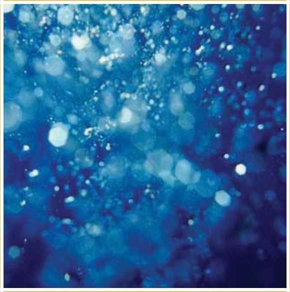

Embedded Energy in Water Studies

Study 1: Statewide and Regional Water-Energy Relationship

Final Work Plan

Prepared by
GEI Consultants in association with
Navigant Consulting

For the
California Public Utilities Commission
Energy Division

January 7, 2009

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1 Executive Summary

In its Decision 07-12-050, the California Public Utilities Commission (CPUC) approved a portfolio of pilot projects and activities that were designed to work in concert to increase understanding about the relationship of California's energy and water resources and infrastructure. The portfolio includes several studies intended to build the databases, models and tools needed to facilitate decisions about whether energy efficiency programs designed to save energy by saving water – i.e., through avoidance of upstream energy consumption "embedded" in water and avoided downstream energy consumption related to the treatment of wastewater - are cost-effective from the perspective of California's investor-owned energy utilities and their ratepayers.

The CPUC engaged the California Institute for Energy and Environment (CIEE) to conduct three studies to support the CPUC's deliberations:

1. Statewide and Regional Water-Energy Relationship
2. Water Agency and Function Component Study and Embedded Energy-Water Load Profiles
3. End-Use Water Demand Profile

This document describes the work plan for Study 1.

The goal of Study 1 is to develop a predictive model of the functional relationship between wholesale water deliveries in California and the energy used to deliver that water. Essential model inputs are the primary determinants of the energy intensity of the state's largest wholesale water systems.

This study will require working closely with California's largest wholesale water agencies to collect and analyze historical monthly water deliveries and their associated energy use. GEI Consultants and Navigant Consulting (hereinafter referred to as "the Study Team") were selected by CIEE to conduct Study 1, in part due to their extensive knowledge of California's wholesale water systems and operations, and their strong relationships with California water agencies.

In addition to the normal types of data gaps and inconsistencies that will need to be resolved in a study of this kind, the Study Team anticipates a number of significant challenges:

- California's water system is comprised of multiple federal, state, regional, and local water agencies; joint powers authorities; and special districts. The state's water-energy balance is comprised of complex delivery, storage, and transfer relationships among all of these entities. The study approach will need to focus its data collection and investigation on the systems and relationships that are most important to developing the predictive model, and document the interrelationships, in order to develop a statewide model.

- Wholesale water deliveries are not directly related to annual hydrology. In fact, wholesale water operations are impacted by a wide variety of non-hydrology factors that ultimately determine the magnitude, pattern and timing of production[1], storage and transport of wholesale water in California. These complexities make it very difficult to infer a relationship between wholesale water supplies and conveyance energy without extensive analyses.

  Non-hydrology factors include: demand, water rights and/or contractual obligations that impact the allocations and timing of water deliveries to various regions and customers; infrastructure changes such as

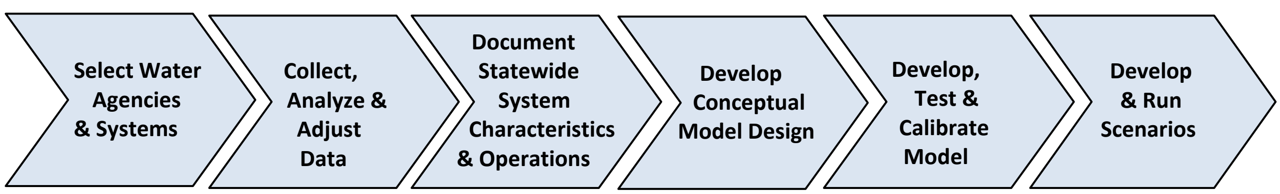
[1] E.g., groundwater pumping.

storage additions or deletions, pipeline changes, major (extended) outages and other major system changes that affect the pattern and timing of water deliveries; and policies and/or regulations that determine the amounts and/or timing of water allowed to be stored or released. Non-water factors include economic factors, such as energy costs, that impact water operations decisions, and extraordinary events that are impossible to predict but can have significant data impacts that will need to be adjusted.

- Water deliveries and water consumption are not necessarily equivalent. Water deliveries are often made, for example, for the purpose of replenishing surface, groundwater and other types of water storage facilities. Annual water deliveries thus often exceed annual water demand, except in the driest years when excess water may not be available to replenish storage. Energy cannot be simply related to current year water demand – adjustments will be needed to allocate energy to that needed to meet energy uses, and that which occurred for other reasons (usually to replenish storage).
- Water demand is not static, and many factors can change the pattern of water use in any particular year. For example, crop changes in response to changed market and economic conditions can change agricultural water demand, water conservation measures and initiatives can change water use amounts and patterns over both the short and the long-term, and changes in water agencies' water supply risk management policies and procedures can also impact water demand.

The most challenging aspect of this study is the selection, characterization and quantification of energy impacts by non-hydrology factors.

Given all of these complexities and challenges, it is essential that the study focus tightly on its ultimate objective – that of identifying and quantifying the primary predictors of energy use by California's major water storage and conveyance systems in order to estimate the potential range of water-related energy consumption (energy intensities of wholesale water systems and supplies) under a variety of climate, policy, regulatory, and other scenarios. The following diagram illustrates the Study Team's planned approach.



Data will be collected and analyzed from California's largest wholesale water systems for five types of water years (Wet, Dry, Average, Critically Dry, and Very Wet) to document:

- The system design, capacities and constraints of the state's largest wholesale water systems
- The water resource characteristics and operations criteria for each system
- The interdependencies of these systems and how they work in conjunction with each other

In addition, the range of energy intensities experienced by each major wholesale water system separately, and for the state overall, will be computed for each of the five types of water years. These inputs will be used to establish the model parameters and algorithms that will be employed in the model design.

When complete, the model will be used to evaluate the potential energy impacts of various types of water resources, system and operational changes. The scenarios will be developed with input from key water and energy stakeholders, including the Climate Action Team's Water-Energy Subcommittee.

2 Introduction

In 2005, the California Energy Commission found that water-related energy consumption and demand account for a significant portion of the state's energy requirements. This finding launched a series of initiatives related to increasing understanding and quantifying the interdependencies of water and energy resources and infrastructure in California.

On behalf of the California Public Utilities Commission (CPUC), the California Institute for Energy and Environment (CIEE) engaged the team of GEI Consultants (GEI) and Navigant Consulting (NCI) (collectively, the "Study Team") to conduct two studies to increase understanding of the relationship between California's energy and water resources and infrastructure. The CPUC Decision, CPUC D. 07-12-050 (December 21, 2007) ordered and approved the projects. The link to the decision and the overall CPUC Embedded Energy in Water proceeding is: http://docs.cpuc.ca.gov/published/proceedings/A0701024.htmhttp://docs.cpuc.ca.gov/published/proceedings/A0701024.htm.

