015 to 2040.

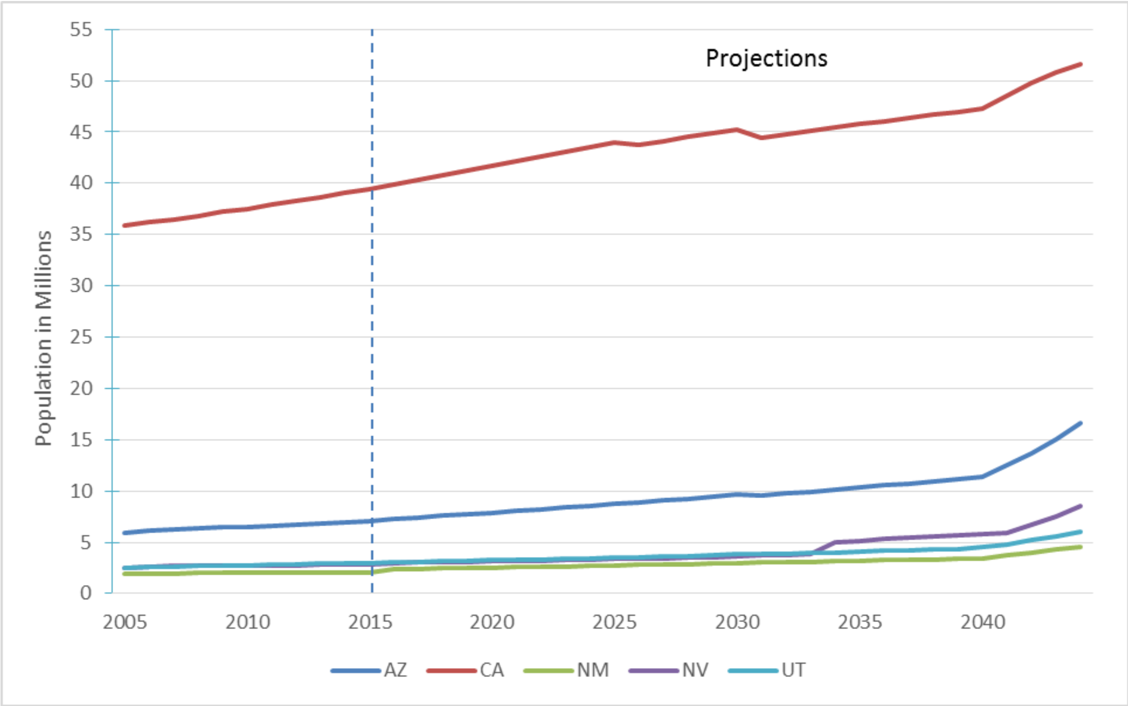



*Figure 3.1.* Projected population for each state (Based on data obtained from U.S. Census).

### 3.1.2. State RPS Data

Projections of future electricity demand and energy fuel substitution scenarios are based on the limitations of each state's RPS program. Some common RPS regulation approaches are to increase various renewable energy sources such as wind, solar, and other alternatives while progressively decrease the dependency on non-renewable fossil fuel electric generation such as coal or natural gas. Table 6 list each states RPS aims and the according sources. For the purpose of this study, only the goals pertaining to PV solar are highlighted in the comparison between each state.

Table 6
*Expected implementation of renewable portfolio standards by state.*

| | |
|---|---|
| Arizona | • Renewable energy to be increased to at least 15% by 2025, 30% from distributed generation (residential or non-utility owned) annual requirement<br>• Source: RPS[1], 2014. |
| California | • To increase eligible renewable energy recourse to 33 % by 2020, 50% by 2030.<br>• Mandated three large electric utilities to procure 250MW of Bioenergy generation (such as biogas, organic waste, food processing, and co-digestion).<br>• Source: RPS[2], 2013; RPS[3], 2007. |
| New Mexico | • Total renewables to be increased to 20% by 2020.<br>• Of which, no less than 30% (30% of the total 20%) should be generated by wind, 20% by Solar thermal/PV energy, 5% by other renewables, and 3% distributed generation. (which translates to only 6% total in wind, and 4% total in solar, 1% in others, and 0.6% from distributed generation)<br>• Source: RPS[6], 1978. |
| Nevada | • Renewable energy to be increased every two years until it reaches 25% by year 2025.<br>• Of which, at least 5% (5% of the total 25%) must be generated by solar facilities by 2015, and 6% (6% of the 25%) must be generated by solar facilities for 2016 and beyond.<br>• For years 2016 and after, 6 % of that amount must be generated or acquired from solar renewable energy systems. This translates to only 1.5% of the total electricity generated will be generated from solar systems.<br>• Retire or eliminate 300MW or more coal-fired electric generating capacity by 2014, in addition, eliminate 250 more MW by 2017, and 250 more on top of previous by 2019.<br>• Source: RPS[4], 1997; RPS[5], 1997. |
| Utah | • "To the extent that it is cost-effective to do so", until then, at least 20% starting 2025.<br>• Source: RPS[6], 2005. |

## 3.2. Methods

Since water is the most essential element associated societal development and at the same time energy is evidently used everywhere in the U.S., the interconnections between water and energy can become complicated to quantify. However, if these two elements can be linked

together via a systematic approach to incorporating different aspects involved that are changing over time, then the behavior could be visualized with a conceptual framework. A systems-thinking analysis, or more commonly referred to as Systems Dynamics (SD), is a feedback control method used to represent and understand how systems change over time. System dynamics contains features that determine ranges of interactions among different components of a system. SD is widely used to frame many complex socioeconomic issues. Behaviors of the system can be linked back to the how the system is structured. The simulation model of how population growth, energy demand, and water demand contact and interact with each other in this research is based on said system dynamic approach.

### 3.2.1. Model Structure

SD modeling simulations were done to compare water use associated with fossil fuel and PV solar energy for the projected water demand and potential water savings. In order to determine the projected water demand, various aspects such as population growth, average household electricity use, electricity retail sales, and the calculated water usage per unit of electricity generated in each state were integrated into the development of the mathematical model. A System Dynamics software, STELLA®, was used to construct a comprehensive model to simulate the interplay of the selected aspect. One of the advantages of the model is that it contains a user interface for ease of use. The interface contains basic building blocks such as stocks, flows, converters and connectors to represent different parameters of the system. A detailed list of different building blocks used in the model is shown in Appendix F. Another advantage of the model is that it can explore various scenarios. To simulate the different energy substitution scenarios, balance between the stocks and flows in the model can show the corresponding outputs. For example, New Mexico needs to increase their total solar energy

production to 4% by the year 2020, the model can yield outputs such as energy demand and resource distributions, if given the corresponding projected population number. In addition, this model can also be used to validate the manually calculated water-use projections. Calculated electric water usage data mentioned in the previous chapter was used to construct the model. Other data included all computed derivatives, digit rounding, and conversions from raw data. The estimated potential water savings were calculated by substituting changeable percentages of fossil fuel generation such as Coal or Natural Gas with PV solar generation. A more detailed description of the different parameters incorporated in the model is provided in Appendix G. The model was set up to output results annually, and it runs from 2015 to 2032.

### 3.2.2. Model Parameters

*Population Sector*

Population data obtained for each state provided a basis for the model. With each state's population annual growth rate, the projected population is calculated every five-year interval from 2015 to 2035. Calculated population values from two estimation sets from the Census Bureau were used as the initial population from the 2012 estimates. The initial growth rate for each state in 2014 was chosen to represent the accurate value based on these estimates. The correlation between population and number of households in each state presented is used to feed into the model to express the corresponding connections. The total residential electricity sales were calculated with respect to time using the total number of households in each state and the average household electricity used in kWh. The average household electricity used in kWh per state was obtained from each state's local energy report. It was assumed that residential sales refer to electricity bought by local household buildings, such as houses, apartments, and condominiums.

