

**Energy Post Processor Development for California Wholesale Water
Operations: Functionality and Adaptability versus Run-Time Efficiency**

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B.S. (University of California, Davis) 2011

MS Plan II

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

In

Civil and Environmental Engineering

In The

OFFICE OF GRADUATE STUDIES

Of the

UNIVERSITY OF CALIFORNIA

DAVIS

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2013

Abstract

This project develops an energy post-processor for the CALVIN and CALSIM2 models with increased user-friendliness, energy costs, and two new forms of energy intensity. An earlier post-processor primarily focused on model results and implications on energy. This project explores the tradeoff between software functionality, adaptability, and run-time efficiency. It also overviews the post-processor development process and key aspects regarding the overall efficiency of the user and post-processor as a unit and some coding practices. By improving the platform of the energy post-processor and streamlining its tasks, future improvements can be implemented. To illustrate the current progress of the energy post-processor a CALVIN model run was explored pertaining to groundwater and a no-overdraft case for the Central Valley. Results indicate that a no-groundwater overdraft scenario will result in an increase of energy usage estimated to be 310 MWH statewide annually. However, by minimizing penalty costs in the CALVIN model via water transfers, the no-groundwater overdraft scenario shows an overall decrease in annual statewide pumping costs of approximately \$100 million. Groundwater pumping costs are reduced a small percent of surface water costs, and surface water pumping is greatly increased.

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1. Introduction

The California water system is large, complex, and dynamic. No single group or person ever has complete control over the system. But, it is managed through government laws, regulations, and contracts with roots extending to the founding of California, private and public water suppliers, and several state agencies. Despite the overwhelming size and complexity, people wake up to a clean, drinkable, and a seemingly never-ending supply of water. Most people in California do not worry if they will have clean water to drink or shower with today or the next day. This is only possible through effective management of California's water. This necessitates tools that help operators and decision-makers gain deeper insight into the water system. This includes hydrologic patterns, groundwater levels, leaks and losses throughout the system, and how much energy is spent to transfer water, or gained through hydropower, among other things. CALVIN and CALSIM2 are two models that help to describe California's water supply. These models output flow information for water bodies such as reservoirs. However, it is not always enough to just have flow information to assess how to properly manage the water system. So, various post-processors that use the flow outputs from these models are needed. The energy post processor described in this paper uses flow data from CALVIN and/or CALSIM2 to estimate energy use and associated costs in California's water system.

1.1. The Problem

Because most water in California falls in the north in the winter, yet most agricultural and densely populated areas are in the south, there is a large spatial and temporal disparity for California water management. The state has been greatly transformed so water needs can be met throughout the state. To facilitate water movement and storage, large pumping facilities are required for aqueducts, wells, and off-stream storage. As one can expect, they use up a lot of energy. In addition, hydropower is a large source of energy within the state and also needs to be accounted for. Approximately 5% of all electrical energy consumption is from water system operation (CEC 2005). With uncertain factors like climate change, global warming, and population growth, energy and water use is also sure to change. For this reason and due to the complexity of the state water system, models and their accompanying post-processors are key to effectively managing California's water.

1.2. Objectives

There are four main objectives for this project. The first objective is to update the existing post processor and make it more user-friendly. User-friendliness can be improved upon on several fronts in regards to the 2010 post-processor. The aim is to reduce the time needed to employ the post-processor.

The second objective is to calculate costs of energy use and generation. Since the post-processor uses flow data to estimate energy use every month, it is also possible to calculate the monthly energy cost of each facility if a unit cost is known. Cost is the dominant factor in many engineering, management, and policy decisions. The CALVIN model for example minimizes penalty costs to find flow releases at reservoirs. It only makes sense to follow suit and be consistent in making cost available for energy analysis for the water system. In addition,

monetary scales are more easily gauged than units of power such as Watts by average people and policy-makers. If someone was given one megawatt of power, they would not intuitively know if that is a small or large amount of power. A fixed unit cost is used in the cost calculation.

The third objective is to enable the post-processor to distinguish and accommodate more intricate forms of energy intensity. The current energy intensity for most of the facilities in the post-processor from the 2010 version are in a fixed form; however, there are other intensities in the form of a monthly time series and a function. These forms may more accurately depict energy use for a specific facility. Therefore, it is important to properly be able to calculate the energy intensity using that form instead of ignoring the station all together or using a less accurate fixed value. The scope of this addition to the post-processor is limited to a monthly time series and a function form of energy intensity.

The fourth objective is to add more facilities to the post-processor, which allows the post-processor to be applicable to a greater spectrum of scenarios. The 2010 energy post-processor included surface water calculations only. As suggested by the 2010 post-processor developer, groundwater facilities were added. This accommodates topics such as conjunctive use and groundwater overdraft, which are currently popular in California water management.

2. The 2010 Post-Processor

The previous post-processor was created by Matthew Bates in 2010 for the CALVIN model and CALSIM2 model. It was written in a mix of standard Microsoft Excel and Visual Basic for Applications. His intention for the post processor was to estimate energy impacts of water operations, compare energy intensities, and run example calculations.

The original post processor had three main inputs, the flow output from CALVIN or CALSIM2 in a .dss file format, energy intensity data saved into the actual spreadsheet, and a facilities worksheet, containing information linking both the energy intensity data and the flow data while also storing other relevant information such as what project it belongs to and what type of facility it was.

Upon opening the Excel file, the user sees a starting worksheet. On this worksheet is the purpose of the post-processor, its version, instructions, and some drop down options for the post-processor to utilize. In total, there are five options. They are: the energy intensity source, what network to use, projects to limit the calculations to, types of facilities to use, and the status of the facilities to use. The energy intensity source refers to the data the user would like to use. For many stations both GEI data and DWR data are available to the post-processor. These data sometimes differ. For example, some facilities using GEI have a fixed energy intensity, while that same facility may be represented by a function in DWR data. The second option is what network to use. The CALVIN and CALSIM2 models use different networks. Therefore, it is necessary to have both facilities' network IDs available when matching up data for calculation in the post-processor. The third option is what project to limit the calculations to. If a user's only focus is facilities in the Central Valley Project, other facilities in the network can be omitted. The fourth option is the facility type, such as reservoirs, pump stations, or generation stations. The fifth option is facility status, whether or not the facility is completed or if has yet to be built and is just proposed.

Table 1. User Options for the Energy Post-Processor

| Energy Intensity Source | Associated Projects | Facility Type | Facility Status | Network |
|-------------------------------|---------------------|------------------------------|---------------------|---------|
| All Stations & Default Source | SWP, CVP, & Local | Pump & Generation Facilities | Existing & Proposed | CALVIN |
| DWR | SWP & CVP | Pump Facilities | Existing | CALSIM2 |
| GEI | SWP | Generation Facilities | Proposed | |
| DWR then GEI | CVP | Reservoirs | | |
| GEI then DWR | Local | | | |

The output for the old post-processor is an error worksheet and the energy worksheet. The energy worksheet contains the total energy used or generated by each facility for each time step. This usually tends to be monthly. The errors worksheet lists facilities that were skipped from the post-processor energy calculation and gives a brief description as to why. This is a handy function added to give the user some troubleshooting in the event that the desired facility is not listed in the final energy calculation worksheet.

3. Development Theory

3.1. Platform

The 2010 version of the post-processor was created using Microsoft Excel 2003, a spreadsheet program, for the Windows operating system and Visual Basic for Applications, a programming language embedded into Excel. Microsoft Excel is widely used for data analysis and calculation. Because of its versatility and its accessibility, Microsoft Excel is ideal for storing and analyzing the present amount of data used by the energy post-processor.

The 2013 version of the post-processor uses the most current available version of Microsoft Excel 2010 (Windows) and 2011 (Mac). Because the data input is dynamic and changes based on the different model runs from CALVIN or CALSIM2, calculations cannot be simply done within the Excel spreadsheet directly. Specifically, the flow information imported from CALVIN and CALSIM2 may include different facilities, a different number of facilities, and output results in different orders. What this means for Excel is that ranges of cells change with each scenario run based on CALVIN and CALSIM2 results. Therefore, more advanced search options not available in the standard Excel functions are needed to identify, match, and then calculate energy and cost. Another advantage of using Visual Basic for Applications is that the code, its object libraries and inner functionality change less dramatically and more slowly than the larger Excel program. Whereas Excel is updated every two to three years, Visual Basic for Applications is generally left untouched and only a few minor changes are made with each release of Excel. This means that Excel spreadsheet functions and formatting may be lost or altered when upgrading from 2003 to 2007 and then to 2010 versions. An example of this is data validation and shape objects. When updating the old post-processor from 2003 to 2010, all data validation options were lost and shape objects could not be properly saved. Also, links to another unknown workbook were deemed “missing.” However, the Visual Basic for Applications code worked as intended from the original developer without any major version upgrade flaws. For this reason, Visual Basic for Applications is used again for this post-processor.

3.2. Available Development Method Options

When developing a post-processor written with a programming language, a coding method must be used to approach its development. There are two main ways to develop the code to better the post-processor and allow it to calculate cost and also have functionality to deal with energy intensity in the form of a monthly time-series and function. The first method is to edit the existing Visual Basic Code and then optimize the code (Alagic 1978). The second method is to disregard the former code and start from scratch and then optimize the newly developed code (Alagic 1978).

The first method is preferred because it is less work. Editing clearly written and well-structured code is much easier than starting from nothing. This decreases the time to develop the code used by the post-processor. It also makes the process of debugging and development much less difficult conceptually in most cases.

The second method is more work, but the developer will be more familiar with the code itself and its minute details. However, it takes much longer, is more work, and may be redundant if a pre-existing code is available. Because it is written from scratch, the developer is more conceptually involved compared to taking the first method.

For the development of the new 2013 version energy post-processor the second method, rewriting the code from scratch, is employed. Because the previous code was contained in several larger cascading loops, the code itself was rigid. Altering the pre-existing code with the first method would make the final code convoluted and confusing for future developers. Re-using the pre-existing code would keep inefficient coding implementations such as redundant searches and calculations. Adding extra code and functionality to the post-processor would increase run-time. Therefore, the code was rewritten from scratch. Some naming conventions were reused for simplicity. By rewriting the code with some more modern coding practices mentioned below, the functionality of the post-processor is increased, while run-time stays the same or decreases.

4. Inputs and Outputs

4.1. Inputs

The inputs for the post-processor are the flow data, the energy intensity data, and the facility data. Each of these data inputs is separated into three different Excel worksheets. Because the layout was well organized and logical in the 2010 version post-processor, the overall formatting was maintained in the 2013 version post-processor.

Table 2. Energy Post-Processor Inputs

| # | Inputs |
|---|-----------------------|
| 1 | Energy Intensity Data |
| 2 | Time Series Flow Data |
| 3 | Facility Data |

Two sets of data are stored within the post-processor. They are the energy intensity data and the facility data. The last set of data required to run the post-processor is the time series flow data, which must be supplied by the user.