The CPUC is authorizing this and a number of other studies to determine how much energy can be saved via implementing water conservation measures:

> *"We intend these studies to provide the information basis for a meaningful* ex-post *assessment following the completing of the pilots to inform the Commission in determining whether future embedded energy in water programs should be added to the energy efficiency portfolio." CPUC D. 07-12-050 December 20, 2007 Pg. 81*
>
> *"These studies should provide the missing link between water use changes and energy use changes that is required to evaluate utility water savings proposals. Combining the results of these studies with the information on measure water use reductions will allow the Commission to use the results of the water-energy pilot activity to redirect future water-energy energy efficiency portfolio additions towards water agencies or components of the water system that are likely to have the largest energy savings, and measures that provide cost effective energy savings." CPUC D. 07-12-050 December 20, 2007 Pg. 82/83*

In its December 21, 2007 decision, the CPUC authorized a portfolio of pilot projects to be conducted by the investor owned energy utilities in conjunction with water and wastewater agencies. The CPUC also provided direction as to the work needed to effectively evaluate the pilot projects performance. In addition, the CPUC directed the conduct of two additional foundational studies that would provide additional information needed for the CPUC to address issues related to the cost effectiveness of energy savings through water savings (CPUC Decision 07-12-050 December 20, 2007 Pg. 99):

1. A Statewide/Regional Water-Energy Relationship Study designed to establish the relationship between annual climate and hydrology variation, regional and statewide water demand variations and statewide energy use by the water system, and

2. A Water Agency/Function Component Study which includes a redefined Load Profile Study designed to establish detailed annual and daily profiles for energy use as a function of water delivery requirements for a full range of local, regional, state and federal water agencies within the California water system.

This is the first of the two foundational studies authorized by the CPUC in December 2007**.** The title of this study is the California Public Utilities Commission – (CPUC) – California Institute for Energy and Environment (CIEE) Study 1, Statewide and Regional Water-Energy Relationship. The cost of the study is $403,793.

The data, analytical methods and findings from this study will be coordinated with, and provided to other CPUC studies that are being performed in parallel. These include the measurement and evaluation study being conducted by ECONorthwest for the water-energy pilots that were approved by the CPUC in its Decision 07-12-050, and a third study being conducted by CIEE and its consultant, Aquacraft, on behalf of the CPUC to develop time-of-use water use profiles for various types of water uses. All of these studies will also provide input to the revision of the CPUC's water-energy calculator.

2.1 Background and Purpose

The CPUC is seeking additional information to facilitate its deliberations as to whether energy embedded in water should be included in California's energy efficiency portfolio. One of the key missing inputs is a strong understanding of the energy impacts of wholesale water supply operations. The CPUC therefore directed that a study be conducted that will provide a better understanding of how energy is used in the California water industry. The goal of this study is to develop a model of the functional relationship between water use in California and energy used in the water sector that can be used in a predictive mode: Given a specific water delivery requirement developed from precipitation pattern information, what is the expected energy use? (CPUC Decision 07-12-050 December 20, 2007, Appendix B, Pgs. 1-2)

In its December 2007 decision, the CPUC directed that data be collected about annual water deliveries for both the agricultural and urban sectors. To facilitate the study objectives, the CPUC directed that data be required statewide and by utility service area. In addition, because there has been active debate about whether conveyance energy from the state's large interbasin transfer systems should be included, the CPUC directed that data also be collected from the State Water Project (SWP), the Federal (Central Valley) Project (CVP), and the Colorado River Project (CRA, for Colorado River Aqueduct). (CPUC Decision 07-12-050 December 20, 2007, Appendix B, Pg. 2)

In response to the CPUC's direction, Study 1 has been structured to identify the primary predictors of the energy intensity of California's wholesale water systems and supplies, especially very large inter-basin transfer systems. The targeted deliverable is a predictive model that estimates the potential range of statewide energy impacts attributable to wholesale water supplies given a variety of significant variables such as climate change and/or possible changes in policies, regulatory rules, and legislation.

The purpose of this document is to describe the planned study approach that will achieve the CPUC's goals and the rationale underlying this draft work plan so that we can obtain input from interested and knowledgeable water and energy stakeholders.

3 Study Challenges

During development of the work plan, the GEI/NCI Study Team identified the following significant challenges.

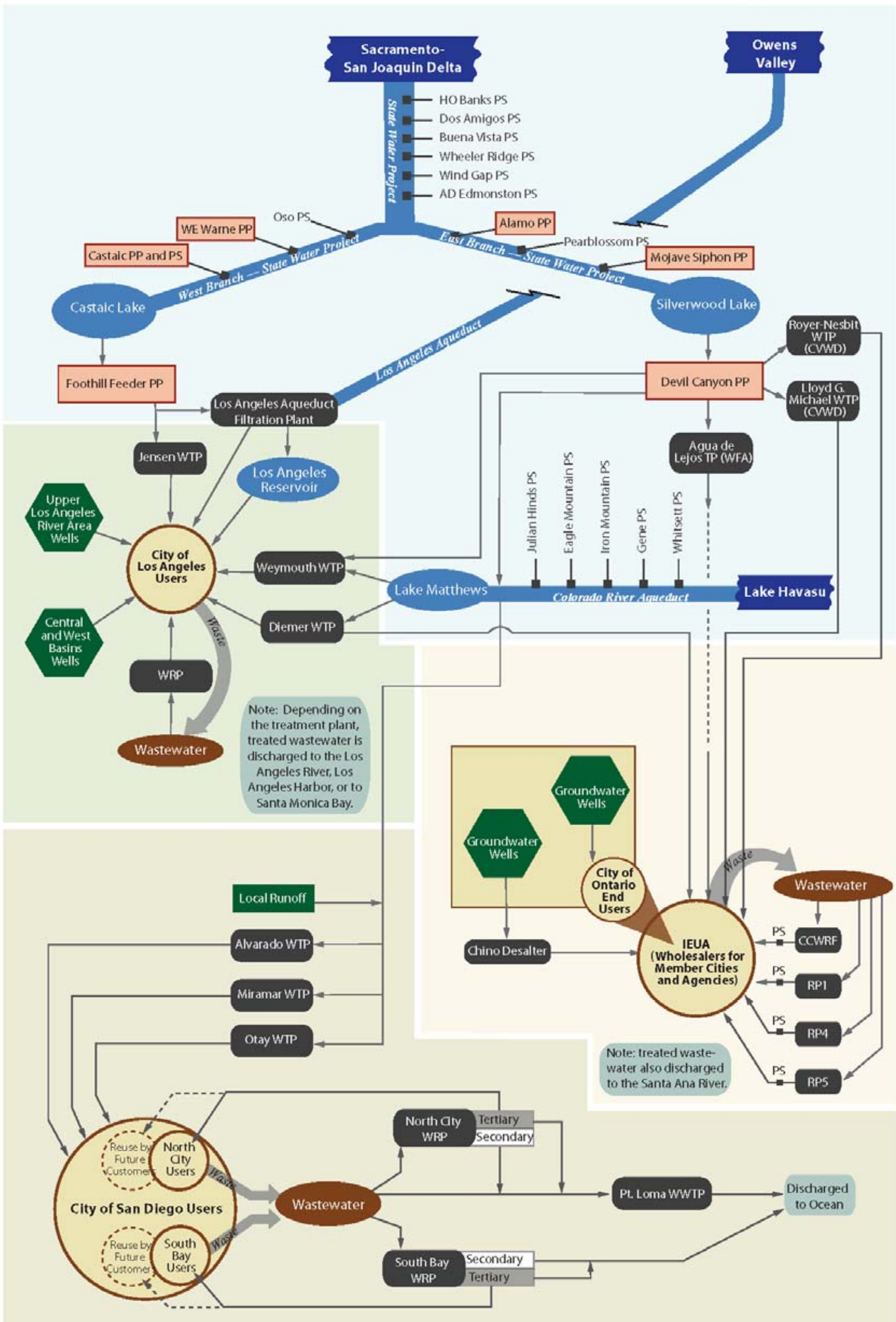
3.1 Large Number of Systems and Entities with Complex Relationships