*Electricity Retail Sales Sector*

The surveyed total electricity retail sales were categorized into four major groups: residential, industrial, commercial, and transportation. Since there was a weak correlation between each year's population and these sectors, the averaged percentage of the total electric sales from 2011 to 2014 was used to represent the individual coefficients for each sector. In addition, electricity data from the EIA only report utility scale solar productions that are greater than one megawatt (MW) in size. Residential PV solar electricity generation that was provided by private solar companies may contribute to the total statewide electricity productions. However, residential PV solar generation data are difficult to keep track of due to the lack of governmental regulation on record keeping. Therefore, an unknown portion of the residential PV solar electricity sales was excluded from the total statewide electricity sales. Sale values for industrial, commercial, transportation, nonresidential, and residential solar electricity are likely to change from year to year. Table 7 shows the averaged percentage distribution of each electric sales group used in the model setup.

Table 7
*Average percent distribution of electric retail sales per state.*

| State | Residential | Commercial | Industrial | Transportation |
|---|---|---|---|---|
| AZ | 42% | 38% | 19% | 0.0% |
| CA | 34% | 46% | 20% | 0.3% |
| NM | 29% | 39% | 33% | 0.0% |
| NV | 34% | 27% | 39% | 0.0% |
| UT | 30% | 37% | 33% | 0.2% |

*Total Electricity Sector*

It was assumed that the total electricity retail sales should be approximately equal to the total electricity generated for each state. To increase the accuracy of the calculated total

electricity generation, the estimated annual gross electricity generation and the total electricity sales are used to determine the percent difference. The calculated percent difference is then incorporated into the equation to accommodate the gap in between. In addition, a percent change rate from 2014 to 2015 is also incorporated into the model to extrapolate the gross total electricity generated. There are four main sub-sectors that contribute to the total electricity sector. These sub-sectors are “PV solar”, “Coal, “Natural Gas”, and “Others”. The ‘Coal’ sector includes the percentage of electricity generated by coal and petroleum products since they have a similar fuel efficiency. The ‘Natural Gas’ sector includes the percentage of electricity generated by natural gas and other gasses for the same reason. To focus more on fossil fuel electricity generation, energy types such as wind, CSP, geothermal, and hydrothermal power were grouped into the “Others” sector. The percent generation for each fuel type is multiplied by the total annual gross electricity generation to obtain the output of gross electricity generated per fuel type. For each simulation scenario, the percentages of electricity generated per fuel type were manipulated in a range of 0 to 100 percent to estimate the total amount of water used. Since the model was set to increase the future PV solar electricity production, the overall increase in PV solar was subtracted from the future coal electricity generation. Although there will eventually be an upper bound to the exponential growth of solar sales, there is no way to predict when this bound will be reached. Therefore, it was assumed that the exponential growth of solar sales will continue for the purposes of this model setup.

*Total Water Usage Sector*

The total water withdrawal or consumption sector in the model is similar to the structure described in Chapter 2. A state specific withdrawal and consumption rate is calculated using the state annual gross generation in megawatt hours to divide by the total water consumed or

withdrew in million gallons.  The modeled total electricity generated per fuel type were multiplied by the calculated state withdrawal or consumption rate to get the total water usage per fuel type per year.  For the purpose of this study, water usage rate was only calculated for “Coal”, “Natural Gas”, and “PV Solar” sub-sectors.  In order to control consistency, the “Others” sub-sector were not incorporated in the “Total Water Usage” sector.  The sum of water withdrawal or consumption of all three sectors would yield the accumulated annual total water usage.  The results are displayed in million gallons of water over time, with January 1, 2015 being the initial start date.  Annual and accumulated water savings for each case scenario in each state can be obtained by subtracting the calculated water consumption value with the modified specs from the value with the initial specs.

### 3.3. Model Analysis Results

This study conducted four case scenarios to simulate the projected energy outlooks by 2032.  The first scenario (Case 1) examined projections with the present state of conditions on electricity generation by fuel distributions.  The second scenario (Case 2) explored the projections based on each state’s expected RPS for their optimized values (Table 6), while the third scenario (Case 3) explored projections on a hypothetical RPS set with a reasonable range of PV solar electric production percentage increase.  The fourth scenario (Reference Case) is a reference case to examine how much water PV Solar saved based on the current electricity production trend.  The hypothetical scenario was then compared with the standard RPS expected electricity production and the current energy trend.  The accuracy of water withdrawal and consumption estimates in the projected scenarios depends on water and electricity data, such as residential sales, water coefficients, and state populations obtained from various publicly

available sources. Details on each state's current electric production distribution and the interpretation of distribution for current RPS goals are shown in Table 8.

Table 8
*Scenario setups for water savings projection in each state.*

| | | **Percent Electricity Production** | | | |
|---|---|---|---|---|---|
| | | PV Solar (%) | Coal (%) | Natural Gas (%) | Others (%) |
| | | Arizona | | | |
| Case 1 | Current Condition | 2.4% | 32.0% | 30.1% | 34.8% |
| Case 2 | Current RPS | 4.5% | 27.5% | 33.2% | 34.8% |
| Case 3 | Hypothetical RPS | 8.0% | 14.0% | 43.2% | 34.8% |
| | | California | | | |
| Case 1 | Current Condition | 6.3% | 2.2% | 61.0% | 30.7% |
| Case 2 | Current RPS | 10.0% | 0.0% | 50.0% | 40.0% |
| Case 3 | Hypothetical RPS | 20.0% | 0.0% | 40.0% | 40.0% |
| | | Nevada | | | |
| Case 1 | Current Condition | 4.0% | 6.9% | 72.4% | 16.4% |
| Case 2 | Current RPS | 4.0% | 2.0% | 74.8% | 18.9% |
| Case 3 | Hypothetical RPS | 8.0% | 0.0% | 72.0% | 20.0% |
| | | New Mexico | | | |
| Case 1 | Current Condition | 1.9% | 62.8% | 28.5% | 6.8% |
| Case 2 | Current RPS | 4.0% | 58.8% | 30.2% | 7.0% |
| Case 3 | Hypothetical RPS | 8.0% | 44.8% | 40.2% | 7.0% |
| | | Utah | | | |
| Case 1 | Current Condition | 0.08% | 75.3% | 19.6% | 5.1% |
| Case 2 | Current RPS | 1.0% | 74.3% | 19.6% | 5.1% |
| Case 3 | Hypothetical RPS | 5.0% | 70.0% | 19.6% | 5.1% |

While SD modeling can comprehensively depict the patterns of change in energy-water balance over time, limitations are present to impede the process to characterize minute details of the complex world. Therefore, assumptions were made in this study to adhere to the study scope. The following are some major assumptions and limitations in the calculation process.

1) Population growth rate for each state was based on the annual projected population data obtained from the U.S. Census and will contribute to the total number of households.

2) Residential sales from each state's total electricity sales were assumed bought only for residential purposes and would have a correlation with the electricity usage per household.
3) Total electricity sales that are from commercial, industrial, transportation electricity sales are independent of each other with the population and are considered averaged constants that can be changed in the model.
4) The exponential growth of PV Solar residential sales was expected to continue in the future for all five states studied.
5) To manifest the effect only on thermoelectric power water usage, the percentage of resources consumed by the "Others" sector remains relatively constant.
6) All increased percentage in PV solar electric production were first deducted from coal, and then the remaining was deducted from natural gas.
7) Factors other than population growth that can affect the future water demand such as regional climate changes, the duration of wet and dry years, and the generating unit characteristics (i.e. type of cooling system and type of technology) within each power plant were assumed to remain the same.

Assumptions pertaining to population and energy were made based on each state's trend of energy usage per capita over the past decade. In general, due to increased energy efficiency in housing units, energy usage per household are showing a decreasing trend. However, population growth is at a higher rate than increased energy efficiency. Therefore, it was assumed that the amount of electricity used would increase as population increase. Assumptions pertaining to total electricity sector were made based on each state's RPS goals to increase future solar energy

production and to diminish future coal fueled energy production. Summarized results for water consumption in each case scenario are provided in Table 9.