The energy intensity input data is contained in its own worksheet within the post-processor workbook. There are three main forms of energy intensity data for the 2013 version post-processor: fixed, fixed monthly, and function.

Table 3. Energy Intensity Forms

| Type | Simple Example |
|---------------|----------------|
| Fixed | 284.5 |
| Function | $Y = 7X + 3$ |
| Fixed Monthly | Jan: 100.7 |
| | Feb: 124.9 |
| | Mar: 115.0 |
| | Apr: 101.8 |
| | May: 70.2 |
| | June: 63.5 |
| | July: 65.1 |
| | Aug: 70.2 |
| | Sept: 71.6 |
| | Oct: 85.2 |
| | Nov: 91.7 |
| | Dec: 102.2 |

The fixed form is requires only one real, positive number. This energy intensity stays constant regardless of the flow values and the time at which they occur. Fixed monthly energy intensity values allow energy intensity to depend on the time at which the flow occurs, specifically the month. This requires twelve separate fixed energy intensity values, one for each month of the year. This sometimes models the energy use and intensity more accurately. The third form of energy intensity is a function. These functions depend on the flow or amount of storage available in the reservoir at any given time. While most .DSS input are flow values, some reservoirs report storage levels instead to accommodate the input needed for the function type energy intensity.

Another input for the post-processor is the time series flow data imported from CALVIN or CALSIM2. Initially, the output from these models is a .dss file; however, this data can be entered into an Excel format in its own worksheet defaulted “Retrieved TS” where “TS” stands for time series. This data has several formats and only two main formats are allowed for the post-processor to function. Fortunately, the post-processor can detect the time-series data format and alert the user on whether or not it is in a usable format. The yellow box from the beginning worksheet of the post-processor listing path names contains the information to extract the facilities necessary to the post-processor. The table below shows the format of the path names and their nomenclature.

Table 4. DSS file pathname nomenclature (HEC 2009)

| Section | Pathname Definition |
|---------|------------------------|
| Part A | Project, River, Basin |
| Part B | Location |
| Part C | Data Parameter |
| Part D | Starting date |
| Part E | Time interval |
| Part F | Additional information |

The nomenclature above, helps clarify list of pathnames needed to retrieve facility flow data. For convenience, it is already listed in the post-processor so that the Excel add-in by HEC can easily retrieve the information. HEC-DSSVue is not needed but is also a valid form of flow data retrieval. It can be downloaded from the official HEC website and was created specifically to review, edit, and handle DSS file types (HEC 2009). Table 5 contains pathnames discussed above for the facilities needed by the post-processor.

The third necessary worksheet to the post-processor is the facility data worksheet. This contains supporting information to the facilities listed from the original beginning worksheet in the yellow box via path names. This worksheet connects the user input (project, facility status, facility type, etc.) to the energy intensity data worksheet and then to the time series flow data worksheet. The time series flow data worksheet identifies each facility by a network link ID. The energy intensity data, since it must be able to be applied to both CALVIN and CALSIM2 networks and both models do not use the exact same network, identifies facilities based on a facility name, not network link ID. In this sense, the facility data worksheet is a keystone to the post-processor. Table 6 illustrates some of the information in this worksheet.

Table 5. DSS facility pathnames

| CALVIN Pathnames |
|--|
| //DT7-C11/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HSU2D77-C6/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //SR-8/STOR/01JAN1920/HMON// |
| //D55-C22/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //C22-T14NAPA/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //CC1 PMP-C70/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //SoBayPMP-D831/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //DYallsPMP-SR-15/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Banks PMP-D801/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Tracy PMP-D701/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //ONeillPMP-D814/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //ONeillPWP-D712/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //GianPMP-SR-12/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //GianPWP-D816/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //SR-12/STOR/01JAN1920/HMON// |
| //SR-12-D714/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //D816-D818/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //DT12-D722/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //DAmigoPMP-D744/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //LPerilPMP-BadgerPMP/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //BadgerPMP-D847/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //D847-D848/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //BuenaPMP-D860/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //WheelrPMP-D862A/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //ChrisPMP-D862B/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //EdmondPMP-C103/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Alamo PWP-D868/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //OSO PMP-D884/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Warne PWP-SR-28/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Cast PWP-D887/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //SR-28/STOR/01JAN1920/HMON// |
| //SR-29/STOR/01JAN1920/HMON// |
| //PB PMP-C124/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Mojava PWP-SR-25/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //Devils PWP-C129/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //C123-C138/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //JuliaH PMP-C136/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //D876-C161/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //D888-C161/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //C133-C161/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP1-C3/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP2-C6/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP3-C303/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP4-C14/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP5-C26/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP6-C17/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP7-C34/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP8-C36/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP9-C68/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP10-C84/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP11-C172/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP12-C45/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP13-C46/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP14-C91/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP15-C90/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP16-C50/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP17-C55/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP18-C60/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP19-C100/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP20-C63/FLOW_DIV(KAF)/01JAN1920/HMON// |
| //HGP21-C66/FLOW_DIV(KAF)/01JAN1920/HMON// |

Table 6. Important Facility Data Worksheet Information Types

| Data | Example |
|---------------------------------|------------------|
| Facility ID | Cordelia PMP |
| Facility Type | Pump Station |
| Project | SWP |
| Applicable Networks | CALVIN & CALSIM2 |
| Facility Status | Existing |
| Default Energy Intensity Source | GEI Data |
| Unit Cost | -\$75/AF |
| Network Link ID | C22-T14NAPA |

4.2. Outputs

The output for the 2013 energy post-processor is simpler than its 2010 counterpart. It outputs two separate worksheets in the same format as the time-series flow data input. They are the energy use and cost calculation. Because the flow data was in a time series format, it only made sense to follow suit and keep the output consistent, so that the user could easily understand where the results were and how they were formatted. Because the user is already be familiar with this format when dealing with the time series flow data input, the output should not confuse the user and the focus can be spent more on the implications of the results and less on deciphering where the results are and how exactly it was outputted.

Table 7. Energy Post-Processor Output

| # | Outputs |
|---|-------------------------|
| 1 | Time Series Energy Data |
| 2 | Time Series Cost Data |
| 3 | Graphs (Optional) |

If desired, the post-processor can also output graphs for every facility in the post-processor run. Because this is a relatively heavy task on the Excel program, the user must choose whether or not to graph the results. By default, the option is to not graph results. Three separate graphs exist for each facility. They are the flow data, energy use data, and unit cost data. Because of the large number of data points, a bar graph is used by default. Each facility also has its own graph. Combining them into one graph looks messy and is illegible. Below are examples of each of these graphs.

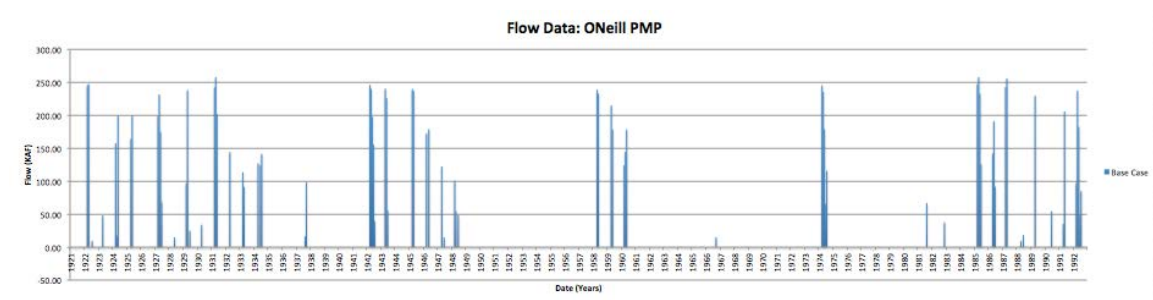


Figure 1: Flow Data Example of the O’Neil Pump Station

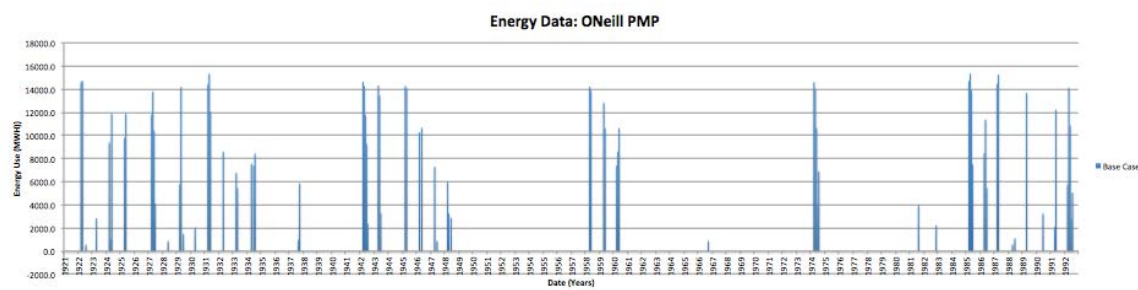


Figure 2: Energy Use Data Example of the O’Neil Pump Station

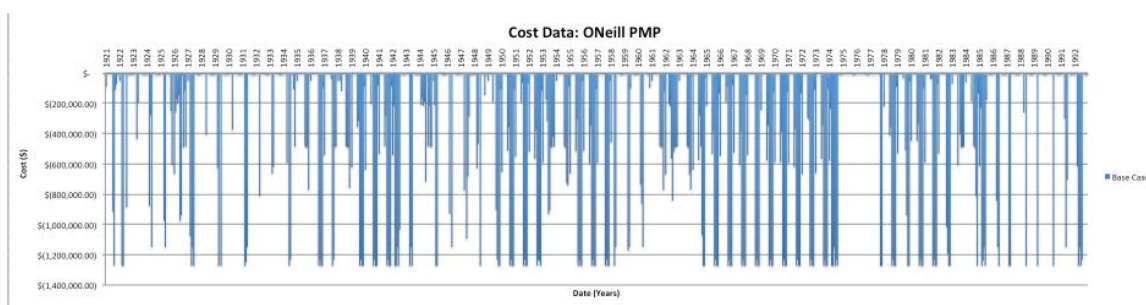


Figure 3: Cost Data Example of the O’Neil Pump Station

Due to the relatively heavy nature of graphing within Excel, it is recommended that only computers with more powerful processors use the automated graphing option, preferably Intel Core i5 processors and up, or the AMD equivalent.