California's water system is comprised of multiple federal, state, regional and local water agencies, joint powers authorities and special districts. The state's water-energy balance is comprised of complex delivery, storage and transfer relationships among all of these entities. For example, Figure 3-1 illustrates the complex water supply relationship between wholesale agencies and three individual retail water agencies in southern California (Role of Recycled Water in Energy Efficiency and Greenhouse Gas Reduction, 2008). The water supply path is unique for each retailer. The figure shows pumping stations (PS) and power generation plants (PP) along the supply path where energy is both needed to move and treat water and where energy is made in the water conveyance process.

For this example it is important to note that there are two wholesale agencies, the State Water Project (SWP) and the Metropolitan Water District of southern California (MWD) that supply all three retailers at some level. Their allotments can vary annually, and thus, the amount of water and energy used to transport that water changes over time. In order to cost-effectively represent the state's wholesale water systems, decisions will need to be made as to which are the most important agencies to include in order to achieve the objectives of Study 1.

Figure 3-1. Water Supply Cycle

City of Los Angeles • Inland Empire Utilities Authority • City of Ontario • City of San Diego



3.2 Wholesale Water Deliveries Are Not Directly Related to Annual Hydrology

The amount of energy used in any one year to transport wholesale water is not directly related to annual hydrology. In fact, wholesale water operations are impacted by a wide variety of non-hydrology factors that ultimately determine the magnitude, pattern and timing of production[2], storage and transport of wholesale water in California. These complexities make it very difficult to infer a relationship between wholesale water supplies and conveyance energy without extensive analyses.

- The significant impact of storage. One of the most notable differences between water and energy resources is that water can be, and is, stored often for multiple years. Consequently, the usual drivers of energy demand do not apply equally to water. Whether water is in short or long supply, the energy intensity of wholesale water operations in any particular year will depend on the cumulative impact of each water purveyor seeking to optimize its water resource portfolio and carryover storage.[3] The pattern of water sector energy use in any particular year is determined by a complex system of resources, infrastructure, storage, water rights, transfers, groundwater pumping, and banking.

- Other Non-Hydrology Factors. From one year to another, a wide variety of non-hydrology factors change the magnitude and timing of wholesale water deliveries.
    - Demand, water rights and/or contractual obligations impact the allocations and timing of water deliveries to various regions and customers.
    - Infrastructure including storage additions or deletions, pipeline changes, major (extended) outages and other major system changes affect the pattern and timing of water deliveries.
    - Policies and/or regulations determine the amounts and/or timing of water allowed to be stored or released.
    - The amount of water requested by an agency during any scheduling period is not necessarily what is ultimately delivered due to a wide variety of factors such as resource availability, priority contractual and water rights, and operating constraints.

- Non-Water Factors. Economic factors, such as energy costs, impact water operations decisions. Extraordinary events also have impacts that are virtually impossible to predict. An example is the California power crisis that caused wholesale water agencies that meet all or a portion of their energy requirements from the wholesale power market to operate their systems differently to mitigate the unprecedented high costs of short term electricity purchases.

The most challenging aspect of this study is the selection, characterization and quantification of energy impacts by non-hydrology factors.

3.3 Water Deliveries and Water Consumption Are Not Necessarily Equivalent

Water deliveries are often made, for example, for the purpose of replenishing surface, groundwater and other types of water storage facilities. Annual water deliveries thus often exceed annual water demand, except in the

[2] E.g., groundwater pumping.
[3] E.g., dry year reserves.

driest years when excess water may not be available to replenish storage. Again, energy cannot be simply related to current year water demand.

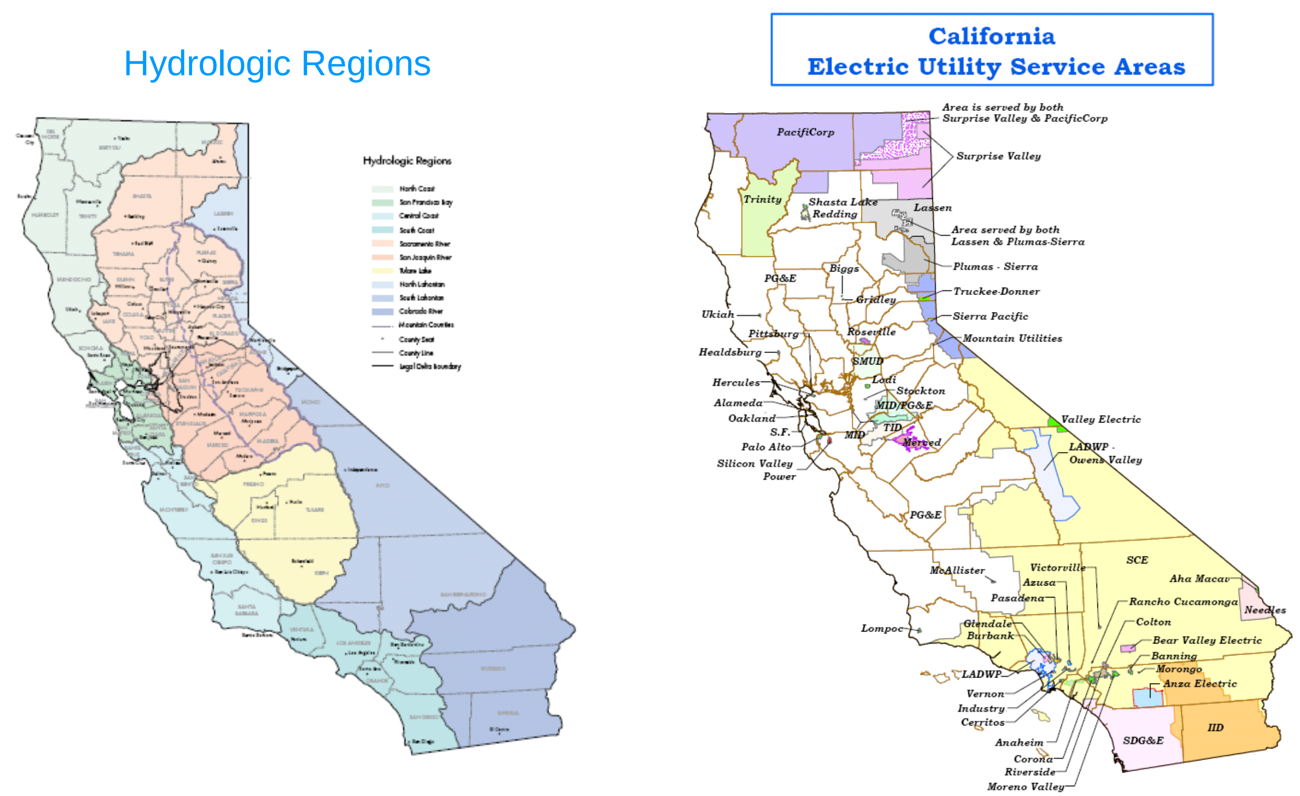
3.4 Water Demand is Not Static

Further, there are a variety of factors that can change the pattern of water use in any particular year, both agricultural and urban. For example:

- Crops are often changed for market and economic reasons, which changes agricultural water demands.
- Improved water conservation measures and initiatives can change water demand for the short term and over time.
- Changes in an agency's acceptance of risk/reliability levels may change its water deliveries and storage operations.