Table 9

*Projected annual and accumulated water savings in 2015, 2022, and 2032 for each state.*

| Year | Scenario | Water Consumed (MGal/Yr) | | | Water Savings (Mgal/Yr) | |
|---|---|---|---|---|---|---|
| | | Thermal | PV Solar | Total | Total | Accumulated (Mgal/Duration) |
| | | | **Arizona** | | | |
| 2015 | Case 1 | 44,289 | 71 | 44,360 | | |
| | Reference | 45,863 | 0 | 45,863 | 1,503 | |
| | Case 2 | 42,871 | 133 | 43,004 | 1,356 | |
| | Case 3 | 39,074 | 237 | 39,311 | 5,050 | |
| 2022 | Case 1 | 49,300 | 79 | 49,379 | | |
| | Case 2 | 47,721 | 148 | 47,869 | 1,510 | 41,499 |
| | Case 3 | 43,495 | 264 | 43,758 | 5,621 | 154,489 |
| 2032 | Case 1 | 58,151 | 93 | 58,244 | | |
| | Case 2 | 56,288 | 175 | 56,463 | 1,781 | 65,729 |
| | Case 3 | 51,303 | 311 | 51,614 | 6,630 | 244,686 |
| | | | **California** | | | |
| 2015 | Case 1 | 56,478 | 331 | 56,808 | | |
| | Reference | 65,315 | 0 | 65,315 | 8,507 | |
| | Case 2 | 43,704 | 527 | 44,232 | 12,577 | |
| | Case 3 | 34,963 | 1,055 | 36,018 | 20,790 | |
| 2022 | Case 1 | 63,227 | 370 | 63,597 | | |
| | Case 2 | 48,927 | 590 | 49,517 | 14,080 | 386,066 |
| | Case 3 | 39,142 | 1,181 | 40,322 | 23,275 | 638,192 |
| 2032 | Case 1 | 74,522 | 436 | 74,958 | | |
| | Case 2 | 57,668 | 696 | 58,363 | 16,595 | 613,200 |
| | Case 3 | 46,134 | 1,392 | 47,526 | 27,433 | 1,013,661 |

| Year | Scenario | Water Consumed (MGal/Yr) | | | Water Savings (Mgal/Yr) | |
|---|---|---|---|---|---|---|
| | | Thermal | PV Solar | Total | Total | Accumulated (Mgal/Duration) |
| **Nevada** | | | | | | |
| 2015 | Case 1 | 8,506 | 34 | 8,540 | | |
| | Reference | 8,865 | 0 | 8,865 | 326 | |
| | Case 2 | 7,357 | 34 | 7,391 | 1,149 | |
| | Case 3 | 6,544 | 68 | 6,612 | 1,928 | |
| 2022 | Case 1 | 8,924 | 35 | 8,959 | | |
| | Case 2 | 7,719 | 36 | 7,754 | 1,205 | 34,174 |
| | Case 3 | 6,865 | 71 | 6,937 | 2,023 | 57,312 |
| 2032 | Case 1 | 9,627 | 38 | 9,665 | | |
| | Case 2 | 8,326 | 39 | 8,365 | 1,300 | 50,181 |
| | Case 3 | 7,406 | 77 | 7,483 | 2,182 | 84,156 |
| **New Mexico** | | | | | | |
| 2015 | Case 1 | 17,668 | 9 | 17,677 | | |
| | Reference | 18,060 | 0 | 18,060 | 383 | |
| | Case 2 | 17,120 | 19 | 17,139 | 538 | |
| | Case 3 | 15,875 | 37 | 15,912 | 1,765 | |
| 2022 | Case 1 | 19,573 | 10 | 19,583 | | |
| | Case 2 | 18,966 | 21 | 18,987 | 596 | 16,412 |
| | Case 3 | 17,586 | 41 | 17,628 | 1,956 | 53,819 |
| 2032 | Case 1 | 23,541 | 12 | 23,553 | | |
| | Case 2 | 22,810 | 25 | 22,835 | 717 | 26,158 |
| | Case 3 | 21,151 | 50 | 21,200 | 2,352 | 85,778 |
| **Utah** | | | | | | |
| 2015 | Case 1 | 25,448 | 0 | 25,449 | | |
| | Reference | 25,448 | 0 | 25,449 | 0 | |
| | Case 2 | 24,601 | 4.0 | 24,605 | 844 | |
| | Case 3 | 23,148 | 23.9 | 23,172 | 2,277 | |
| 2022 | Case 1 | 26,688 | 0.3 | 26,689 | | |
| | Case 2 | 25,800 | 4.2 | 25,804 | 885 | 25,051 |
| | Case 3 | 24,276 | 25.1 | 24,301 | 2,388 | 67,596 |
| 2032 | Case 1 | 28,768 | 0.4 | 28,768 | | |
| | Case 2 | 28,650 | 4.5 | 28,654 | 114 | 507,158 |
| | Case 3 | 27,326 | 22 | 27,348 | 1,420 | 484,040 |

To highlight the permanent effect on electric water usage, results are shown as water consumption in million gallons. In the result tables, “Annual Water Savings” refers to the potential water that can be saved each year from the increased PV solar generation percentage.

“Accumulated Water Savings” refers to the sum of all potential water that can be saved for the duration of 7 (2022) or 17 years (2032) in this model. In the reference case scenario, the model was set to calculate how much water is consumed if the current PV solar energy generation were entirely replaced by coal, natural gas, or other fuel sources. Since the model assumes that the category “Other” remains constant and coal consumption is always decreasing, the deducted percentage would be taken from coal fuel and the remaining was allocated to natural gas. Description of each state’s results are discussed in sections below

### 3.3.1. Arizona

With Lake Mead’s dropping water level persists, many companies in Arizona are looking into withdrawing groundwater as an alternative (NPR, 2015). Despite whether the source comes from groundwater or surface water, the Southwest states’ water supply still originates from the same basin. As the second largest population in the Southwest, Arizona has the highest household electric use (12,732 KWh/household) amongst the other basin states, which in turn consumes more water per unit of energy. As of 2015, Arizona’s population to PV solar energy ration is lower than its neighboring state of Nevada. With such distribution, Arizona saves less water than the other basin states (excluding Utah). Even with the current trend of RPS goals (Case 2), Arizona would have a much smaller effect on water savings than Nevada. However, if Arizona could increase its RPS goals to the hypothetical 8 percent of the total electricity generated (Case 3); it would considerably increase its performance on water conservations. With an average of 78 to 90 percent annual sunshine, Arizona’s RPS goals would be more appropriate if it can adjust to an increased rate (Case 3).

### 3.3.2. California

As the most impacted state by severe and extreme droughts, California mandated urban water cutbacks in early 2015 to enforce water conservation (NPR, 2016). SD Modeling showed that the state saved approximately 8.5 billion gallons of water in 2015 based on the current distribution of PV solar energy generating 6.3 percent of the total electricity (Case 1). If the percent PV solar generations were to increase from the current 6.3 percent to the RPS goal based value of 10 percent (Case 2), the predicted maximum savings would be approximately 14 billion gallons in 2022 and 16.5 billion gallons in 2032. Such goal would reduce the total water consumption in California down to a similar range with Arizona's current status quo. Considering the fact that California's population is almost six times more than that of Arizona, achieving the optimal RPS goals for California would be an effective water management move. With a high possibility of entering its sixth consecutive year of drought in 2016, California's continuation on its ambitious goal (Case2) for further clean energy appropriation is desirable.

#### 3.3.3. Nevada

In recent years, Nevada has been catching up with California on commissioning more solar power with improved technologies. However, most of Nevada's solar power comes from CSP technologies rather than PV solar. Recently in late 2015, the world's first thermal solar energy plant with storage, Crescent Dunes Solar Energy Plant, has been operational in Nevada. The 1,600-acre power plant claims it can supply electricity to 75,000 homes. On October 2016, the energy firm further proposed to expand the facility by building ten more similar units to increase its supply for one million homes. Although new CSP plants like Crescent Dunes utilize renovated technology to reduce water usage by having liquid salt as the heat transfer fluid, about one million gallon of operational water such as cooling tower and boiler blowdown water, reverse osmosis reject water, heliostat washing, and dust control water are still needed each day

(NDEP, 2015). Not to mention other thermal solar energy plants that still utilize water as the heat transfer fluid. The electricity generated by PV solar energy in Nevada has increased from 2.84 percent to 4 percent of the total electricity generated from 2014 to 2015. This change has increased Nevada's water savings from the previous study's projected estimates of 216 million gallons to this study's SD Modeled 326 million gallons of water in 2022. The percent increase also exceeds its initial RPS intention that only 1.5 percent of the total electricity generated will be from solar systems. Therefore, Case 2 scenario in Nevada for PV solar generation percentage remains the same while reducing coal percentage for natural gas. With the continuation of current RPS plan, Nevada would save approximately 1.2 billion and 1.3 billion gallons of water in 2022 and 2032, respectively. To maximize the potential water savings for Nevada in the near future, adapting the alternative RPS goals (Case 3) would be more appropriate.