5. Calculations and Equations

The energy post-processor uses two main equations to calculate energy use and associated energy costs. Energy use is estimated by multiplying flow and energy intensity (Equation 1).

$$\text{energy use} = \text{flow} \times \text{energy intensity} \quad (1)$$

Where flow outputs are generated by the CALVIN and CALSIM2 models. The flow and storage measurements are in units of thousand acre-feet per month (KAF/month) and energy intensity in the units of megawatt-hours per thousand acre-feet (MWH/KAF). The energy intensity data is stored within the post-processor but was originally taken from a DWR or GEI database. For post-processor analysis, pumping facilities have positive energy intensity while generation stations have a negative energy intensity. Flow is typically a positive value; however, the CALVIN and CALSIM2 models can output negative flow values so this should be considered when running the post-processor. Helper macros within the post-processor are available to ignore negative values if desired.

$$\text{energy cost} = \text{flow} \times \text{unit cost} \quad (2)$$

Where flow is in the unit of KAF/month and unit cost in units of dollars per acre-foot (\$/AF). Unit cost data also is stored within the post-processor, similar to the energy intensity data. The data was originally taken from the CALVIN model database. For post-processor analysis, pumping facilities have negative unit cost while generation stations have a positive unit cost. In general though, unit cost can be changed so that the energy cost is calculated as:

$$\text{energy cost} = \text{energy use} \times \text{unit energy cost} \quad (3)$$

In this case, which is not used by the post-processor, energy use is taken from equation 1 and is in units of MWH and unit energy cost is in units of dollars per MWH. In this case, unit energy cost can be taken from bulk electrical prices from the California Independent system operator (Cal ISO).

6. Post-Processor Testing

Because the code for the post-processor was rewritten from scratch, the results must be tested with the former post-processor's results. Both the 2010 and 2013 version post-processors were run using the same example time series flow data and the same user inputs. In addition, because some facilities were represented by a function or fixed monthly energy intensity, those facilities were ignored for the 2013 version post-processor validation because the older version could not accommodate these energy intensity forms.

| | |
|------------|------------------------|
| Part A: | EnergyPostProcessor |
| Part B: | Corning PMP |
| Part C: | ENERGY(MWH) |
| Part D: | |
| Part E: | 1MON |
| Part F: | |
| Beg. Date: | 7975 |
| Beg. Time: | 2400 |
| End Date: | 34242 |
| End Time: | 2400 |
| Units: | MWH |
| Data Type: | Index PER-AVER |
| | 10/31/1921 646.9499493 |
| | 11/30/1921 0 |
| | 12/31/1921 0 |
| | 01/31/1922 0 |
| | 02/28/1922 0 |
| | 03/31/1922 658.3495307 |
| | 04/30/1922 2208.75 |
| | 05/31/1922 2208.75 |
| | 06/30/1922 0 |
| | 07/31/1922 0 |
| | 08/31/1922 0 |
| | 09/30/1922 0 |
| | 10/31/1922 646.9499493 |

| | |
|------------|--------------------------|
| Part A: | Energy Post Processor () |
| Part B: | Corning PMP |
| Part C: | Energy (MWH) |
| Part D: | |
| Part E: | 1MON |
| Part F: | |
| Beg. Date: | 10/31/21 |
| Beg. Time: | 2400 |
| End Date: | 9/30/93 |
| End Time: | 2400 |
| Units: | MWH |
| Data Type: | Index PER-AVER |
| | 10/31/21 646.9 |
| | 11/30/21 0.0 |
| | 12/31/21 0.0 |
| | 1/31/22 0.0 |
| | 2/28/22 0.0 |
| | 3/31/22 658.3 |
| | 4/30/22 2208.8 |
| | 5/31/22 2208.8 |
| | 6/30/22 0.0 |
| | 7/31/22 0.0 |
| | 8/31/22 0.0 |
| | 9/30/22 0.0 |
| | 10/31/22 646.9 |

Figure 4. 2010 Energy Post-Processor Output Sample (Left)
Figure 5. 2013 Energy Post-Processor Output Sample (right)

The results above are snippets of a single facility and just a small sample of time series output data. This is to illustrate the confirmed post-processor results from the old and new versions of the post-processor. However, more than just this small snippet of code was tested for correctness. Instead the entire time series outputs were compared for facilities utilizing a fixed energy intensity. In each case, the results matched perfectly.

7. Upgrades and Changes from the 2010 Post-Processor to the 2013 Post-Processor

7.1. User-Friendliness

User-friendliness was a major issue with the 2010 version post-processor. To improve on the previous version, several changes were made. There are four categories of changes made, to improve user-friendliness. They are: appearance, user interface, feedback information, graphing. Each change helps to increase overall user efficiency by lessening the time spent post-processing.

The first change removed all unnecessary worksheets from the post-processor. This included “price metadata”, “price data”, “~cost results” worksheets. The old post-processor did not have any function for these and the new 2013 version handles the data so that these worksheets are not needed. So, they were removed entirely. The “system data” worksheet, which was renamed “data validation options” is now a hidden worksheet because the user never needs to use this worksheet. It is only for developers adding data or changing data in the post-processor. The second change to the appearance of the post-processor was to remove all questions or random comments from all worksheets. Third, the large amount of text on the starting worksheet was reduced and displaced to a user form, which shall be discussed later. The yellow box containing the pathnames of the necessary facilities was moved so that it would be clear to see and a small amount of text was used to indicate its purpose to the post-processor. All of these cosmetic changes decrease the time the user spends trying to understand and use the post-processor. It makes the post-processor simpler to understand and more intuitive to use at the start.

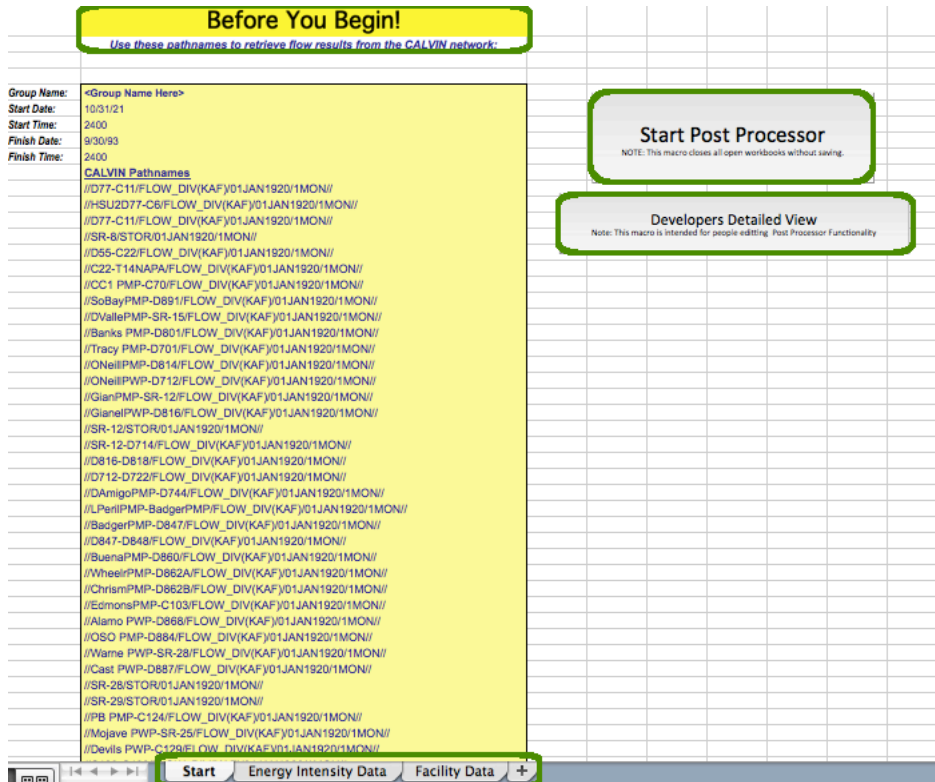


Figure 6. Updated Start Screen for 2013 Energy Post-Processor

The next change was to the user-interface of the post-processor, particularly to retrieve output. The large amount of text describing purpose and instructions for the post-processor on the starting worksheet was reduced and placed inside a user-form. This user-form is simpler to use and employs radio buttons instead of a drop down menu within the starting worksheet. This makes the post-processor more intuitive to use and comprehend. Now, the user pushes one button to select various options instead of two or three. When completing several post-processing runs back to back, the amount of work is reduced significantly. Another feature of this user-form is the file navigation ability. This allows the user to retrieve the time series data from another Excel workbook more simply. Now, all the user has to do is navigate to the other Excel workbook's file location. Previously, the user would have to open the other workbook containing the time series data, then open the post-processor, and then either copy or move the worksheet to the post-processor workbook. This is a simple task but gets tedious with multiple post-processing runs done back to back. Overall, the button clicks that the user must complete are no longer separated throughout the workbook but are instead focused all in one user-form.