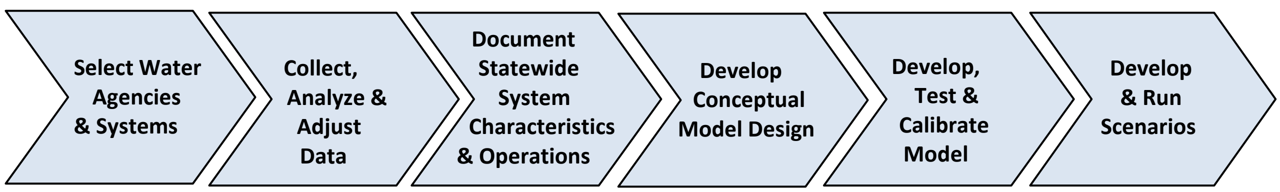
In addition to the multitude and complexity of energy drivers, other study elements will prove challenging. For example, one of the study requirements is to identify the amount of conveyance energy used within by wholesale water systems within each of the four investor-owned energy utilities' (IOUs') service areas. IOU service areas are not coincident with water agency boundaries. Further, many wholesale water suppliers such as cities or water projects may reside within an IOU service area but are independent of the IOU activities (e.g., supplied by other sources of energy) and would not influence IOU energy demands. These types of circumstances will require adjusting data before they can be used in the model.

Figure 3-2. Hydrologic Regions and Electric Utility Service Areas



4 Recommended Approach

Given all of these complexities and challenges, it is essential that the study focus tightly on its ultimate objective – that of identifying and quantifying the primary predictors of energy use by California's major water storage and conveyance systems in order to estimate the potential range of water-related energy consumption (energy intensities of wholesale water systems and supplies) under a variety of climate, policy, regulatory, and other scenarios. The following diagram illustrates the Study Team's plan.



The below narrative describes the primary issues and challenges anticipated by the Study Team in conducting the above work, and our planned approach to resolving these issues.

4.1 Selection of Water Agencies and Systems

The three largest inter-basin transfer systems (federal Central Valley Project, Colorado River Aqueduct, and the State Water Project) form the backbone for this study. However, these large water purveyors are primarily surface water systems, thereby omitting the energy impacts associated with groundwater.

- During dry years, if surface water supplies are reduced, some water agencies may need to rely upon more energy intensive resources to meet net demand after conservation. These higher energy intensity supplies are often groundwater. The switch from surface water to groundwater could either increase or decrease energy consumption in that year, depending on the relative energy intensity of the water supply being replaced.
- Groundwater basins depleted during dry years will need to be replenished when surface water supplies become available (recharge). Hence, even during wet years, significant quantities of water may be reallocated among hydrological regions, much of it through water agencies other than the three largest systems.

Many of the state's water systems are interconnected. These points of interconnection are extremely important for purposes of water supply security (i.e., to enable access to additional supplies and to provide redundant delivery paths in case of major pipeline outages) and for moving water supplies from where they are available to where they might be needed throughout the state. A study of the state's wholesale water system could not be conducted without understanding the points of transfer to other agencies.

Table 4-1. California Water Supplies with Existing Facilities and Programs

California Water Supplies with Existing Facilities and Programs[a] (taf)

Supply	*1995*		*2020*	
	Average	*Drought*	*Average*	*Drought*
Surface				
CVP	7,004	4,821	7,347	4,889
SWP	3,126	2,060	3,439	2,394
Other Federal Projects	910	694	912	683
Colorado River	5,176	5,227	4,400	4,400
Local Projects	11,054	8,484	11,073	8,739
Required Environmental Flow	31,372	16,643	31,372	16,643
Reapplied	6,441	5,596	6,449	5,575
Groundwater[b]	12,493	15,784	12,678	16,010
Recycled and Desalted	324	333	415	416
Total (rounded)	77,900	59,640	78,080	59,750

[a] Bulletin 160-98 presents water supply data as applied water, rather than net water. This distinction is explained in a previous section. Past editions of Bulletin 160 presented water supply data in terms of net supplies.

[b] Excludes groundwater overdraft.

*California Water Plan Update B-160-98, 1998, pg ES3-5

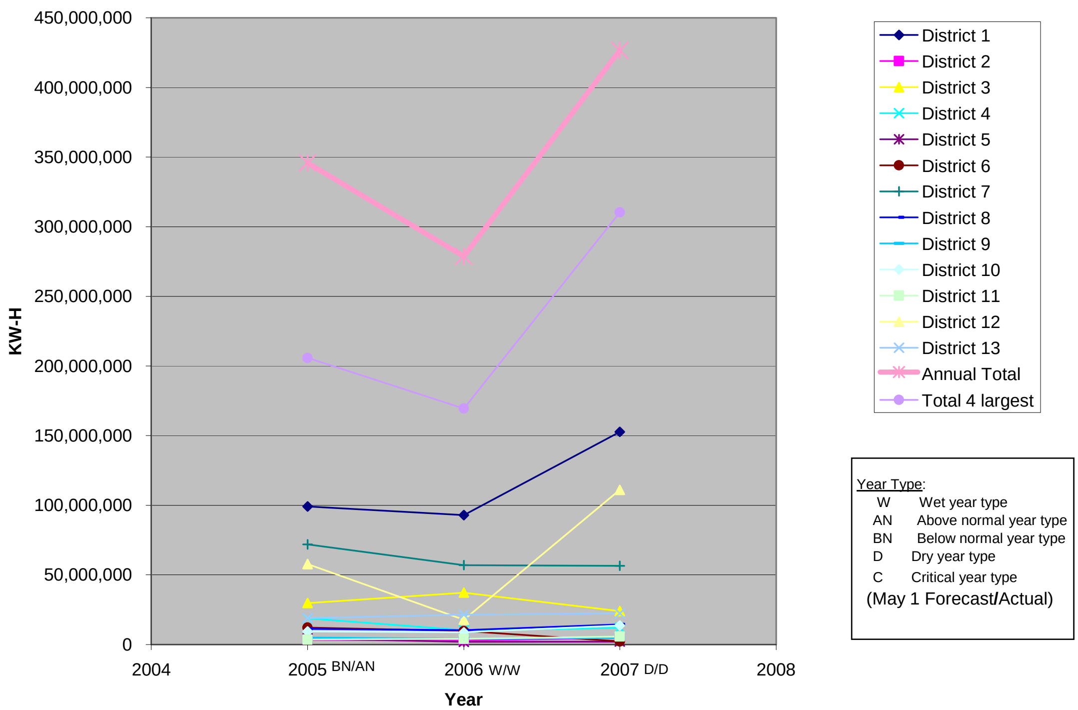
Figure 4-1. California's Major Water Projects

(California Water Plan Update, Bulletin 160-98, 1998)

The good news is that related work conducted by the Study Team on behalf of the Power and Water Resources Pooling Authority (PWRPA) indicates three major water purveyors dominate the water-energy picture for the Authority's 13 members. Swings in use, some based on contracts or water marketing, essentially absorb the hydrologic swings of smaller districts. This current relevant experience has led the Study Team to believe that the water-energy story for the state can be effectively captured through the state's largest water agencies that collectively account for most of the state's wholesale water supplies.[4]

[4] A prior study conducted by NCI on behalf of the California Energy Commission's Public Interest Energy Research division (PIER) found that 12 water agencies (wholesale and retail) account for 50% of California's water entitlements. "Statewide Small Hydropower Resource Assessment", CEC-500-2006-065, June 2006.