### 3.3.4. New Mexico

As a state that receives the least percentage of water from the Upper Colorado Basin, New Mexico has been dealing with water resource challenges for almost ten years (NPR, 2015). Conservation projects such as reduction in mining and industrial activities or adaptation in alternative agriculture species has helped to decrease water usage. Despite rapid population growth, in cities like Albuquerque was mandated to cut back its water consumption by a quarter in 20 years (Wines, 2015). The abundance of sunlight, with an average of 75 to 80 percent annual sunshine in New Mexico, has led to greater support of solar energy development in recent years. Currently, all of New Mexico's utility scale solar energy comes from PV solar, which accounts for 1.9 percent of the total electricity generated. This trend may prove significant for future water savings. SD Modeling showed that if New Mexico continues with the current RPS trend (Case 2) to generate PV solar up to 4 percent of the total electricity demand, 596 million

gallons and 717 million gallons of water could be saved in 2022 and 2032, respectively. Since an average household of three in Albuquerque can consume about 110 thousand gallons of water annually (Maupin et al, 2010). Water savings from cases 2 and 3 can supply water to 5.4 thousand and 6.6 thousand average households in Albuquerque, respectively. Comparing to other basin states, New Mexico has a slower population growth, which should make it easier to adhere to the current RPS goals (Case 2).

#### 3.3.5. Utah

Compared to its neighboring basin states, Utah's electricity production is almost exclusively coming from fossil fuels. With more than 97 percent of the total electricity generation from burning fossil fuels, the current PV solar energy development is almost nonexistent. As of 2015, Utah's renewable energy production accounted for only 2 percent of the total, of which, PV solar was only at 0.08 percent of the total. One of the major causes for such striking difference in fossil fuel dominance is that Utah is a major fossil fuel producing state (USGS, 2016). Projections on SD Modeling showed that if the portion of electricity generated by PV solar energy in Utah was increased to only five percent by 2032 (Case 2), an estimated 1.4 billion gallons of operational water could be saved annually. An average household of four in Salt Lake City can consume 240 thousand gallons of water annually. The water savings from case 2 scenario could supply water to more than 58 thousand homes. However, while Utah has a great potential to develop PV solar energy, current trend to favor electricity generated by fossil fuels due to the economic advantages they provide. Based on the vague wording in Utah's RPS goals, renewable energy resources are required only when it becomes "economically feasible" (RPS[7], 2005). While Utah recognizes the decreased demand in fossil fuels from neighboring states, the intent to decrease fossil fuel electricity generation is less likely to happen since steady

fossil fuel production is expected to continue or even increase in the near future. In order to improve the water savings from electricity production in Utah, the improved RPS scenario (Case 3) would be a more suitable option to sustaining similar standards in neighboring states.

# CHAPTER FOUR - SUMMARY

Based on the results from SD modeling, the hypothesis that more water could be saved if coal was to be replaced by PV solar energy than from the replacement of natural gas was proven true. As model simulation increased PV solar electricity generation and decreased coal fueled electricity generation, the total consumptive water use decreased. Data analysis results indicate that this trend is similar amongst the five study states. Despite the lower water usage rate, natural gas fueled electricity generation consumes a similar rate compared to coal fueled electricity generation. There is a high potential for PV solar development in the study states. It is recommended that each state should consider revising and reinforcing renewable energy goals and standards. Collectively, the Southwest will not be able to meet future water demand if energy sectors in each of the stakeholder states continue to overlook the water saving potential from switching to PV solar electricity generation.

The analysis highlights the differences in water usage associated with coal, natural gas, petroleum products, and PV solar energy. Water-use coefficients in conventional thermal energy were generally higher because using coal to generate electricity requires considerably more water than natural gas. In addition, the pre-operational water consumption rate in thermoelectric generation further widens the gap. Even excluding preoperational water use by thermoelectric power plants, the water consumption rate of conventional thermoelectricity generation was still significantly higher than PV solar electricity generation. Utility-scale PV solar energy uses approximately 89 percent less water per MWh (26 gal/MWh) on average than thermoelectric

generating units (227.4 gal/MWh). Take Arizona for example, with only 2.4 percent of the total electricity generated by PV solar energy in the current distribution, an estimated 1,503 million gallons of water is saved annually. The estimates presented in this study demonstrate that water use for thermoelectric energy generation is substantially more than PV solar energy generation.

In addition to data analysis, details on each state's RPS standards revealed interesting facts on each state's attitude towards promoting renewable energy. Historically, these Basin States were involved in long-term legal battles with each other over the issue of water allotments. According to the Boulder Canyon Project Act in 1928, of the 7,500,000 acre-feet (2,400 billion gallons) annual Lower Basin allotment, California receives approximately 58.7 percent while Arizona and Nevada shares the remaining at 37.3 percent and 4 percent, respectively, of the total (Boulder Canyon Project, 1928). Moreover, Arizona receives an additional 0.7 percent of water allotment from the Upper Basin while New Mexico and Utah take 11.2 percent and 22.8 percent, respectively, of the total (Upper Colorado Basin Compact, 1948). Population increase throughout all basin states without proactive actions towards averting a water crisis would put them in a dangerous situation. Since the reallocation of the water allotment is unlikely to happen, governmental policies have been developed to increase the conservation of water. Although the idea of implementing RPS for each state is not directly targeting water conservations, it has indirectly led to water savings. However, some states implement regulations that tend to preserve renewable energy production near the status quo. Some of these RPS goals are excellent while the other RPS program and goals should be revised. Based on each state's RPS policies, California currently have the highest standards while Utah's conservative standards are not having much of an input on water savings. In conclusion, improvement on the state's RPS goals would be beneficial for Arizona, Nevada, and Utah, while

continual compliance to the current RPS goals would be sufficient for California and New Mexico. There is enough evidence to support the fact that the current resources being used for thermoelectricity may not be available in the future. Thus, the continuation of plans that seems efficient in the moment is not coordinating with actions that can be productive on water issues in the future. Based on findings of this study, the situation can be reevaluated to see the hidden opportunities for PV solar energy in the Southwest. However, the impediments to shift our society from fossil fuels to non-thermal renewable energy such as Wind or PV Solar power are still largely within the political realm. Water conservation agencies should take the necessary aggressive steps to move the energy sector toward alternative energy sources to maximize water savings. Residential development in the Southwest will continue to expand and increase the demand for water services. Even with the most effective residential water conservation plans, water consumption by thermoelectric power plants will remain the largest component of a community's water usage. Because water shortage in the Southwest is a critical issue, PV solar energy could be the emerging technology that improves water-use efficiency for generating electricity and helps conserve this valuable resource. When conservation agencies become more proactive instead of reactive, with a better understanding of how water and energy interrelates are related, then greater water savings will be achievable.