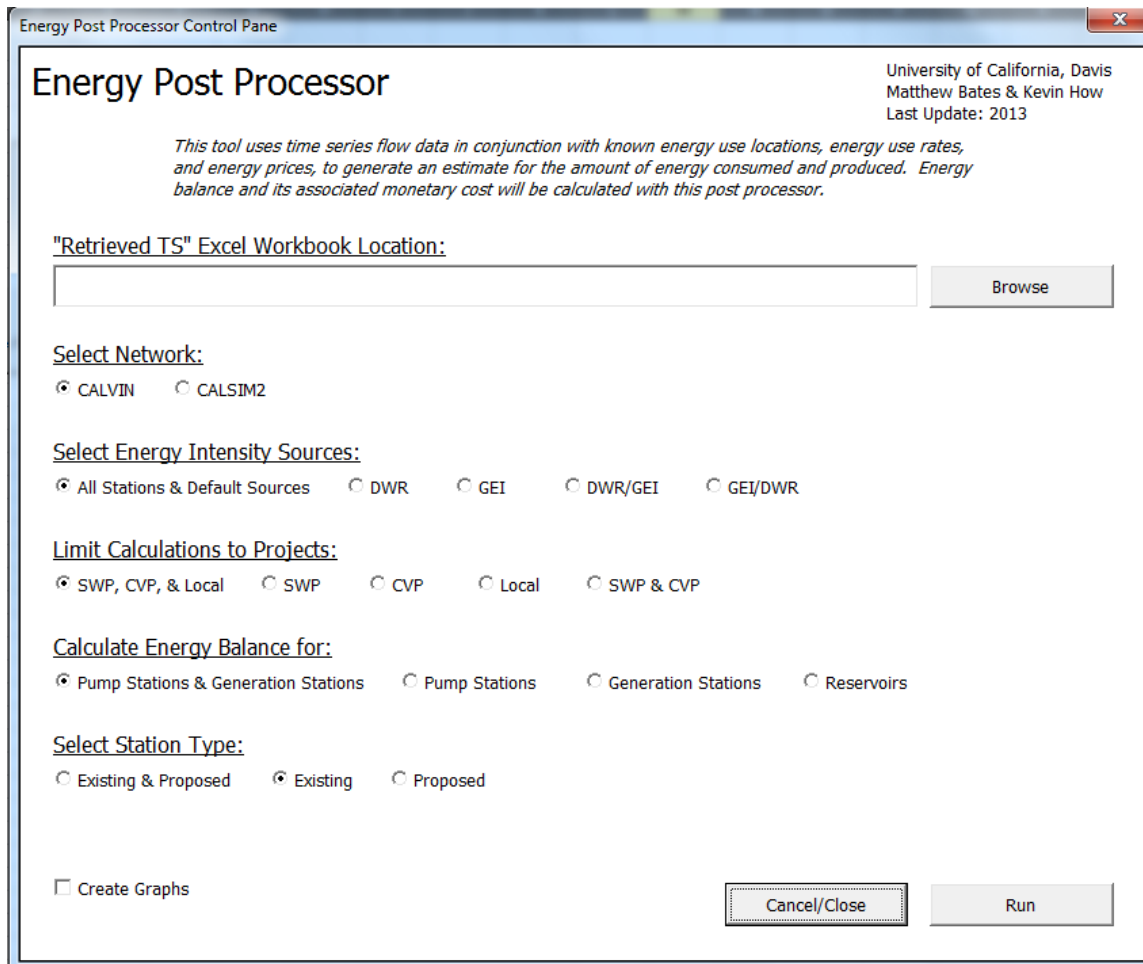


Figure 7. User Control Pane to Run Post-Processor

The third alteration was to the user feedback. In the previous post-processor, an entire worksheet was created showing the user what facilities were skipped. In addition, message boxes would arise if an error does not allow the post-processor to run. While this is a good idea, it is not necessary. The 2013 version post-processor continues to use message boxes if an error prevents the post-processor code from running; however, the error worksheet was removed and replaced instead with a column in the facility data worksheet. This column will tell the user if a facility is used or not. This way, the user can immediately see why the facility was skipped in regards to their previous input choices, while reducing the amount of text the user has to read more text. This change achieves the same task using less space on the post-processor workbook. Simplicity was the main theme in this change, without compromising the functionality of the post-processor. It also saves time for the user. The tradeoffs to this increased user-friendliness and ease of use is an increased complexity in Visual Basic for Applications and the actual program run-time. However, this is acceptable because the code is well structured and easy to comprehend. Also because the post-processor will be used more by users and less frequently edited by developers, this tradeoff is acceptable.

The last improvement on user-friendliness is the graphing option made available to the energy post-processor. While this task is relatively heavy on the Excel program and increases run-time

greatly relative to the overall post-processor run-time; it is well worth it. For this function, graphs of every relevant facility are created for flow data, energy use data, and energy cost data. Because there is so much time series data, each facility has its own set of graphs. Combining facilities would create an overly cluttered graph that is nearly unreadable. This is one of the most powerful add-ons to the post-processor because it creates 3 graphs for every facility. So if 25 facilities are analyzed by the post-processor, 75 graphs would be produced. Doing this by hand and then formatting all of these graphs is a tedious and time consuming. By having a function that automatically graphs and formats data, the user can save time and post-process many sets of data consecutively within a short time.

7.2. Cost Calculation

Adding cost calculations for energy use increases the post-processor's functionality. As mentioned previously, the equation below is the general equation used to calculate cost from energy use for the post-processor.

$$\text{energy cost} = \text{flow} \times \text{unit cost} \quad (2)$$

7.3. Energy Intensity Forms

Increasing the number of usable forms of energy intensity by the post-processor also increases the functionality of the post-processor. As mentioned above, actual scenarios may be better represented with energy intensities in the form of monthly fixed values or a function. Data from the Department of Water Resources (DWR) has several facilities' energy intensity represented as a function for example. Therefore it is important to also be able to utilize these forms of energy intensities.

There are tradeoffs for adding this extra functionality just as with adding the cost calculation. While the code is longer and more complex, it is again, negligible due to the organization and structure of the code. Unlike the cost calculation however, there is no added worksheet, so the workbook size remains the same. The main difference is in the actual energy results, which should be more accurate, now that the post-processor can accommodate more forms of given energy intensity.

7.4. Agricultural Groundwater Data

Groundwater is a popular topic in California water management lately. Adding groundwater pumping data to the energy post-processor increases the adaptability and functionality of the post-processor. Scenarios involving groundwater overdraft and conjunctive use can be better explained with this modification to the post-processor. However, only agricultural groundwater is included currently. Agricultural groundwater demands are much larger than urban groundwater demands. More data was also available for agricultural demands and pumping than the urban counterpart. For this reason, agricultural groundwater demands were added to the post-processor. In total, 21 groundwater facilities were added to the existing 56 surface water facilities. The absolute minimum data required to successfully add a facility includes cost data, energy intensity, facility name, and its network ID for the CALVIN or CALSIM2 models. Most

of this data was available in the 2001 Appendix G found on the CALVIN website. Energy intensity was back calculated using equation 4.

$$energy\ intensity\ \left(\frac{kWh}{AF}\right) = \frac{Volume(m^3) \times Head(m)}{367} \quad (4)$$

The CALVIN network link was manually searched from the master database used to run the CALVIN model itself. Head data was not available for every agricultural and urban groundwater facility. Because of this, those stations were not added to the post-processor. Appendix G also notes that the unit cost is in 2008 dollars.

7.5. Summary of Upgrades

Below is a table of the upgrades completed for the post-processor. It also shows what type of upgrade it is and how it affects the post-processor’s ability to calculate associated costs and energy given user input and time series flow data.

Table 8. Summary of Upgrades Completed to Energy Post-Processor

| Upgrade | Upgrade Type |
|---------------------------------------|---------------|
| New Start Screen & User Form | Efficiency |
| Cleaned Up Workbook | Efficiency |
| Graphing Option | Functionality |
| Energy Intensity Form - Monthly Fixed | Functionality |
| Energy Intensity Form - Function | Functionality |
| Cost Calculation | Functionality |
| Groundwater Data | Adaptability |
| Restructured and Rewritten Code | Adaptability |

8. Application

The scenarios described below were provided by Prudentia Zikalala (Zikalala 2013; Chou 2012). Each scenario was modeled via CALVIN, using CALVIN’s most up to date database information. Each model run spans 72 years over several hydrologic sub regions of California with special attention to the Central Valley. The two scenarios described below are the base case of water operations and alternative case of no-groundwater overdraft. Below, each case is briefly overviewed to give insight to post-processor results discussed later.

8.1. Base Case

The base case represents California as it presently is with historical hydrology and estimated 2050 water demands. Standard water demands and constraints are used from the CALVIN database (Chou 2012).

8.2. No-Overdraft Case

The alternative case was for a no-groundwater overdraft case. Groundwater overdraft is important in California especially due rise in environmental concerns. For this case, the

beginning and ending storages are constrained to be equal for all reservoirs and ground water storage links (Chou 2012).

8.3. Energy Post-Processor Results

Each case yielded both energy use and energy cost results. To more efficiently analyze the results, facilities were analyzed in groups based upon their physical location.

Table 9: Region Description

| Region | General Description of Region | General Northern Limit of Region | General Southern Limit of Region |
|--------|-------------------------------|----------------------------------|----------------------------------|
| 1 | Sacramento North | Trinity River | Knight's Landing Ridge Cut |
| 2 | Sacramento South | Butte Creek | Los Vaqueros Reservoir |
| 3 | San Joaquin | Bethany Reservoir | Millerton Lake Friant Dam |
| 4 | Tulare | Millerton Lake Friant Dam | Edmonston Pumping Plant |
| 5 | Southern California | Edmonston Pumping Plant | Imperial Dam |

8.3.1. Storage Reservoir

The four storage reservoirs included by the post-processor are Folsom Reservoir, San Luis Reservoir, Pyramid Reservoir, and Castaic Reservoir. Folsom storage levels were higher in the base case than the no-groundwater overdraft case for almost the entire model run time period. However, Table 10 indicates that the no-overdraft case had a greater average annual volume of water. This can be explained by the greater peak volumes in the no-overdraft case. This indicates that in the no overdraft case, Folsom makes up for a loss of water that would normally be supplied by groundwater aquifers. To keep up with water demands, Folsom releases more water, resulting in an overall lower storage level. The San Luis Reservoir had the opposite reaction to the no overdraft case compared to Folsom. In the San Luis Reservoir, storage levels were greater for the no overdraft case. This may occur because region 3 fewer groundwater aquifers than regions 1,2, and 4 and because CALVIN minimizes penalty costs, water was taken from other reservoirs to make up for the lack of groundwater supplies, leaving the San Luis Reservoir with greater storage levels on average than in the base case. Pyramid and Castaic are located in region 5. Region 5 (Southern California) was not shown above because groundwater-dependent agricultural demand areas are located there and would see less dramatic changes due to a no-groundwater overdraft case. They also have a lower average annual flow volume. Both Pyramid and Castaic have similar volume storage patterns as the San Luis Storage. Each facility was about even in the amount of times that it had larger storage levels, which is why the change in average annual flow volume from the base case to the no-overdraft case is so small. Penalty costs for using water from these facilities may have been too great, so water accumulated until demands grew to large and penalty costs were deemed “worth it,” resulting in large draw down of reservoir supplies.

Table 10: Reservoir Storage

| Facility | Region | Avg. Annual Base Flow (TAF) | Δ Avg. Annual Flow (TAF) |
|------------------|--------|-----------------------------|--------------------------|
| Folsom Storage | 2 | 6291 | 161 |
| San Luis Storage | 3 | 3766 | -2662 |
| Pyramid Storage | 5 | 538 | -39 |
| Castaic Storage | 5 | 1353 | -31 |

8.3.2. Unaffected Facilities

Some facilities showed no change in flow between the base case and no-overdraft case. Because of this, the energy and cost results are the same for each scenario. Each of these facilities is located in either regions 4 or 5. The facilities located in region 4 are all part of the coastal aqueduct. Because of its location within the network and physical location in the California water system, it makes sense that there is little or no change in these facilities. Region 5 facilities see little change because much of the water is diverted elsewhere within the region in the optimization process, flow is kept constant for these facilities by the CALVIN model. Also, because little agricultural groundwater demand is located within this region, it makes sense that Alamo Gen and the Colorado River Aqueduct sees little change between the two scenarios.

Table 11: No Flow Change Facilities

| Facility | Region |
|-------------------------|--------|
| Las Perillas PMP | 4 |
| Badger Hill PMP | 4 |
| Devil's Den PMP | 4 |
| Bluestone PMP | 4 |
| Polonia Pass PMP | 4 |
| Alamo Gen | 5 |
| Colorado River Aqueduct | 5 |

8.3.3. Surface Water Facilities

Surface water facilities tended to use more energy in no-overdraft case than in the base case. Facilities had peak differences ranging up to 300 TAF. However, approximately two thirds of facilities had peak differences ranging from 0 to 100 TAF. The last third had peak differences consistently ranging from 100 to 300 TAF. In terms of energy, there was a relatively even spread of MWH ranging from 0 to 50 MWH for all surface water facilities. This is because the energy intensities are a fixed constant for most of the facilities as described in the CALVIN master database and Appendix G of the 2001 CALVIN report. Most pumping facilities incurred several peak costs up to \$6 million. Some stations incurred costs on the order of tens of thousands of dollars; however, about 33% incurred a cost on the order of millions, between \$1 and \$6 million. This is quite a lot considering that the generation stations resulted in peak yields of up to \$1.5 million. However, the increase in flow and energy is understandable because of the greater volume of water needed to compensate for the lack of groundwater pumping in the no-groundwater overdraft scenario. More water must be released from reservoirs and then pumped to various locations to meet urban and agricultural demand. Average annual statewide costs to the state show a net decrease. This is possible because the CALVIN model minimizes penalty costs and pumps water through facilities that incur lower costs throughout the California water system to meet demands. Because of this, it is possible to have a slightly lower cost in the no-overdraft case in surface water.