Figure 4-2. Annual PWRPA District Energy Use (with Total)



4.2 Data Collection Strategy

The purpose of this task is to collect historical water delivery data and associated net energy consumption by California's largest wholesale water systems. These data will be reviewed to identify the key drivers of water delivery decisions over the data collection period and associated energy impacts of these water decisions. This analysis will be used to establish the system and operating capacities and constraints for the statewide model.

The Study Team has very strong ties to California's water agencies – agricultural and urban - and will work closely with them throughout this process to identify and obtain the best sources of data available to support the study's objectives. The number and complexity of energy drivers of wholesale water supplies could easily overwhelm the study with too much data, much of which would not be significant in terms of predicting water system operations and thus not relevant to the study. Therefore, the Study Team plans to carefully define its data requirements, matching the types and level of precision of data, to the need at hand.

4.2.1 Types of Data

The Study Team initially contemplated collecting the standard types of data typically used by water agencies for water supply forecasting. "Typical" water data include hydrology (e.g., precipitation, both rain and snow), runoff, temperature, ground saturation, evapotranspiration, and a wide variety of other variables that have historically been recognized as important predictors of annual water supply yield. However, the purpose of this study is not to replicate water supply forecasts that are already conducted by a wide variety of public and private agencies at significant cost; the purpose of this study is to identify the key drivers of energy intensity of California's wholesale water supplies. As discussed previously, the primary drivers of water delivery decisions are only partially related to hydrology. The Study Team consequently adjusted its strategy to focus instead on the following types of data which, in conjunction with the quantity of water use by hydrologic region, will provide the foundational data needed to develop the model.

- ***River Indices***. A surrogate for water condition factors that would provide more meaningful data for these analyses is the "river index"[5], a composite factor prepared by the California Department of Water Resources (DWR) that benchmarks current year unimpaired runoff[6] for the state's major river basins, adjusted for impacts attributable to the prior year's water conditions. These indices are used by California water planners to classify water year type. Since runoff is determined by precipitation, temperature, evapotranspiration, ground saturation, and many other factors, using these indices to represent hydrology, water supply and environmental factors accomplishes the same goals but greatly simplifies data collection and modeling. Another benefit is that river indices are already being used by water regulators and are well known and understood by the water industry.

  The State of California primarily uses two year classification systems to assess the amount of water originating within the Sacramento River and San Joaquin River basins. The Sacramento Valley 40-30-30 Index and the San Joaquin Valley 60-20-20 Index were developed by the State Water Resources Control Board (SWRCB) for the Sacramento and San Joaquin River hydrologic basins as part of SWRCB's Bay-Delta regulatory activities. Both systems define one "wet" classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical).

  The Sacramento Valley 40-30-30 Index is computed as a weighted average of the current water year's April-July unimpaired runoff forecast (40 percent of the sum of Sacramento River flow above Bend Bridge near Red Bluff, Feather River inflow to Oroville, Yuba River flow at Smartville, and American River inflow to Folsom), the current water year's October-March unimpaired runoff forecast (30 percent), and the previous water year's index (30 percent). A cap of 10 million acre feet (maf) is put on the previous year's index to account for required flood control reservoir releases during wet years. A water year with a 40-30-30 index equal to or greater than 9.2 maf is classified as "wet." A water year with an index equal to or less than 5.4 maf is classified as "critical (dry)."

  The San Joaquin Valley 60-20-20 Index is computed as a weighted average of the current water year's April-July unimpaired runoff forecast (60 percent of the sum of inflows to New Melones Reservoir from the Stanislaus River, Don Pedro Reservoir from the Tuolumne River, New Exchequer Reservoir from the Merced River, and Millerton Lake from the San Joaquin River), the current water year's October-March unimpaired runoff forecast (20 percent), and the previous water year's index (20 percent). A cap of 4.5 maf is placed on the previous year's index to account for required flood control reservoir releases during wet years. A water year with an index equal to or greater than 3.8 maf is classified as "wet." A water year with an index equal to or less than 2.1 maf is classified as "critical."

  The following charts display the Sacramento and San Joaquin Valley Indexes from 1995 to 2007.

[5] http://www.waterplan.water.ca.gov/docs/cwpu2005/vol4/vol4-hydrology-californiariverindices.pdf
[6] "Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, and export of water to or import of water from other basins." Ibid, p.4-630.