APPENDIX A – Query Equations

The following query commands were utilized in Microsoft SQL Server® to sort, extract, and calculate the total electricity generated and the past total water withdrawal and consumption for each generating unit in the five study states based on the electric raw data retrieved from both EIA forms 923 and 860. Prior to performing the following query commands, another simpler query was performed to extract necessary columns to only include essential information such as plant ID, plant name, operator name, state, year, fuel type, cooling type, latitude and longitude, total net generation, etc. Once the following query is complete, customized results such as to display only the total electricity generated and total water consumption per state per fuel can be done using the "SELECT" and the "GROUP BY" Commands.

```
IF OBJECT_ID('tempdb..#tblGenCool') IS NOT NULL
    DROP TABLE #tblGenCool;
with tblCool as (select distinct coo.[Plant Code],
            case when coo.[Cooling Type 1] in ('DC') then 'DryCool'
                  when coo.[Cooling Type 1] in ('OC','ON') then 'OnceThrough'
                  when coo.[Cooling Type 1] in ('RF','RI','RN','HT') then
'Tower'
                  when coo.[Cooling Type 1] in ('RC') then 'Pond'
                  when coo.[Cooling Type 1] in ('HRC','HRF','HRI') then
'Hybrid'
                  when coo.[Cooling Type 1] in ('OT') then 'Other'
            end as [Cooling1],
            case when coo.[Cooling Type 2] in ('DC') then 'DryCool'
                  when coo.[Cooling Type 2] in ('OC','ON') then 'OnceThrough'
                  when coo.[Cooling Type 2] in ('RF','RI','RN','HT') then
'Tower'
                  when coo.[Cooling Type 2] in ('RC') then 'Pond'
                  when coo.[Cooling Type 2] in ('HRC','HRF','HRI') then
'Hybrid'
                  when coo.[Cooling Type 2] in ('OT') then 'Other'
            end as [Cooling2]
from [ElectricFile2015].[dbo].[PlantCool2015$] coo
where coo.[Cooling Status] in ('OP','SB','TS')),
tblCool2 as (select a.[Plant Code],a.Cooling1,a.Cooling2,
ROW_NUMBER() over (partition by a.[Plant Code] order by a.Cooling1) as RowNum
from tblCool as a),
tblCoolest as (select a.[Plant Code],a.Cooling1,
coalesce(b.Cooling1,a.Cooling2) as Cooling2
```

```
from tblCool2 as a
inner join tblCool2 as b on a.[Plant Code] = b.[Plant Code] and a.RowNum+1 =
b.RowNum
), tblCoolFinal as (
select *
from tblCoolest union
select *
from tblCool
where [Plant Code] not in (select [Plant Code] from tblCoolest)
),
tblTotalNet as (
select pg.[Plant Id],
sum(pg.[Net Generation (Megawatthours)]) as TotalNetGen
from  [ElectricFile2015].[dbo].[PlantGen2015$] as pg
group by pg.[Plant Id]),
tblGenCoolPrep as (
select gen.[Plant Id],
gen.[Plant Name],
gen.[Operator Id],
gen.[Operator Name],
gen.[State],
case when gen.[Reported Prime Mover] in ('BA', 'OT', 'CE', 'ES', 'FC', 'FW')
then 'Other'
      when gen.[Reported Prime Mover] in ('BT') then 'Binary'
      when gen.[Reported Prime Mover] in ('ST', 'CA') then 'Steam'
      when gen.[Reported Prime Mover] in ('CT', 'GT', 'IC') then 'Combust'
      when gen.[Reported Prime Mover] in ('CS') then 'CombinedCycle'
      when gen.[Reported Prime Mover] in ('CP') then 'CSP'
      when gen.[Reported Prime Mover] in ('HY', 'HK', 'HB', 'HA', 'PS') then
'HydroPower'
      when gen.[Reported Prime Mover] in ('WT', 'WS') then 'Wind'
      when gen.[Reported Prime Mover] in ('PV') then 'PV'
else gen.[Reported Prime Mover] end as [Reported Prime Mover],
case when gen.[Reported Fuel Type Code] in ('NG','OG','BFG') and gen.[AER
Fuel Type Code] in ('NG','OOG') then 'NG'
      when gen.[Reported Fuel Type Code] in ('GEO') and gen.[AER Fuel Type
Code] in ('GEO') then 'GEO'
      when gen.[Reported Fuel Type Code] in ('MWH') and gen.[AER Fuel Type
Code] in ('OTH') then 'Storg'
      when gen.[Reported Fuel Type Code] in ('DFO', 'JF', 'WO', 'KER', 'PG',
'PC', 'RFO', 'SGP') and gen.[AER Fuel Type Code] in ('PC', 'DFO',
'WOO','RFO') then 'Petrolm'
      when gen.[Reported Fuel Type Code] in ('AB', 'OBG', 'OBS', 'OBL') and
gen.[AER Fuel Type Code] in ('ORW') then 'Bio'
      when gen.[Reported Fuel Type Code] in ('SUN') and gen.[AER Fuel Type
Code] in ('SUN') then 'Solar'
      when gen.[Reported Fuel Type Code] in ('WAT') and gen.[AER Fuel Type
Code] in ('HYC','HPS') then 'Water'
      when gen.[Reported Fuel Type Code] in ('WH', 'LFG', 'MSB') and gen.[AER
Fuel Type Code] in ('OTH','MLG') then 'OtherGas'
```

```
      when gen.[Reported Fuel Type Code] in ('OTH','PUR','TDF','MWH', 'SLW',
'BLQ', 'MSN') and gen.[AER Fuel Type Code] in ('OTH') then 'Other'
      when gen.[Reported Fuel Type Code] in ('SUB','SC','BIT','ANT','LIG',
'WC', 'RC', 'SGC','WDS') and gen.[AER Fuel Type Code] in ('COL','WOC','WWW')
then 'Coal'
      when gen.[Reported Fuel Type Code] in ('NUC') and gen.[AER Fuel Type
Code] in ('NUC') then 'Nuclear'
      when gen.[Reported Fuel Type Code] in ('WND') and gen.[AER Fuel Type
Code] in ('WND') then 'Wind'
end as [Fuel Type],
gen.[Net Generation (Megawatthours)],
gen.[YEAR],
ll.Latitude,
ll.Longitude,
cf.Cooling1,
cf.Cooling2,
case when tn.TotalNetGen = 0 then 0
else gen.[Net Generation (Megawatthours)]/tn.TotalNetGen
end as TotalNetShare
FROM [ElectricFile2015].[dbo].[PlantGen2015$] as gen
inner join tblTotalNet as tn on gen.[Plant Id] = tn.[Plant Id]
left join [ElectricFile2015].[dbo].[PlantLatLong2015$] as ll on gen.[Plant
Id] = ll.[Plant Code]
left join tblCoolFinal as cf on gen.[Plant Id] = cf.[Plant Code]
)
--Create tblGenCool as a temp table
select gcp.[Plant Id],
gcp.[Plant Name],
gcp.[Operator Id],
gcp.[Operator Name],
gcp.State,
gcp.[Reported Prime Mover],
gcp.[Fuel Type],
gcp.[Net Generation (Megawatthours)],
gcp.YEAR,
gcp.Latitude,
gcp.Longitude,
case when gcp.[Reported Prime Mover] in ('PV','Wind','HydroPower') then 'N/A'
else gcp.Cooling1 end as Cooling1,
gcp.Cooling2,
gcp.TotalNetShare
into #tblGenCool
from tblGenCoolPrep as gcp

update #tblGenCool
set Cooling1 = ['2013FinalCalc$'].Cooling1
from [ElectricFile2013].[dbo].['2013FinalCalc$']
where [#tblGenCool].[Plant Id] = ['2013FinalCalc$'].[PlantID]
and [#tblGenCool].[Cooling1] is null;
```

```
update #tblGenCool
set [Reported Prime Mover] = ['2013FinalCalc$'].PrimeMover
from [ElectricFile2013].[dbo].['2013FinalCalc$']
where [#tblGenCool].[Plant Id] = ['2013FinalCalc$'].[PlantID]
and (([Fuel Type] = 'GEO' and [Reported Prime Mover] = 'Steam')
or ([Fuel Type] = 'Solar' and [Reported Prime Mover] = 'Other'));

update #tblGenCool
set [Fuel Type] = ['2013FinalCalc$'].FuelType
from [ElectricFile2013].[dbo].['2013FinalCalc$']
where [#tblGenCool].[Plant Id] = ['2013FinalCalc$'].[PlantID]
and  (([Fuel Type] is null and [Reported Prime Mover] = 'Steam')
or ([Fuel Type] is null and [Reported Prime Mover] = 'Combust'));

Update #tblGenCool set Latitude =['2013FinalCalc$'].Latitude
from [ElectricFile2013].[dbo].['2013FinalCalc$']
where #tblGenCool.[Plant Id] = ['2013FinalCalc$'].[PlantID]

Update #tblGenCool set Longitude =['2013FinalCalc$'].Longitude
from [ElectricFile2013].[dbo].['2013FinalCalc$']
where #tblGenCool.[Plant Id] = ['2013FinalCalc$'].[PlantID]

--with tblCheck as (
select gc.[Plant Id],
gc.[Plant Name],
gc.[Operator Id],
gc.[Operator Name],
gc.[State],
gc.[Reported Prime Mover],
gc.[Fuel Type],
gc.[Net Generation (Megawatthours)],
gc.[YEAR],
gc.Latitude,
gc.Longitude,
gc.Cooling1,
gc.Cooling2,
case
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('Tower') then 235
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('DryCool') then 35
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Combust')
then 35
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') then 300
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Tower') then 553
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') then 390
```

```
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('Tower') then 235
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Other')
then 35
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam')
then 553
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond') then 545
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower') then 687
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('DryCool') then 42
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
then 687
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Combust')
then 471
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('Tower') then 378
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('OnceThrough') then 100
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('DryCool') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('N/A') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('Combust')then 378
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('Tower') then 378
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('N/A') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') then
378
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('DryCool') and gc.Cooling2 in
('Pond')then 121
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('DryCool') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('OnceThrough') then 100
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower') and gc.Cooling2 in ('Other')
then 198
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower') then 198
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') then 229
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('DryCool') and gc.Cooling2 in ('Pond') then 290
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('DryCool') then 340
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when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') and gc.Cooling2 in ('Tower')then 533
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') then 240
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') and gc.Cooling2 in ('Tower')then 533
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') then 240
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Tower')then 826
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') then
468
when gc.[Fuel Type] in ('Nuclear') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('OnceThrough')then 296
when gc.[Fuel Type] in ('Nuclear') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 672
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') and gc.Cooling1 in ('Tower')then 826
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') and gc.Cooling1 in ('DryCool')then 340
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') then 378
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Tower')then 378
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('DryCool')then 2
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') then 198
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Other') then 378
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') then 229
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('OnceThrough')then 100
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower')then 198
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('DryCool')then 340
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('OnceThrough')then 240
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond') and gc.Cooling2 in ('Tower')then 533
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond')then 240
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 826
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
then 468
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Pond')then 240
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when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Tower')then 198
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('OnceThrough')then 100
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('DryCool')then 2
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') then 198
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('PV') and
gc.Cooling1 in ('Tower')then 786
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('CSP') and
gc.Cooling1 in ('Tower')then 865
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 865
when gc.[Fuel Type] in ('Solar') and gc.Cooling1 in ('Tower')then 786
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in
('Steam')then 865
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Flash
Steam') and gc.Cooling1 in ('Tower')then 2583
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Flash
Steam') and gc.Cooling1 in ('Pond')then 2583
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Dry Steam')
and gc.Cooling1 in ('Tower')then 1796
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('Tower')then 3600
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('DryCool')then 135
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('Pond')then 221
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
then 221
when gc.[Fuel Type] in ('Storg') and gc.[Reported Prime Mover] in ('Other')
then 0
when gc.[Reported Prime Mover] in ('PV') then 26
when gc.[Fuel Type] in ('Wind') then 0
when gc.[Fuel Type] in ('Water') then 4491
when gc.[Fuel Type] in ('Other') then 826
end as WtrConsmQ,

case when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Tower') then 478
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('DryCool') then 35
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Combust')
then 35
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') then 35000
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Tower') then 878
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when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') then 450
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Steam')
then 878
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('Tower') then 478
when gc.[Fuel Type] in ('Bio') and gc.[Reported Prime Mover] in ('Other')
then 35
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond') then 12225
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower') then 1005
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('DryCool') then 1277
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Steam')
then 1005
when gc.[Fuel Type] in ('Coal') and gc.[Reported Prime Mover] in ('Combust')
then 586
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('Tower') then 253
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('OnceThrough') then 11380
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('DryCool') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Combust')
and gc.Cooling1 in ('N/A') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('Combust')then 496
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('Tower') then 253
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') and
gc.Cooling1 in ('N/A') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Other') then
425
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('DryCool') and gc.Cooling2 in
('Pond')then 3000
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('DryCool') then 2
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('OnceThrough') then 11380
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower') and gc.Cooling2 in ('Other')
then 496
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower') then 496
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in
('CombinedCycle') then 5950
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('DryCool') and gc.Cooling2 in ('Pond') then 3000
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when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('DryCool') then 425
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') and gc.Cooling2 in ('Tower')then 15000
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('OnceThrough') then 35000
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') and gc.Cooling2 in ('Tower')then 3000
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Pond') then 5950
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') and
gc.Cooling1 in ('Tower')then 1203
when gc.[Fuel Type] in ('NG') and gc.[Reported Prime Mover] in ('Steam') then
425
when gc.[Fuel Type] in ('Nuclear') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('OnceThrough')then 44350
when gc.[Fuel Type] in ('Nuclear') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 1101
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') and gc.Cooling1 in ('Tower')then 1203
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') and gc.Cooling1 in ('DryCool')then 425
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Steam') then 425
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Tower')then 496
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('DryCool')then 2
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Combust') then 253
when gc.[Fuel Type] in ('OtherGas') and gc.[Reported Prime Mover] in
('Other') then 425
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') then 5950
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('OnceThrough')then 11380
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('CombinedCycle') and gc.Cooling1 in ('Tower')then 496
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('DryCool')then 425
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('OnceThrough')then 35000
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond') and gc.Cooling2 in ('Tower')then 3000
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Pond')then 5950
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 1203
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in ('Steam')
then 425
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when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Pond')then 5950
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('Tower')then 496
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('OnceThrough')then 11380
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') and gc.Cooling1 in ('DryCool')then 2
when gc.[Fuel Type] in ('Petrolm') and gc.[Reported Prime Mover] in
('Combust') then 586
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('PV') and
gc.Cooling1 in ('Tower')then 786
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('CSP') and
gc.Cooling1 in ('Tower')then 865
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in ('Steam')
and gc.Cooling1 in ('Tower')then 865
when gc.[Fuel Type] in ('Solar') and gc.Cooling1 in ('Tower')then 786
when gc.[Fuel Type] in ('Solar') and gc.[Reported Prime Mover] in
('Steam')then 786
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Flash
Steam') and gc.Cooling1 in ('Tower')then 2583
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Flash
Steam') and gc.Cooling1 in ('Pond')then 2583
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Dry Steam')
and gc.Cooling1 in ('Tower')then 1796
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('Tower')then 3600
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('DryCool')then 135
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
and gc.Cooling1 in ('Pond')then 221
when gc.[Fuel Type] in ('Geo') and gc.[Reported Prime Mover] in ('Binary')
then 221
when gc.[Fuel Type] in ('Storg') and gc.[Reported Prime Mover] in ('Other')
then 0
when gc.[Reported Prime Mover] in ('PV') then 26
when gc.[Fuel Type] in ('Wind') then 0
when gc.[Fuel Type] in ('Water') then 4491
when gc.[Fuel Type] in ('Other') then 1203
end as WtrWdrQ,
coalesce(gc.TotalNetShare*gg.[Gross Generation],gc.[Net Generation
(Megawatthours)]) as GrossGen
from #tblGenCool as gc
left join [ElectricFile2015]..[GrossGen2015$] as gg on gc.[Plant Id] =
gg.[Plant Code]
```