Table 12: Surface Water Annual Averaged Results

| # | Facility | Region | Avg. Annual Base Flow (TAF) | Δ Avg. Annual Flow (TAF) | Avg. Annual Base Energy (MWH) | Δ Avg. Annual Energy (MWH) | Avg. Annual Base Cost (\$ millions) | Δ Avg. Annual Cost (\$ millions) |
|-------------------------|-----------------------------|--------|-----------------------------|--------------------------|-------------------------------|----------------------------|-------------------------------------|----------------------------------|
| 1 | Corning PMP | 1 | 173 | 9 | 32,872 | 1,655 | \$ - | \$ - |
| 2 | Tehama-Colusa Relift PMP | | 640 | -14 | 27,656 | -592 | \$ - | \$ - |
| 3 | Barker Slough PMP | 2 | 111 | -2 | 20,502 | -388 | \$ - | \$ - |
| 4 | Cordelia PMP | | 111 | -2 | 40,971 | -775 | \$ (8.33) | \$ 0.16 |
| 5 | Contra Costa PMP | | 63 | 1 | 10,300 | 127 | \$ (1.24) | \$ 0.02 |
| 6 | Banks PMP | | 4,390 | -104 | 1,249,744 | -29,568 | \$ (0.02) | \$ (0.00) |
| 7 | Jones PMP | | 904 | -719 | 210,403 | -167,334 | \$ (94.82) | \$ 2.24 |
| 8 | South Bay PMP | 3 | 1 | 0 | 981 | -1 | \$ (3.44) | \$ (0.04) |
| 9 | Del Valle PMP | | 1 | 0 | 68 | 1 | \$ (0.01) | \$ 0.00 |
| 10 | ONeill PMP | | 158 | -391 | 9,419 | -23,272 | \$ (4.07) | \$ 3.24 |
| 11 | ONeill GEN | | 1,157 | 228 | -37,267 | -7,338 | \$ 0.55 | \$ (1.37) |
| 12 | San Luis SWP PMP | | 578 | -384 | 95,525 | -63,684 | \$ (30.21) | \$ (5.95) |
| 13 | San Luis CVP PMP | | 578 | -384 | 95,525 | -63,684 | \$ (15.09) | \$ 10.01 |
| 14 | San Luis SWP GEN | | 299 | -373 | -22,559 | 38,848 | \$ 4.12 | \$ (5.15) |
| 15 | San Luis CVP GEN | | 299 | -373 | -22,559 | 38,848 | \$ 51.93 | \$ (36.70) |
| 16 | San Felipe PMP | | 264 | 0 | 117,797 | 43 | \$ - | \$ - |
| 17 | San Luis Relift PMP | | 3,101 | -712 | 289,971 | -66,569 | \$ - | \$ - |
| 18 | DMC Relift PMP | | 1,885 | -100 | 943 | -50 | \$ (40.72) | \$ 2.16 |
| 19 | Dos Amigos SWP PMP | | 3,045 | -699 | 412,944 | -94,745 | \$ (34.26) | \$ 7.86 |
| 20 | Dos Amigos CVP PMP | 3,045 | -699 | 412,944 | -94,745 | \$ (0.71) | \$ - | |
| 21 | Las Perillas PMP | 4 | 63 | 0 | 4,826 | 0 | \$ (0.34) | \$ - |
| 22 | Badger Hill PMP | | 63 | 0 | 12,410 | 0 | \$ (1.05) | \$ - |
| 23 | Devil's Den PMP | | 63 | 0 | 45,330 | 0 | \$ (612.02) | \$ - |
| 24 | Bluestone PMP | | 63 | 0 | 46,194 | 0 | \$ (657.89) | \$ - |
| 25 | Polonia Pass PMP | | 63 | 0 | 44,859 | 0 | \$ (657.31) | \$ - |
| 26 | Buena Vista PMP | | 1,889 | 16 | 462,412 | 3,836 | \$ (38.16) | \$ (0.29) |
| 27 | Teerink PMP | | 2,031 | 16 | 543,778 | 4,196 | \$ (23.65) | \$ - |
| 28 | Chrisman PMP | | 2,029 | 16 | 1,265,524 | 9,775 | \$ (53.87) | \$ (1.09) |
| 29 | Edmonston PMP | | 2,029 | 16 | 4,627,134 | 35,740 | \$ (132.29) | \$ (2.78) |
| 30 | Alamo GEN | 5 | 1,257 | 0 | -146,622 | 0 | \$ 6.13 | \$ 0.13 |
| 31 | Oso PMP | | 772 | 16 | 210,714 | 4,278 | \$ (11.53) | \$ 0.83 |
| 32 | Warne GEN | | 746 | 16 | -435,823 | -9,153 | \$ 61.58 | \$ (1.42) |
| 33 | Castaic GEN | | 743 | 16 | -902,713 | -19,732 | \$ 82.17 | \$ (0.97) |
| 34 | Pearblossom PMP | | 1,120 | -13 | 764,950 | -9,035 | \$ (51.65) | \$ 0.68 |
| 35 | Mojave Siphon GEN | | 1,009 | -13 | -78,064 | 1,031 | \$ 7.48 | \$ (0.10) |
| 36 | Devil's Canyon GEN | | 1,008 | -13 | -1,220,683 | 16,127 | \$ 123.57 | \$ - |
| 37 | Colorado River Aqueduct PMP | | 1,301 | 0 | 2,570,570 | 0 | \$ 0.00 | \$ - |
| Statewide Totals | | | 37,051 | -4,648 | 10,760,979 | -496,162 | -2,135 | -29 |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

* Costs are negative values; benefits are positive values

8.3.4. Groundwater Pumping

In a previous thesis, the groundwater pumping facilities were analyzed by sub regions and regions. To be consistent, the same facilities will also be viewed in the same groupings.

Table 13: Groundwater Region Grouping

| Region | Sub region | Agricultural Demand Area | CALVIN Link ID |
|--------|------------|--------------------------|----------------|
| 1 | 1 | CVPM 1 | HGP1-C3 |
| | 2 | CVPM 2 | HGP2-C6 |
| | 3 | CVPM 3 | HGP3-C303 |
| | 4 | CVPM 4 | HGP4-C14 |
| 2 | 5 | CVPM 5 | HGP5-C26 |
| | 6 | CVPM 6 | HGP6-C17 |
| | 7 | CVPM 7 | HGP7-C34 |
| | 8 | CVPM 8 | HGP8-C36 |
| | 9 | CVPM 9 | HGP9-C68 |
| 3 | 10 | CVPM 10 | HGP10-C84 |
| | 11 | CVPM 11 | HGP11-C172 |
| | 12 | CVPM 12 | HGP12-C45 |
| | 13 | CVPM 13 | HGP13-C46 |
| 4 | 14 | CVPM 14 | HGP14-C91 |
| | 15 | CVPM 15 | HGP15-C90 |
| | 16 | CVPM 16 | HGP16-C50 |
| | 17 | CVPM 17 | HGP17-C55 |
| | 18 | CVPM 18 | HGP18-C60 |
| | 19 | CVPM 19 | HGP19-C100 |
| | 20 | CVPM 20 | HGP20-C63 |
| | 21 | CVPM 21 | HGP21-C66 |

Table 14: Groundwater Annual Averaged Results

| # | Facility | Region | Avg. Annual Base Flow (TAF) | Δ Avg. Annual Flow (TAF) | Avg. Annual Base Energy (MWH) | Δ Avg. Annual Energy (MWH) | Avg. Annual Base Cost (\$ millions) | Δ Avg. Annual Cost (\$ millions) |
|-------------------------|-----------|--------|-----------------------------|--------------------------|-------------------------------|----------------------------|-------------------------------------|----------------------------------|
| 1 | GW-1 PMP | 1 | 51 | -5 | 7,903 | -744 | \$(27.22) | \$(0.78) |
| 2 | GW-2 PMP | | 145 | 5 | 20,974 | 706 | \$(2.15) | \$0.20 |
| 3 | GW-3 PMP | | 110 | 13 | 13,450 | 1,612 | \$(5.11) | \$(0.17) |
| 4 | GW-4 PMP | | 12 | 5 | 996 | 437 | \$(2.61) | \$(0.31) |
| 5 | GW-5 PMP | 2 | 230 | 9 | 22,187 | 890 | \$(0.34) | \$(0.15) |
| 6 | GW-6 PMP | | 169 | -4 | 15,792 | -336 | \$(6.21) | \$(0.25) |
| 7 | GW-7 PMP | | 153 | 25 | 22,528 | 3,657 | \$(7.22) | \$0.15 |
| 8 | GW-8 PMP | | 472 | 84 | 69,155 | 12,236 | \$(6.46) | \$(1.05) |
| 9 | GW-9 PMP | | 79 | -2 | 8,281 | -170 | \$(14.25) | \$(2.52) |
| 10 | GW-10 PMP | 3 | 306 | 45 | 24,442 | 3,605 | \$(1.83) | \$0.04 |
| 11 | GW-11 PMP | | 67 | 10 | 7,023 | 1,091 | \$(9.33) | \$(1.38) |
| 12 | GW-12 PMP | | 107 | 25 | 12,897 | 3,025 | \$(2.32) | \$(0.36) |
| 13 | GW-13 PMP | | 616 | 119 | 94,646 | 18,284 | \$(4.74) | \$(1.11) |
| 14 | GW-14 PMP | 4 | 596 | 96 | 233,393 | 37,651 | \$(69.64) | \$(13.45) |
| 15 | GW-15 PMP | | 956 | 6 | 228,207 | 1,320 | \$(41.13) | \$(6.64) |
| 16 | GW-16 PMP | | 52 | 27 | 7,985 | 4,191 | \$(42.17) | \$(0.24) |
| 17 | GW-17 PMP | | 215 | 15 | 34,859 | 2,411 | \$(2.45) | \$(1.28) |
| 18 | GW-18 PMP | | 824 | 35 | 190,847 | 8,187 | \$(14.41) | \$(1.00) |
| 19 | GW-19 PMP | | 607 | 191 | 214,036 | 67,154 | \$(83.94) | \$(3.60) |
| 20 | GW-20 PMP | | 212 | 168 | 73,118 | 57,726 | \$(60.41) | \$(18.95) |
| 21 | GW-21 PMP | | 178 | -98 | 63,623 | -35,052 | \$(21.88) | \$(17.28) |
| Statewide Totals | | | 6,161 | 770 | 1,366,342 | 187,880 | -426 | -70 |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