Figure 4-3. Sacramento Valley Hydrologic Index

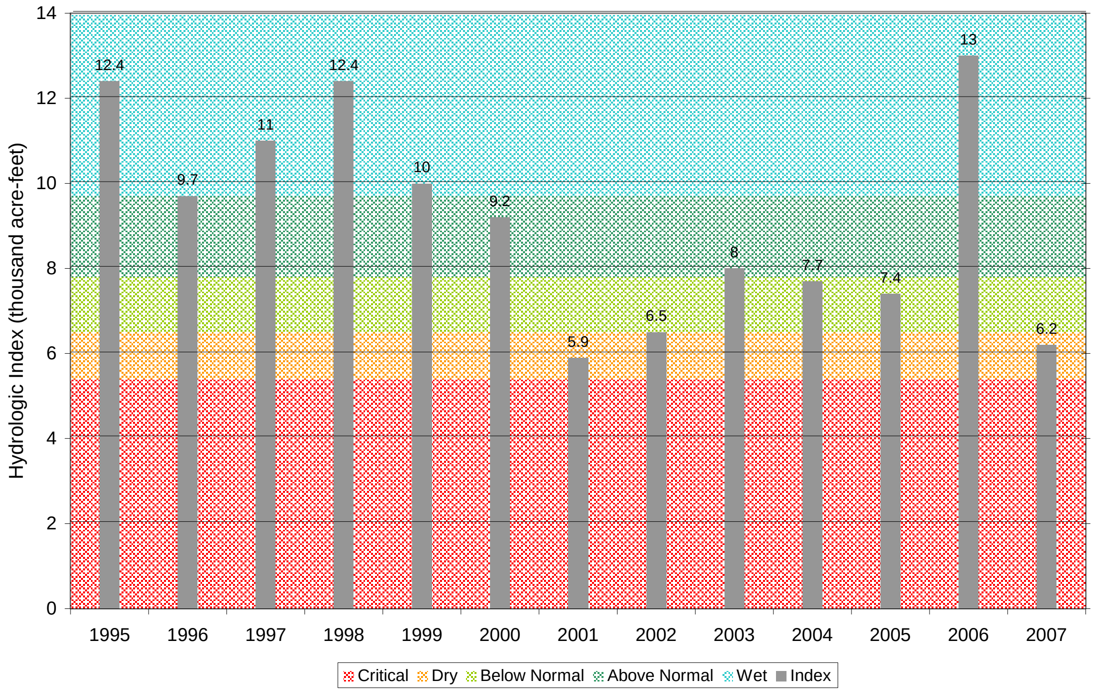
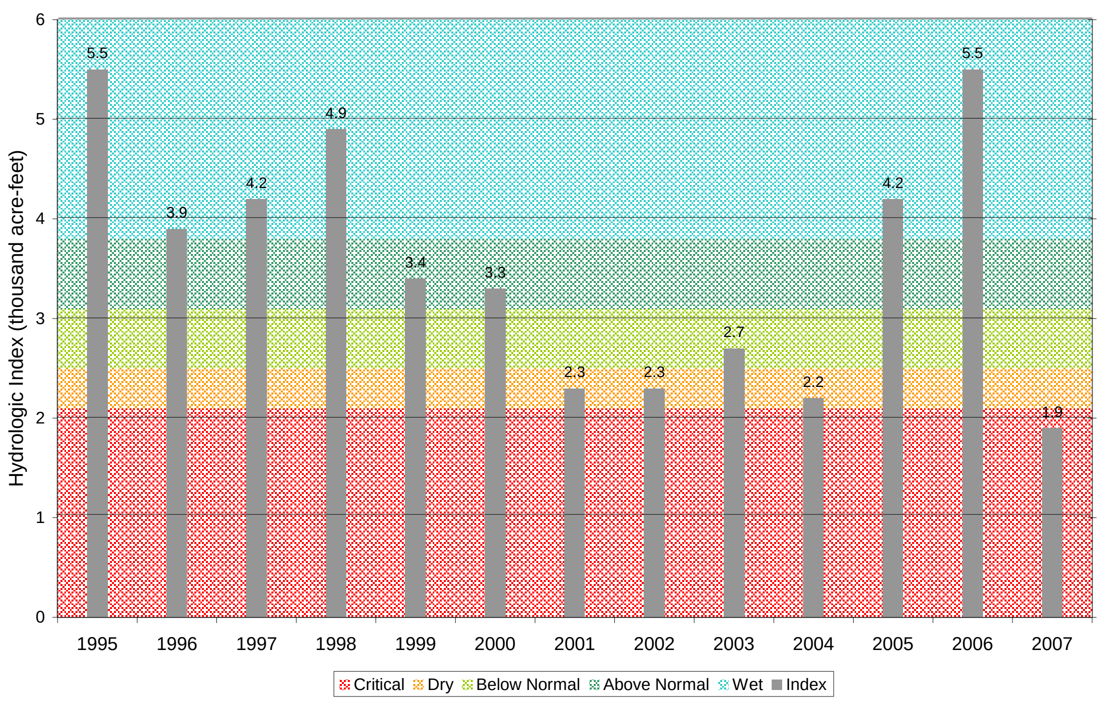


Figure 4-4. San Joaquin Valley Hydrologic Index

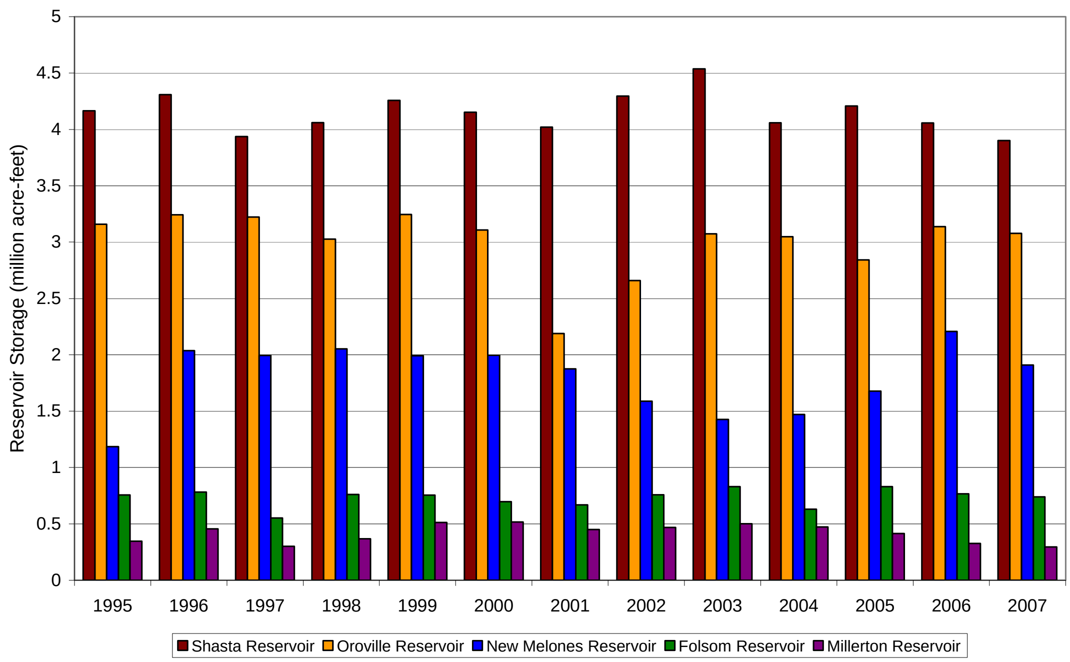


Ultimately, while many complex variables affect the amount of usable water that is produced in any year, the key hydrology driver for energy intensity of wholesale water deliveries ("conveyance") is not precipitation – it is "water yield", the result of the interaction of precipitation, topology, vegetation, evapotranspiration, and many other complex variables that collectively determine the amount of runoff that creates naturally occurring water supplies. The River Indices thus provide an effective means of determining the amount of usable water supplies without the extensive data collection and computations that would be needed to model those interactions to estimate the end result - the quantity of natural water resources produced in any year - and that would be less accurate than that which was actually observed, measured and recorded through the River Indices.

- ***Water Storage***. As noted previously, the amount of water stored and available to meet water demand in any year is a significant factor in the timing and magnitude of wholesale water deliveries. The amount of water stored in the state's largest reservoirs and groundwater basins are thus additional important data points that will be captured.

  Figure 4-5 shows the May 1 reservoir storage for the major reservoirs in California's Central Valley from 1995 through 2007. These storage reservoirs provide most of the surface water that is used, transported, and retained for carry over use in the state. While they do not capture all surface water available to Californians, they are typical of the remaining storage.