APPENDIX B – Primary Fuel Type Categories in Calculation

| EIA Energy Source Code | Description | Category in Calculation |
|---|---|---|
| ANT | Anthracite Coal | Coal |
| BIT | Bituminous Coal | |
| LIG | Lignite Coal | |
| SUB | Subbituminous Coal | |
| WC | Waste/Other Coal | |
| RC | Refined Coal | |
| SGC | Coal-Derived gas | |
| DFO | Distillate Fuel Oil | Petroleum Products |
| JF | Jet Fuel | |
| KER | Kerosene | |
| PC | Petroleum Coke | |
| RFO | Residual Fuel Oil | |
| PG | Propane, gaseous | |
| SGP | Petroleum Coke Derived Gas | |
| WO | Waste/Other oil | |
| NG | Natural Gas | Natural Gas |
| BFG | Blast Furnance Gas | Other Gases |
| OG | Other Gas | |
| LFG | Landfill gas | |
| AB | Agricultural By-products | Biomass |
| MSW | Municipal Solid Waste | |
| OBS | Other Biomass Solid | |
| SLW | Sludge Waste | |
| BLQ | Black Liquor | |
| WDL | Wood Waste Liquids | |
| OBG | Other Biomass Gas | |
| GEO | Geothermal | Geothermal |
| WAT | Conventional Hydroelectric Turbine | Hydropower |
| WND | Wind | Wind |
| $SUN_{steam}$ | Units that display ‘SUN’ in the fuel type and ‘ST’ in the prime Mover type | CSP Solar |
| $SUN_{pv}$ | Units that display ‘SUN’ in the fuel type and ‘PV’ in the prime Mover type | PV Solar |
| NUC | Nuclear | Nuclear |
| OTH | Storage or other derived fuels | Other |