* Costs are negative values; benefits are positive values

8.3.4.1. Groundwater Pumping Volume

Table 15: Groundwater Average Annual Flow Quantities and Regional Summaries

| # | Facility | Region | Avg. Annual Base Flow (TAF) | Δ Avg. Annual Flow (TAF) | Regional Total Avg. Annual Base Flow (TAF) | Regional Total Δ in Avg. Annual Flow (TAF) | Statewide Total Avg. Annual Base Flow (TAF) | Statewide Total Δ in Avg. Annual Flow (TAF) |
|----|-----------|--------|-----------------------------|--------------------------|--|--|---|---|
| 1 | GW-1 PMP | 1 | 51 | -5 | 319 | 19 | 6,161 | 770 |
| 2 | GW-2 PMP | | 145 | 5 | | | | |
| 3 | GW-3 PMP | | 110 | 13 | | | | |
| 4 | GW-4 PMP | | 12 | 5 | | | | |
| 5 | GW-5 PMP | 2 | 230 | 9 | 1,104 | 112 | | |
| 6 | GW-6 PMP | | 169 | -4 | | | | |
| 7 | GW-7 PMP | | 153 | 25 | | | | |
| 8 | GW-8 PMP | | 472 | 84 | | | | |
| 9 | GW-9 PMP | | 79 | -2 | | | | |
| 10 | GW-10 PMP | 3 | 306 | 45 | 1,095 | 199 | | |
| 11 | GW-11 PMP | | 67 | 10 | | | | |
| 12 | GW-12 PMP | | 107 | 25 | | | | |
| 13 | GW-13 PMP | | 616 | 119 | | | | |
| 14 | GW-14 PMP | 4 | 596 | 96 | 3,643 | 439 | | |
| 15 | GW-15 PMP | | 956 | 6 | | | | |
| 16 | GW-16 PMP | | 52 | 27 | | | | |
| 17 | GW-17 PMP | | 215 | 15 | | | | |
| 18 | GW-18 PMP | | 824 | 35 | | | | |
| 19 | GW-19 PMP | | 607 | 191 | | | | |
| 20 | GW-20 PMP | | 212 | 168 | | | | |
| 21 | GW-21 PMP | | 178 | -98 | | | | |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

Flow across all four regions was greater in the base case than the no-groundwater overdraft case. Regions 3 and 4 were impacted the most by the no-overdraft case. The base case consistently

had over 100 TAF more pumping volume per year than the no-overdraft case. Regions 1 and 2 had consistent amounts of more water pumped in the base case as well. This can be seen in the consistent peaks. This implies that the CALVIN model managed groundwater pumping in a similar pattern but on a different scale.

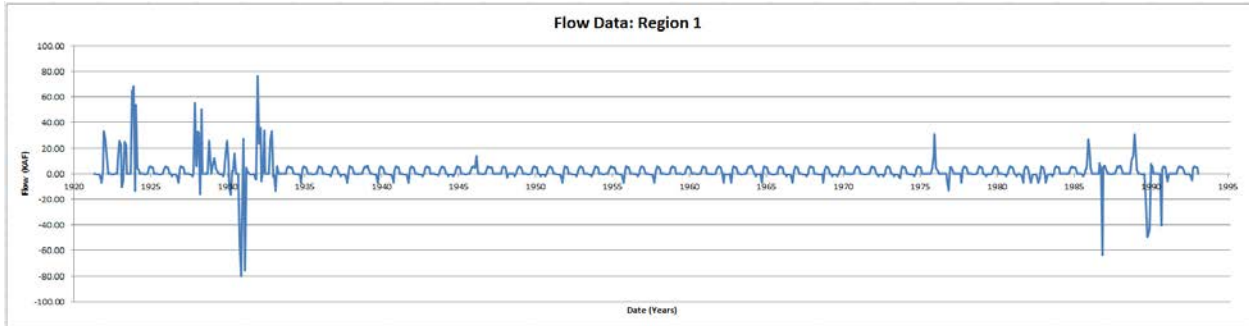


Figure 8: Monthly Region 1 Flow Difference (base case – alternative case)

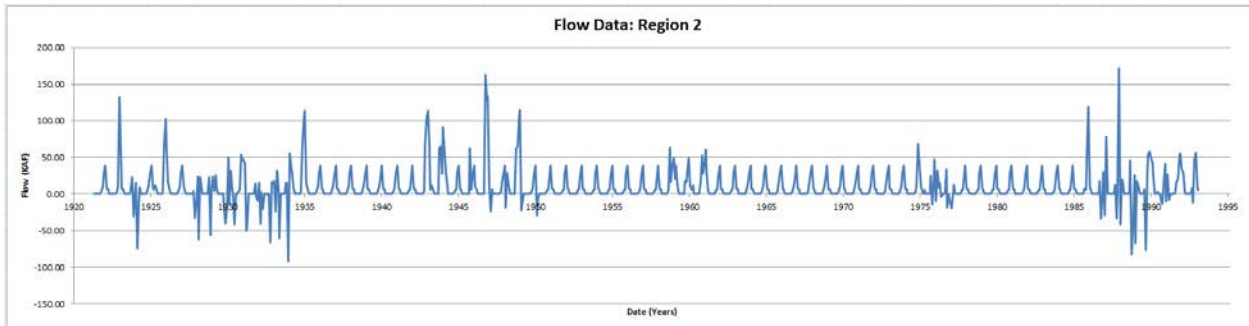


Figure 9: Monthly Region 2 Flow Difference (base case – alternative case)

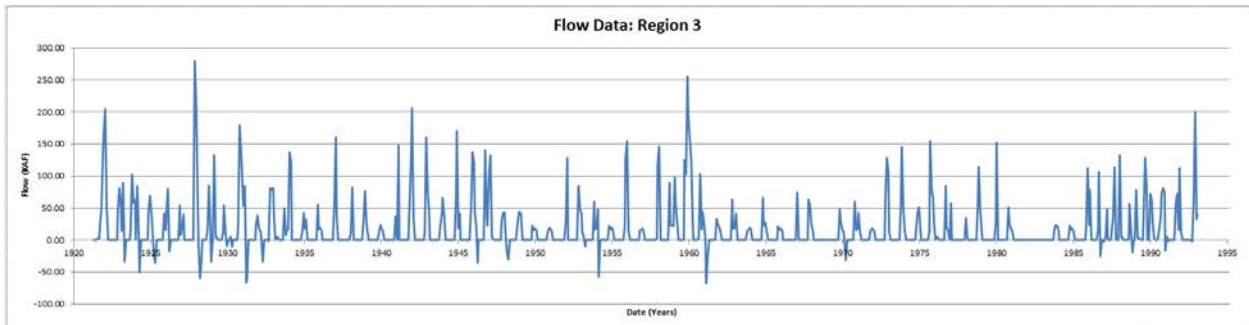


Figure 10: Monthly Region 3 Flow Difference (base case – alternative case)

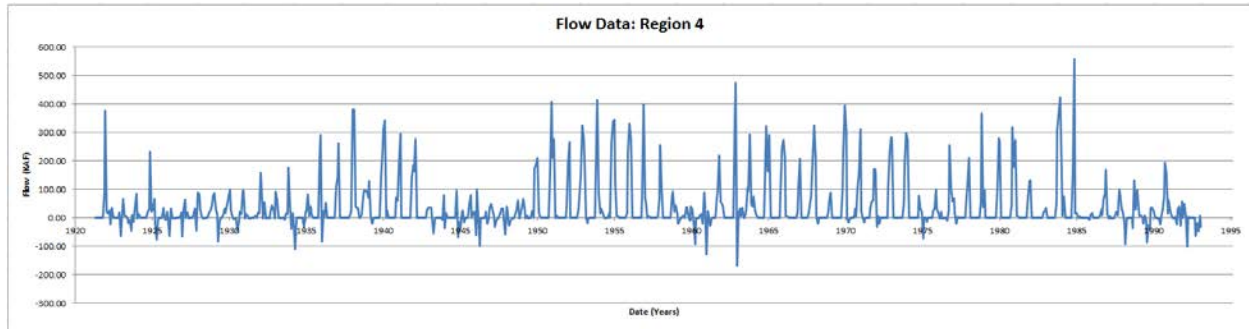


Figure 11: Monthly Region 4 Flow Difference (base case – alternative case)

8.3.4.2. Groundwater Energy

Table 16: Groundwater Average Annual Energy Use and Regional Summaries

| # | Facility | Region | Avg. Annual Base Energy (MWH) | Δ Avg. Annual Energy (MWH) | Regional Avg. Annual Base Energy (MWH) | Regional Δ in Avg. Annual Energy (MWH) | Statewide Total Avg. Annual Energy (MWH) | Statewide Total Δ in Avg. Annual Energy (MWH) |
|----|-----------|--------|-------------------------------|----------------------------|--|--|--|---|
| 1 | GW-1 PMP | 1 | 7,903 | -744 | 43,323 | 2,011 | 1,366,342 | 187,880 |
| 2 | GW-2 PMP | | 20,974 | 706 | | | | |
| 3 | GW-3 PMP | | 13,450 | 1,612 | | | | |
| 4 | GW-4 PMP | | 996 | 437 | | | | |
| 5 | GW-5 PMP | 2 | 22,187 | 890 | 137,943 | 16,277 | | |
| 6 | GW-6 PMP | | 15,792 | -336 | | | | |
| 7 | GW-7 PMP | | 22,528 | 3,657 | | | | |
| 8 | GW-8 PMP | | 69,155 | 12,236 | | | | |
| 9 | GW-9 PMP | | 8,281 | -170 | | | | |
| 10 | GW-10 PMP | 3 | 24,442 | 3,605 | 139,009 | 26,004 | | |
| 11 | GW-11 PMP | | 7,023 | 1,091 | | | | |
| 12 | GW-12 PMP | | 12,897 | 3,025 | | | | |
| 13 | GW-13 PMP | | 94,646 | 18,284 | | | | |
| 14 | GW-14 PMP | 4 | 233,393 | 37,651 | 1,046,068 | 143,587 | | |
| 15 | GW-15 PMP | | 228,207 | 1,320 | | | | |
| 16 | GW-16 PMP | | 7,985 | 4,191 | | | | |
| 17 | GW-17 PMP | | 34,859 | 2,411 | | | | |
| 18 | GW-18 PMP | | 190,847 | 8,187 | | | | |
| 19 | GW-19 PMP | | 214,036 | 67,154 | | | | |
| 20 | GW-20 PMP | | 73,118 | 57,726 | | | | |
| 21 | GW-21 PMP | | 63,623 | -35,052 | | | | |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

Energy, patterns were similar to those found for flow. For all regions, energy use in the base case exceeded that in the no-overdraft case because groundwater pumping was reduced without overdraft; less water was available to be pumped. Regions 3 and 4 had more energy use than regions 1 and 2. Regions 1 and 2 also had more consistent peak energies, which are caused because CALVIN managed the water very similarly in those time periods but just on a different magnitude.