Figure 4-5. May 1 Storage in Central Valley Reservoirs



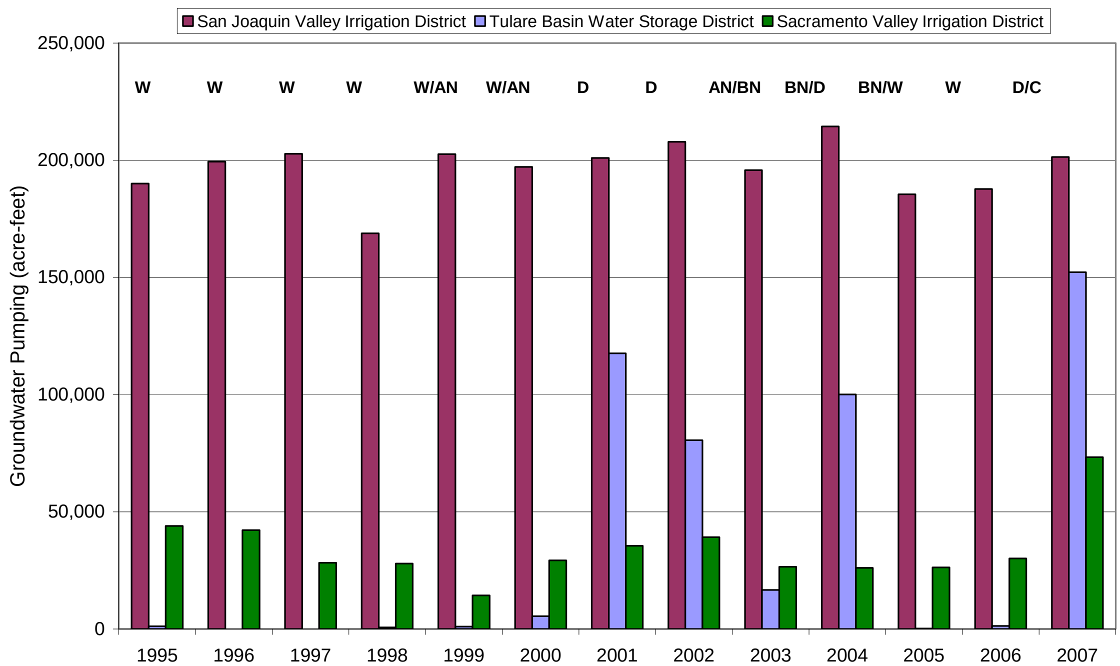
  These reservoirs were selected for this analysis since they are representative of the largest reservoirs in the Central Valley and they are the principal storage reservoirs for the Central Valley Project (CVP) and the State Water Project (SWP). These reservoirs are geospatially distributed throughout the valley. The storage on May 1 is significant since it is the date that the CVP and SWP make their final decisions regarding allocation of water to their contractors.

- ***Groundwater***. Groundwater use is significant in many parts of California, and its energy intensity is significant in context of the energy intensity of California's wholesale water systems. In some cases, when surface water supplies are reduced, many agencies and individuals turn to groundwater sources to fulfill their needs. The Statewide water-energy picture needs to include groundwater and the energy needed to use it.

  "In an average year, about 30 percent of California's urban and agricultural applied water is provided by groundwater extraction. In drought years when surface supplies are reduced, groundwater supports an even larger percentage of use. The amount of water stored in California's aquifers is far greater than that stored in the State's surface water reservoirs, although only a portion of California's groundwater resources can be economically and practically extracted for use." (California Water Plan Update, DWR Bulletin 160-1998, 1998).

Figure 4-6 shows the annual groundwater pumping from 1995 through 2007 for example water districts in three areas of the Central Valley: Sacramento, Tulare, and San Joaquin regions. The figure is meant to show the relative groundwater use between years for the same district, not necessarily between water districts. The water year classification is displayed for each year. In general, the examples show that some additional water is pumped for use in Dry or Critically Dry years than wetter years.

Figure 4-6. Groundwater Pumping



Year Type= C-Critical, D-Dry, BN-Below Normal, AN-Above Normal, W-Wet

Unlike surface storage, groundwater storage is not as limited by "reservoir size" as much as the capability to extract water. This could mean the number of wells and sizes of pumps in the wells provide the constraints to groundwater use than the size of the groundwater basin. Therefore, the groundwater capability needs to be considered within the statewide picture.

4.2.2 Level of Precision

The level of precision of the data to be collected will be determined first by the model requirements, and then by what is reasonably accessible. For example, while the CPUC only required annual data, the Study Team believes that the utility of the model will be substantially enhanced by capturing monthly data wherever possible. Monthly data will be especially useful for examining the relationships of water deliveries and energy consumption during months of high water supply availability vs. months of high water demand, which typically do not coincide. Monthly data will also increase the ability to identify the contribution of wholesale water deliveries to California's energy demand during summer months.

The Study Team anticipates that some data may not be available at the desired precision level (i.e., monthly). In that case, engineering and professional judgment may be needed to relate annual data to the likely distribution of monthly experience. Methods that are typically applied by water and energy experts will be used to effect these allocations, if needed. Similarly, if data is only available at a more detailed level, appropriate methods will be used to adjust the data to the level required for optimal study results.

4.2.3 Data Frequency

Similarly, the frequency of data needed for this analysis should also be synchronized with the need (i.e., whether data is needed on a daily, weekly, monthly, seasonal and/or annual basis). If the model will only be used to predict annual trends, then data probably isn't needed at a daily or monthly level. Likewise, if the data that is to be collected in the study will be needed for other correlations or other parts of the study, this should be determined and confirmed during the planning stage.

In any event, data will not always be available at the preferred levels of precision or frequency. Data limitations may therefore require "stretching" or adjusting the data to allow analysis and to identify likely trends to support development of the study's conclusions.

4.3 Significance of Historical Data

The Study Plan initially contemplated collecting 20-30 years of historical water and energy data, and then attempting to find the historical long term relationship between wholesale water and energy intensity. Upon further consideration, the Study Team decided that this approach would be very costly and time consuming, and would not serve the project objectives well. A better approach would be to assure that the correct data is applied appropriately, and to the appropriate use. In particular, the Study Team recommends the following approach.

4.3.1 "Freeze" the State's Wholesale Water Systems Infrastructure as of "Today"

The key drivers of the energy intensity of wholesale water – i.e., pumping of both surface and groundwater supplies – is very well understood at an engineering level to be a function of volume, distance, elevation and friction. The factors that cannot be readily determined are the human decisions that intervene to decide "when," "where," and "how much."

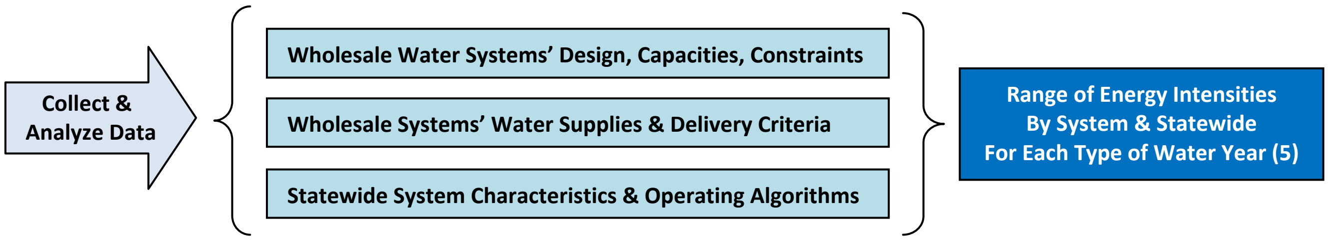
The Model needs to provide a baseline from which scenarios can be run and interpreted. The Model's "base case" should be represented by California's wholesale water systems design and capacities as of "today." Scenarios (including climate change separately or in combination with potential changes in storage and capacity) can then be evaluated against this base case. In other words, it would be of limited value to try to understand how systems *would have* operated 20-30 years ago, since they were very different systems operating under very different market, regulatory, policy and economic conditions. This study should instead focus on answering the following question:

> *Given today's water supplies and infrastructure; policies, rules and regulations; etc., how do the large water conveyance systems "typically" operate under various hydrology scenarios, and what is the resultant energy intensity of wholesale water supplies?*

There are four primary objectives of this task:

- Document the system design, capacities and constraints of the state's largest wholesale water systems.
- Identify the water resource characteristics and operations criteria for each system.
- Diagram the interdependencies of these systems and how they work in conjunction with each other.
- Develop the range of energy intensities experienced by each major wholesale water system separately, and for the state overall, for the five types of water years.