APPENDIX C - Prime Mover Type Categories in Calculation

| EIA Prime Mover Code | Description | Category in Calculation |
|---|---|---|
| BT | Turbines Used in a Binary Cycle | Binary |
| CS | Combined-Cycle Single-Shaft Combustion turbine and steam turbine share a single generator | Combine Cycle |
| CT | Combined-Cycle Combustion Turbine Part | Combustion |
| IC | Internal Combustion Engine | |
| GT | Combustion (Gas) Turbine | |
| $ST_{csp}$ | Units that are labeled 'ST' in prime mover types but with 'SUN' as fuel types | CSP |
| CP | Energy Storage, Concentrated Solar Power | |
| | Manually added based on research | Dry Steam |
| | Manually added based on research | Flash Steam |
| HA | Hydrokinetic, Axial Flow Turbine | Hydropower |
| HB | Hydrokinetic, Wave Buoy | |
| HK | Hydrokinetic, Other | |
| HY | Hydraulic Turbine | |
| BA | Energy Storage, Battery | Other |
| CE | Energy Storage, Compressed Air | |
| FC | Fuel Cell | |
| FW | Energy Storage, Flywheel | |
| PS | Energy Storage | |
| OT | Other | |
| PV | Photovoltaic | PV Solar |
| ST | Steam Turbine (including nuclear, geothermal) | Steam |
| CA | Combined-Cycle- Steam Part | |
| WT | Wind Turbine, Onshore | Wind |
| WS | Wind Turbine, Offshore | |

APPENDIX D – Primary Cooling System Categories in Calculation

| EIA Cooling System Type Code | Description | Category in Calculation |
|---|---|---|
| DC | Dry (air) cooling System | Dry Cooling |
| HRC | Hybrid: recirculating cooling pond(s) or canal(s) with dry cooling | Hybrid |
| HRF | Hybrid: recirculating with forced draft cooling tower(s) with dry cooling | |
| HRI | Hybrid: recirculating with induced draft cooling tower(s) with dry cooling | |
| OC | Once through with cooling ponds | Once through |
| ON | Once through without cooling pond(s) or canal(s) | |
| RC | Recirculating with Cooling Ponds | Cooling Pond |
| RF | Recirculating with Forced Draft Cooling Tower | Tower |
| RI | Recirculating with Induced Draft Cooling Tower | |
| RN | Recirculating with Natural draft Cooling tower | |
| Null Value 1 | Cells that have a null value in Wind and PV Solar fuel types | No Cooling System |
| Null Value 2 | Cells that have a null value in fuel types other than Wind and PV Solar | Null |

APPENDIX E - Number of Different Types of Generation Units per State per Year

| AZ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Bio | CoalAndP | NGAndOtl | Nuclear | Other | PV | CSP | Geo | Hydro | Wind | Total |
| 2005 | 1 | 34 | 60 | 3 | 0 | 5 | 0 | 0 | 14 | 0 | 117 |
| 2006 | 1 | 32 | 56 | 3 | 0 | 4 | 1 | 0 | 13 | 0 | 110 |
| 2007 | 1 | 36 | 56 | 3 | 0 | 4 | 1 | 0 | 13 | 0 | 114 |
| 2008 | 1 | 48 | 57 | 3 | 0 | 4 | 1 | 0 | 13 | 0 | 127 |
| 2009 | 1 | 38 | 59 | 3 | 1 | 5 | 1 | 0 | 13 | 1 | 122 |
| 2010 | 1 | 36 | 57 | 3 | 1 | 8 | 1 | 0 | 13 | 2 | 123 |
| 2011 | 1 | 38 | 59 | 3 | 1 | 20 | 2 | 0 | 13 | 3 | 141 |
| 2012 | 1 | 35 | 61 | 3 | 1 | 32 | 1 | 0 | 13 | 5 | 153 |
| 2013 | 1 | 34 | 65 | 3 | 1 | 46 | 1 | 0 | 13 | 4 | 170 |
| 2014 | 1 | 41 | 64 | 3 | 1 | 55 | 0 | 0 | 12 | 4 | 182 |
| 2015 | 1 | 36 | 63 | 3 | 0 | 57 | 0 | 0 | 12 | 5 | 178 |

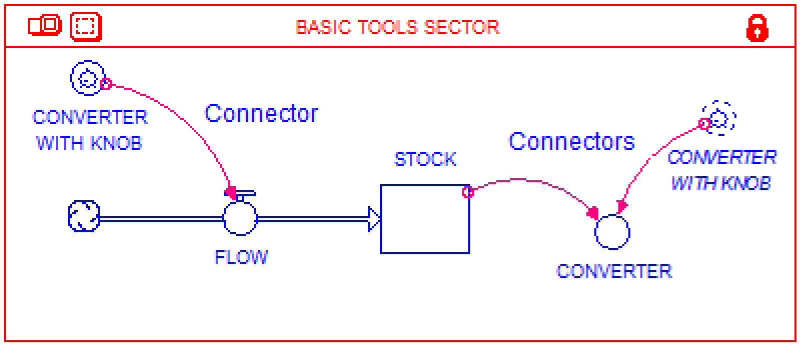
| CA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Bio | CoalAndP | NGAndOtl | Nuclear | Other | PV | CSP | Geo | Hydro | Wind | Total |
| 2005 | 18 | 130 | 428 | 4 | 13 | 1 | 9 | 33 | 256 | 73 | 965 |
| 2006 | 17 | 132 | 442 | 4 | 14 | 1 | 9 | 33 | 255 | 78 | 985 |
| 2007 | 16 | 131 | 453 | 4 | 15 | 2 | 9 | 34 | 254 | 73 | 991 |
| 2008 | 17 | 135 | 461 | 4 | 13 | 9 | 9 | 38 | 254 | 74 | 1014 |
| 2009 | 17 | 117 | 468 | 4 | 15 | 21 | 11 | 38 | 253 | 77 | 1021 |
| 2010 | 19 | 121 | 485 | 4 | 12 | 31 | 11 | 37 | 254 | 79 | 1053 |
| 2011 | 25 | 118 | 486 | 4 | 14 | 60 | 10 | 37 | 255 | 89 | 1099 |
| 2012 | 32 | 124 | 522 | 4 | 15 | 134 | 11 | 38 | 258 | 112 | 1251 |
| 2013 | 39 | 115 | 537 | 4 | 9 | 196 | 15 | 37 | 256 | 104 | 1312 |
| 2014 | 56 | 127 | 550 | 2 | 11 | 286 | 16 | 37 | 256 | 114 | 1455 |
| 2015 | 63 | 121 | 542 | 2 | 8 | 358 | 14 | 37 | 254 | 117 | 1516 |

| NM | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Bio | CoalAndP | NGAndOtl | Nuclear | Other | PV | CSP | Geo | Hydro | Wind | Total |
| 2005 | 1 | 14 | 31 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 54 |
| 2006 | 1 | 13 | 32 | 0 | 0 | 0 | 0 | 0 | 5 | 4 | 55 |
| 2007 | 1 | 13 | 34 | 0 | 0 | 0 | 0 | 0 | 5 | 4 | 57 |
| 2008 | 1 | 15 | 40 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 66 |
| 2009 | 1 | 14 | 35 | 0 | 0 | 0 | 0 | 0 | 5 | 7 | 62 |
| 2010 | 1 | 15 | 35 | 0 | 0 | 1 | 0 | 0 | 5 | 8 | 65 |
| 2011 | 1 | 15 | 35 | 0 | 0 | 14 | 0 | 0 | 5 | 9 | 79 |
| 2012 | 1 | 14 | 35 | 0 | 1 | 19 | 0 | 0 | 5 | 10 | 85 |
| 2013 | 1 | 14 | 34 | 0 | 1 | 27 | 0 | 1 | 5 | 10 | 93 |
| 2014 | 1 | 16 | 34 | 0 | 1 | 32 | 0 | 1 | 5 | 14 | 104 |
| 2015 | 1 | 13 | 38 | 0 | 1 | 41 | 0 | 1 | 5 | 15 | 115 |