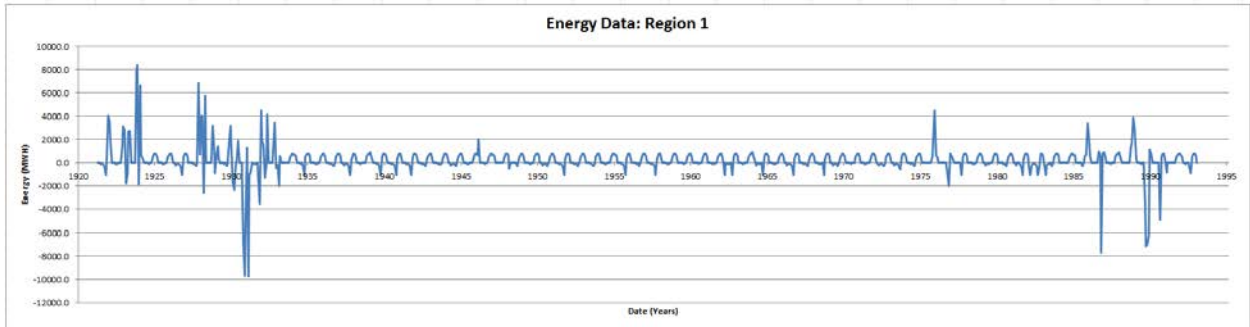


Figure 12: Monthly Region 1 Energy Difference (base case – alternative case)

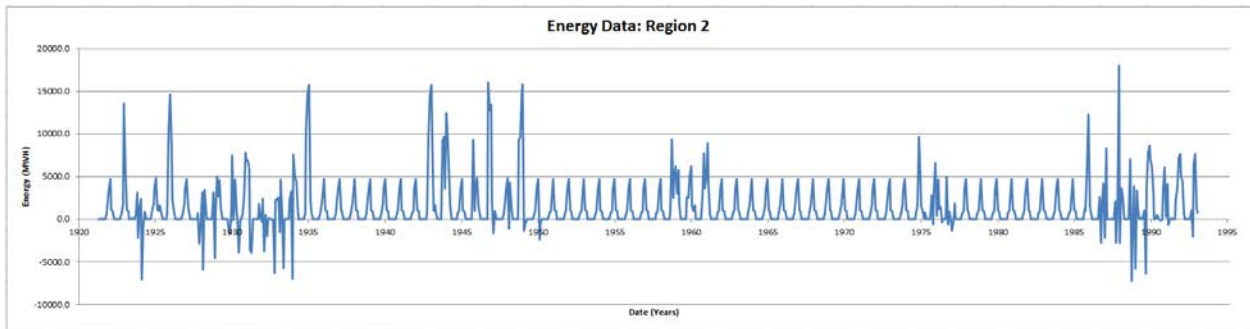


Figure 13: Monthly Region 2 Energy Difference (base case – alternative case)

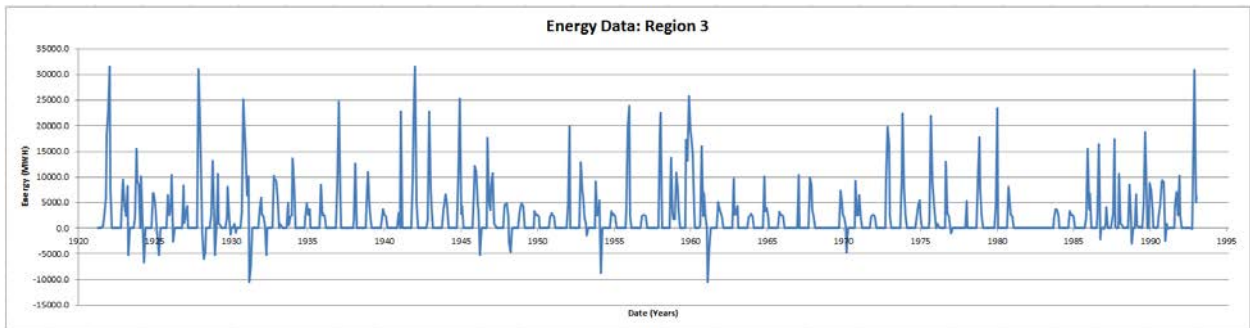


Figure 14: Monthly Region 3 Energy Difference (base case – alternative case)

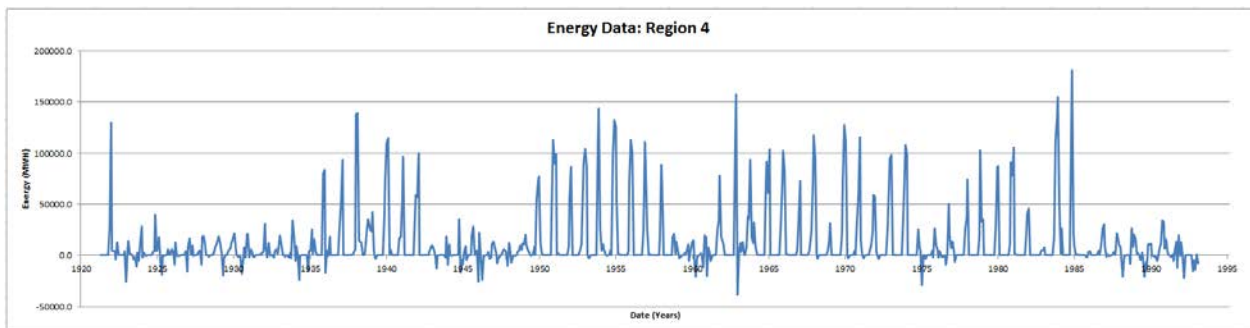


Figure 15: Monthly Region 4 Energy Difference (base case – alternative case)

8.3.4.3. Groundwater Costs

Table 17: Groundwater Average Annual Costs and Regional Summaries

| # | Facility | Region | Avg. Annual Base Cost (\$ millions) | Δ Avg. Annual Cost (\$ millions) | Regional Avg. Annual Base Cost (\$ millions) | Regional Δ in Avg. Annual Cost (\$ millions) | Statewide Total Avg. Annual Cost (\$ millions) | Statewide Total Δ in Avg. Annual Cost (\$ millions) |
|----|-----------|--------|-------------------------------------|----------------------------------|--|--|--|---|
| 1 | GW-1 PMP | 1 | \$ (27.22) | \$ (0.78) | -37 | -1 | -426 | -70 |
| 2 | GW-2 PMP | | \$ (2.15) | \$ 0.20 | | | | |
| 3 | GW-3 PMP | | \$ (5.11) | \$ (0.17) | | | | |
| 4 | GW-4 PMP | | \$ (2.61) | \$ (0.31) | | | | |
| 5 | GW-5 PMP | 2 | \$ (0.34) | \$ (0.15) | -34 | -4 | | |
| 6 | GW-6 PMP | | \$ (6.21) | \$ (0.25) | | | | |
| 7 | GW-7 PMP | | \$ (7.22) | \$ 0.15 | | | | |
| 8 | GW-8 PMP | | \$ (6.46) | \$ (1.05) | | | | |
| 9 | GW-9 PMP | | \$ (14.25) | \$ (2.52) | | | | |
| 10 | GW-10 PMP | 3 | \$ (1.83) | \$ 0.04 | -18 | -3 | | |
| 11 | GW-11 PMP | | \$ (9.33) | \$ (1.38) | | | | |
| 12 | GW-12 PMP | | \$ (2.32) | \$ (0.36) | | | | |
| 13 | GW-13 PMP | | \$ (4.74) | \$ (1.11) | | | | |
| 14 | GW-14 PMP | 4 | \$ (69.64) | \$ (13.45) | -336 | -62 | | |
| 15 | GW-15 PMP | | \$ (41.13) | \$ (6.64) | | | | |
| 16 | GW-16 PMP | | \$ (42.17) | \$ (0.24) | | | | |
| 17 | GW-17 PMP | | \$ (2.45) | \$ (1.28) | | | | |
| 18 | GW-18 PMP | | \$ (14.41) | \$ (1.00) | | | | |
| 19 | GW-19 PMP | | \$ (83.94) | \$ (3.60) | | | | |
| 20 | GW-20 PMP | | \$ (60.41) | \$ (18.95) | | | | |
| 21 | GW-21 PMP | | \$ (21.88) | \$ (17.28) | | | | |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

* Costs are negative values; benefits are positive values

Cost result patterns were similar to energy result patterns. It is cheaper in the no-overdraft case for groundwater use. Regions 1, 2, and 3 show a reduced cost in the no-overdraft case. This value tended to be less than \$3 million per peak value (local maximum) in the time series. However, other peaks in regions 1, 2, and 3 reach a maximum of approximately \$3 million, \$4 million and \$8 million respectively. Region 4 showed a large cost reduction on the order of tens of millions of dollars, with peaks ranging from \$10 million to \$45 million. This is understandable because there is less water to pump. On an annual average regional scale, the cost reduced is on the order of millions of dollars for regions 1, 2 and 3 and on the order of tens of millions for region 4, shown on table 17.

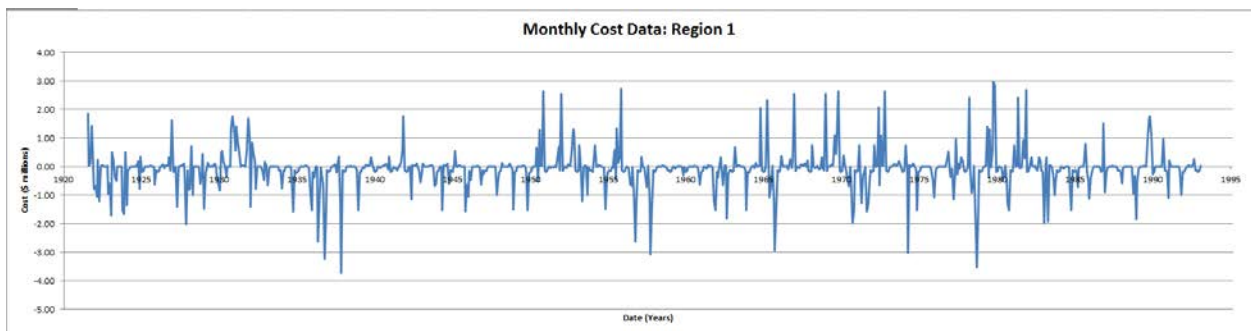


Figure 16: Monthly Region 1 Cost Difference (base case – alternative case)