| NV | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Bio | CoalAndP | NGAndOtl | Nuclear | Other | PV | CSP | Geo | Hydro | Wind | Total |
| 2005 | 0 | 21 | 36 | 0 | 0 | 0 | 0 | 15 | 5 | 0 | 77 |
| 2006 | 0 | 20 | 37 | 0 | 0 | 0 | 0 | 14 | 5 | 0 | 76 |
| 2007 | 0 | 21 | 39 | 0 | 0 | 1 | 1 | 16 | 5 | 0 | 83 |
| 2008 | 0 | 34 | 39 | 0 | 0 | 3 | 1 | 18 | 6 | 0 | 101 |
| 2009 | 0 | 20 | 40 | 0 | 0 | 3 | 1 | 20 | 6 | 0 | 90 |
| 2010 | 0 | 20 | 42 | 0 | 0 | 4 | 1 | 20 | 6 | 0 | 93 |
| 2011 | 0 | 18 | 43 | 0 | 2 | 4 | 1 | 20 | 6 | 0 | 94 |
| 2012 | 0 | 17 | 41 | 0 | 0 | 8 | 1 | 24 | 6 | 1 | 98 |
| 2013 | 0 | 17 | 42 | 0 | 0 | 10 | 1 | 23 | 6 | 1 | 100 |
| 2014 | 0 | 19 | 42 | 0 | 0 | 13 | 1 | 24 | 6 | 1 | 106 |
| 2015 | 0 | 20 | 45 | 0 | 0 | 17 | 1 | 24 | 6 | 1 | 115 |

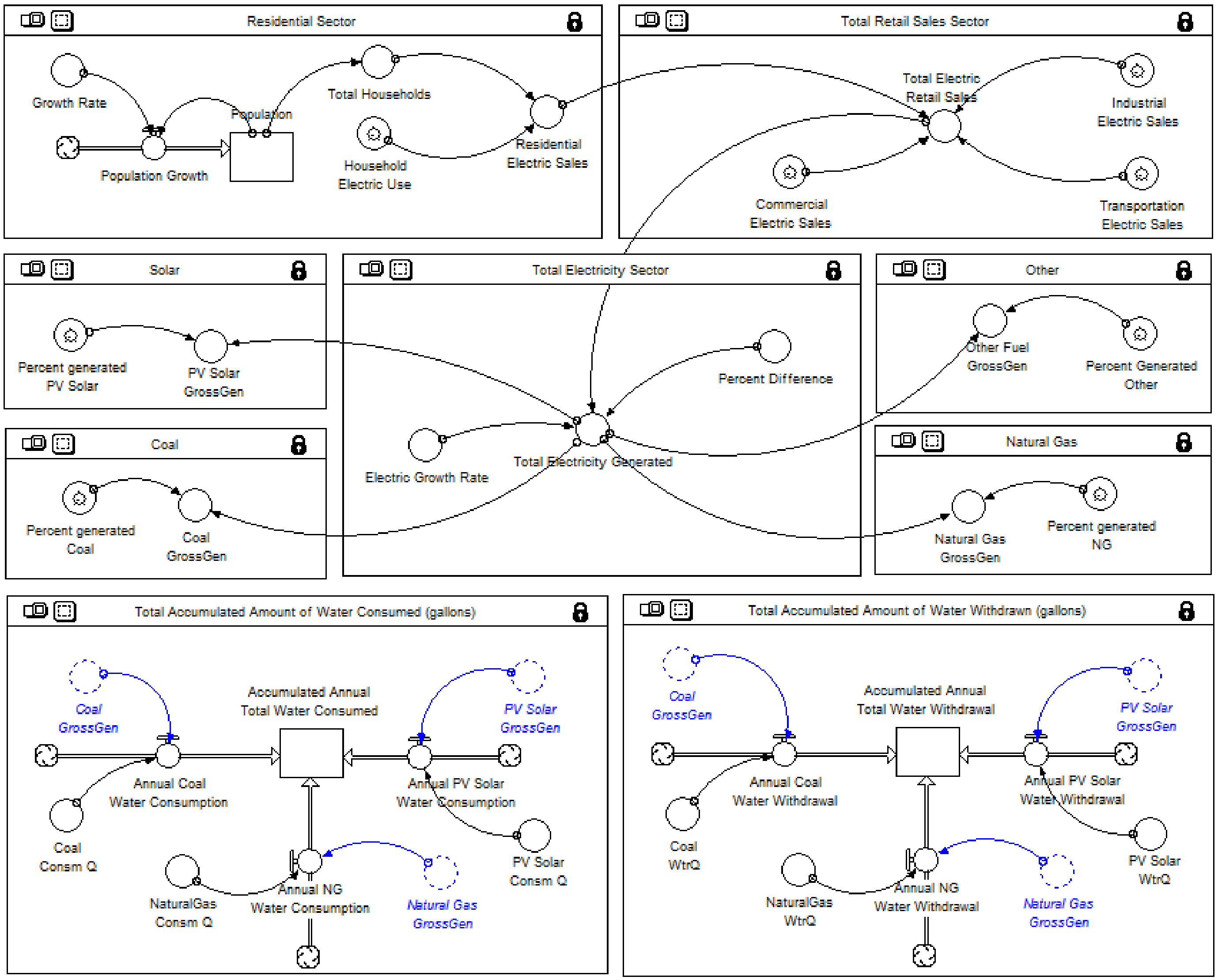
| UT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Bio | CoalAndP | NGAndOtl | Nuclear | Other | PV | CSP | Geo | Hydro | Wind | Total |
| 2005 | 0 | 24 | 24 | 0 | 1 | 0 | 0 | 1 | 29 | 0 | 79 |
| 2006 | 0 | 23 | 27 | 0 | 2 | 0 | 0 | 1 | 29 | 0 | 82 |
| 2007 | 0 | 28 | 29 | 0 | 1 | 0 | 0 | 1 | 29 | 0 | 88 |
| 2008 | 0 | 33 | 30 | 0 | 1 | 0 | 0 | 1 | 29 | 1 | 95 |
| 2009 | 0 | 26 | 31 | 0 | 1 | 0 | 0 | 1 | 29 | 3 | 91 |
| 2010 | 0 | 26 | 32 | 0 | 1 | 0 | 0 | 2 | 29 | 2 | 92 |
| 2011 | 0 | 27 | 32 | 0 | 1 | 0 | 0 | 2 | 29 | 3 | 94 |
| 2012 | 1 | 27 | 35 | 0 | 1 | 1 | 0 | 2 | 29 | 3 | 99 |
| 2013 | 1 | 29 | 36 | 0 | 1 | 1 | 0 | 4 | 29 | 3 | 104 |
| 2014 | 1 | 31 | 37 | 0 | 1 | 1 | 0 | 3 | 29 | 3 | 106 |
| 2015 | 1 | 31 | 37 | 0 | 1 | 15 | 0 | 3 | 29 | 3 | 120 |

APPENDIX F – Basic Building Blocks in STELLA®




- *Stocks* represent anything that accumulates. Stocks act as a reservoir or tub, storing what is collected from the inflow and what remains from the outflow, such as water, population, or information.
- *Flows* represent different valued rates. These rates can be constant or change with respect to time or another component in the system. Flows act as drains and/or spouts and either add to the stock or take away from the stock. Flows can either be bidirectional or unidirectional.
- *Converters* represent different functions. Given the required inputs and correct expression, the converters will create an equation and generate an output at a specific moment in time. Converters can also be represented as a graphical function instead of an expression.
- *Connectors* transmit information from one component to the next. The first component influences the second component, which establishes a cause-and-effect relationship by using the information from the first component as part of the output for the second component. Connectors can connect to any flow or converter but never to a stock.

APPENDIX G – Schematic Logical Flow of the Developed Mathematical Model



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