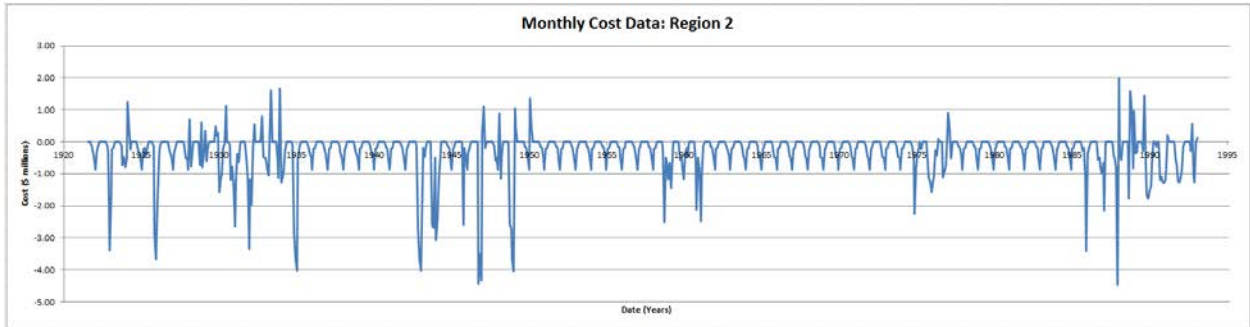


Figure 17: Monthly Region 2 Cost Difference (base case – alternative case)

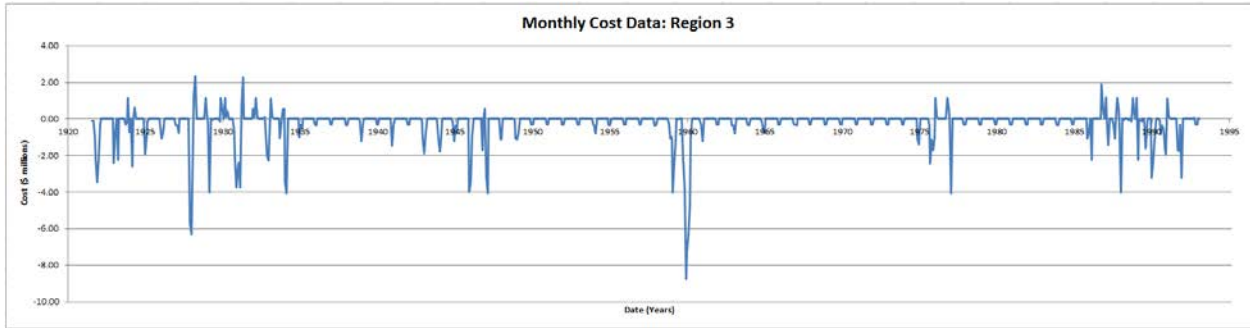


Figure 18: Monthly Region 3 Cost Difference (base case – alternative case)

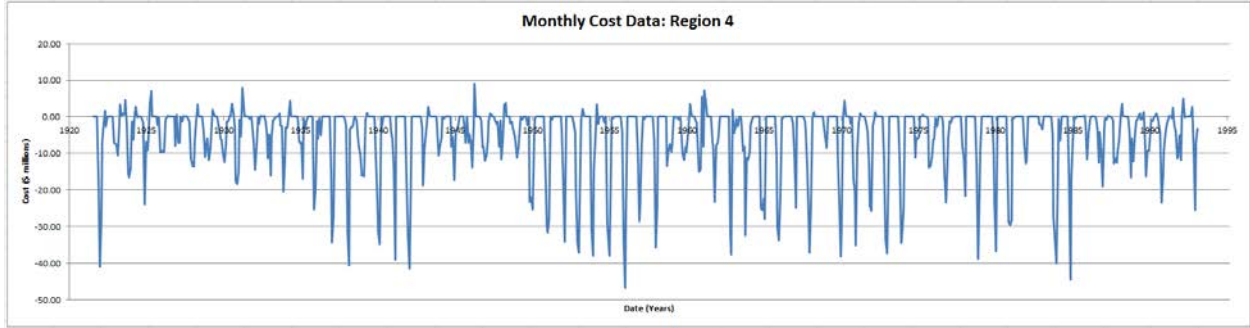


Figure 19: Monthly Region 4 Cost Difference (base case – alternative case)

8.3.4.4. Base Case and No-Overdraft Final Results

It may be beneficial to the environment to have a purely no-groundwater overdraft scenario; however, it will cost the state hundreds of millions of dollars annually on average for both scenarios. The money saved from pumping less ground water is significant, and approximately two and a half times the amount saved in surface water pumping statewide. Table 18 shows that while energy from groundwater pumping is reduced in most regions in the no-overdraft scenario, it tends to be less than 10% of the total energy from extra surface water pumping, which is created when more water must be released to meet urban and agricultural demands. Additionally, groundwater pumping costs are reduced by 3% to 19% in regions 1, 2, 3, and 4 in the no-overdraft case. The regional annual average values can be found in Table 19 below. Ultimately, the cost incurred from extra surface water pumping is less in the no-overdraft case though very similar in magnitude. From a purely economic standpoint, this post-processor suggests that switching California’s water system to a no-groundwater overdraft scenario is presently favorable.

Table 18: Regional Groundwater and Surface Water Average Annual Flow Quantity Comparisons

| Flow (TAF) | Region 1 | | Region 2 | | Region 3 | | Region 4 | | Region 5 | | Statewide | |
|---------------|----------|----------------|----------|----------------|----------|----------------|----------|----------------|----------|----------------|-----------|----------------|
| | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) |
| Surface Water | 813 | (5) | 5,579 | (826) | 14,413 | (3,887) | 8,290 | 63 | 7,956 | 7 | 37,051 | (4,648) |
| Ground Water | 319 | 19 | 1,104 | 112 | 1,095 | 199 | 3,643 | 439 | - | - | 6,161 | 770 |
| Total | 1,132 | 14 | 6,682 | (714) | 15,508 | (3,687) | 11,933 | 502 | 7,956 | 7 | 43,211 | (3,878) |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

Table 19: Regional Groundwater and Surface Water Average Annual Energy Use Comparisons

| Energy (MWH) | Region 1 | | Region 2 | | Region 3 | | Region 4 | | Region 5 | | Statewide | |
|---------------|----------|----------------|-----------|----------------|-----------|----------------|-----------|----------------|----------|----------------|------------|----------------|
| | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) |
| Surface Water | 60,528 | 1,063 | 1,531,921 | (197,939) | 1,353,733 | (336,349) | 7,052,468 | 53,548 | 762,330 | (16,485) | 10,760,979 | (496,162) |
| Ground Water | 43,323 | 2,011 | 137,943 | 16,277 | 139,009 | 26,004 | 1,046,068 | 143,587 | - | - | 1,366,342 | 187,880 |
| Total | 103,851 | 3,074 | 1,669,864 | (181,662) | 1,492,741 | (310,344) | 8,098,536 | 197,135 | 762,330 | (16,485) | 12,127,321 | (308,282) |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

Table 20: Regional Groundwater and Surface Water Average Annual Cost and Benefit Comparisons

| Cost (\$ millions) | Region 1 | | Region 2 | | Region 3 | | Region 4 | | Region 5 | | Statewide | |
|--------------------|------------|----------------|-------------|----------------|------------|----------------|---------------|----------------|-----------|----------------|-----------|----------------|
| | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) | Base | Δ (base - alt) |
| Surface Water | \$ - | \$ - | \$ (104.41) | \$ 2.42 | \$ (71.88) | \$ (25.94) | \$ (2,176.60) | \$ (4.17) | \$ 217.76 | \$ (0.85) | (2,135) | (29) |
| Ground Water | \$ (37.10) | \$ (1.06) | \$ (34.48) | \$ (3.81) | \$ (18.22) | \$ (2.81) | \$ (336.02) | \$ (62.44) | \$ - | \$ - | (426) | (70) |
| Total | \$ (37.10) | \$ (1.06) | \$ (138.89) | \$ (1.39) | \$ (90.10) | \$ (28.75) | \$ (2,512.62) | \$ (81.84) | \$ 195.88 | \$ (0.85) | (2,561) | (99) |

* Region 1: North Sacramento; Region 2: South Sacramento; Region 3: San Joaquin; Region 4: Tulare; Region 5: Southern California

* Where change, Δ is the base case minus no-overdraft case

* Costs are negative values; benefits are positive values

9. Future Direction

While some major changes have been made from the 2010 version energy post-processor to the 2013 version energy post-processor, additional upgrades still can be made to the post-processor. However, before adding on the upgrades mentioned below, a new platform had to be employed. Increasing the complexity of the post-processor without increasing the ease of use would only make the energy post-processor more of a burden than a help.

This 2013 version post-processor can calculate cost based on fixed unit costs. Sometimes, the unit cost is a function that varies with the amount of energy used and the time period it occurs, such as monthly varying energy prices or declining or increasing wholesale energy rates. In addition costs do not stay static every year. Every year, new rates are applied across the state. To more accurately portray cost data, time series cost data should also be incorporated.

Another upgrade to the post-processor is to more accurately describe energy intensity. Some facilities list a fixed value. According Bates (2010), this may not be the case. If time and more accurate data are available, the post-processor should also be updated. This applies to the fixed unit cost presently in the post-processor.

Approximately 77 facilities are currently included within the post-processor. Adding more facilities would also increase its functionality and usefulness. If the data and time are available, then this should also be updated in the post-processor.

In terms of code writing, the searches to match facilities to network links and then from facilities to their corresponding energy intensity can be transformed from linear searches to more efficient forms of searching. This decrease increases the computational run-time dramatically, since most of the run-time comes from linear searching the Excel cells and ranges. Several methods are available such as binary search. However, this requires a numbered ordered search; whereas, our data is a name. To employ such a method, a work-around will be needed.

10. Conclusion

The previous 2010 energy post-processor was a good platform to start from. The 2013 energy post-processor aimed to better the 2010 version by improving on: functionality, adaptability, and user-friendliness. It did this in five ways. The first four were planned and included cleaning up the post-processor's worksheets and creating a new user-interface, calculating associated energy costs, adding new usable forms of energy intensity data (monthly fixed rates and functions), and adding a graphing function. The unplanned improvement was the redevelopment of the entire post-processor code, which makes the post-processor more adaptable for future improvements.

In general, development costs and user time is more expensive than the actual cost of computers and computational run-time (Bentley 1982). For this reason, user-friendliness was a major improvement on the post-processor because it reduced the time the users spend on the post-processor itself.

Energy cost is a more easily understandable scale to base comparisons on for non-engineers, politicians, and the general public who may not be familiar with the post-processor. To help convey the results to a broader range of people and to also analyze the model output in terms of cost, associated cost calculation was a priority.

By giving the post-processor the ability to accommodate new forms of energy intensity, the post-processor becomes more powerful and gains greater validity. By increasing the types of usable energy intensity, the post-processor gains functionality, but at the cost of a small amount of run-time efficiency.

Redeveloping the entire code for the post-processor was an unseen yet needed upgrade for the post-processor. In doing so, several modern practices were utilized such as making the code more modular organized. This allowed the above changes to be made more easily. It also makes future upgrades to the post-processor functionality a smoother process. Run-time efficiency from the 2010 to the 2013 versions have remained approximately the same while the 2013 post-processor has greater functionality in terms of cost calculation and energy calculation.

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