Figure 4-7. Application of Data to Model Design



With this baseline understanding, we will have a rational basis for estimating changes in energy intensity due to both hydrology and non-hydrology factors. We will also then be able to estimate through scenario analyses the potential impacts on energy intensity given significant changes in natural water supply yield, water demand, markets, regulations, economic conditions, and major infrastructure additions, such as construction of a new reservoir or loss of a major conveyance artery.

4.3.2 Use Historical Hydrology Data to Develop Scenario Assumptions

The primary significance of historical hydrology data is to establish climate scenarios. The DWR used 3 years in its Water Plan Update 2005: "Wet" (1998), "Dry" (2001), and "Average" (2000). The Study Team proposes to use these same years, plus two additional years: "Critical Dry" (1994) and "Very Wet" (1995). These five hydrology cases should be sufficient to view the range of energy intensities of wholesale water supplies that could be expected under various climate change scenarios. If, during the course of the study, the Study Team and its advisors believe it would be beneficial, additional extreme years could be selected for analysis.

In past updates of DWR's Bulletin 160 (California Water Plan), the current water demands were "normalized" mathematically to produce an "average" year, which was then extrapolated for future conditions. DWR has already characterized the water year type with these three specific years. Consequently, gathering the energy data for these specific years and linking that with DWR's previous analysis on those specific years would simplify and correlate the water-year – water-energy relationship. In essence, this would form typical dry, wet, and average years from actual annual historical water data.

In the following section, we describe the planned steps for collecting and analyzing data, developing the model and climate scenarios, and testing the potential range of energy consumption by large wholesale water systems under these scenarios.

5 Study Plan

The tasks to accomplish this project are described below.

5.1 Task 1: Project Kickoff Meeting

The Study Team will participate in a project kickoff meeting with CIEE and CPUC. **(*COMPLETED*)**

5.2 Task 2: Prepare Draft and Final Study Plans

The purpose of this task is to develop a Draft Study Plan that describes the work to be conducted. (***DRAFT STUDY PLAN IN PROGRESS.***)

- The Study Team will prepare a Draft Study Plan for review by CIEE and CPUC staff and consultants and update as necessary.
- The approved Draft Study Plan will be presented by the Study Team at a Stakeholder (Public) Workshop for public review and comment.
- Public comments will be reviewed by the CPUC, CIEE and the Study Team to determine what, if any, changes should be made to the Draft Study Plan in order to successfully achieve the study objectives.
- Upon agreement with CIEE and CPUC, the Study Team will issue the Final Study Plan.

5.3 Task 3: Conduct Literature Review

A literature review will be conducted to determine what information is available and to provide insight into significant gaps in available data. An understanding of the current state of knowledge and information will help define the steps that will need to be taken during collection and compilation of data, and help build upon what information currently exists.

The Study Team will compile a list of authoritative documents and data sets with which it is familiar and bring to the Public Workshop with a request that stakeholders supplement the list of documents and data.

Following is a preliminary illustrative list of some of the primary reports and data sources that will be reviewed and may be relied upon for this study.

5.3.1 General References on California's Water-Energy Intensity

- California Energy Commission, 2005, "Integrated Energy Policy Report" and "California's Water-Energy Relationship" [http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF]
- Dr. Robert Wilkinson, "Methodology for Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures", Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency, 2000 [http://www.es.ucsb.edu/faculty/wilkinson.pdfs/Wilkinson_EWRPT01%20DOC.pdf]

5.3.2 General References on California's Wholesale Water Systems

- California Department of Water Resources Bulletin 160, California Water Plan [http://www.waterplan.water.ca.gov/cwpu2009/ae/index.cfm]

5.3.3 Sources of Data About Wholesale Water Systems (Design, Capacity, Resources, Operations, Models)

- California Department of Water Resources, Bulletin 120 series Water Conditions in California, [http://cdec.water.ca.gov/snow/bulletin120/]
- Bulletin 132, Management of the California State Water Project (available since 1963 but only complete through 2005 at this time) [http://www.water.ca.gov/swpao/bulletin.cfm]
- Central Valley Operations Office, Report of Operations Monthly Delivery Tables, U.S. Bureau of Reclamation [http://www.usbr.gov/mp/cvo/deliv.html]
- Colorado River Accounting and Water Use Report (Arizona, California and Nevada; available 1964-2006) [http://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2006/2006.pdf]
- Lower Owens River Project Monthly Reports [http://www.ladwp.com/ladwp/cms/ladwp009817.jsp]
- "Water Storage and Electricity Demand in California", DOE Energy-Water Nexus Team [http://water-energy.lbl.gov/node/26]
- River Schematics, California Department of Water Resources [http://cdec.water.ca.gov/riv_flows.html]
- Reservoir Information, California Department of Water Resources [http://cdec.water.ca.gov/misc/resinfo.html]
- CALVIN [http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/] and other functional component models (including some which may only cover water.)

5.3.4 Groundwater

- Groundwater Atlas [http://pubs.usgs.gov/ha/ha730/] and "Ground-Water Recharge in the Arid and Semiarid Southwestern United States", U.S. Geological Survey, Professional Paper 1703, 2007 [http://pubs.usgs.gov/pp/pp1703/]
- "A Status Report on the Use of Groundwater in the Service Area of the Metropolitan Water District of Southern California", Report Number 1308, September 2007 [http://www.mwdh2o.com/mwdh2o/pages/yourwater/supply/groundwater/GWAS.html]

5.3.5 Sources of Climate Change Scenarios

- California Climate Change Research Center [http://climatechange.ca.gov/research/index.html]
- "California Water 2030: An Efficiency Future", Pacific Institute, September 2005 [http://www.pacinst.org/reports/california_water_2030/ca_water_2030.pdf]
- Climate Action Team's Water-Energy Technology Sub-Committee (WETCAT) [http://www.climatechange.ca.gov/wetcat/index.html]
- Climate Change and Reliability of Water Supplies, Water Energy Technology Team (WETT), Lawrence Berkeley National Laboratory [http://water-energy.lbl.gov/node/20]
- "In Hot Water: Water Management Strategies to Weather the Effects of Global Warming", Natural Resources Defense Council, 2007 [http://www.nrdc.org/globalWarming/hotwater/contents.asp]

The Study Team will then review these documents and data, and potentially also identify additional documents and data through internet research and stakeholder interviews. Existing Statewide water models will be reviewed and included in the literature review.

The Study Team will summarize the state of current knowledge about the predictors of energy consumption by California's wholesale water systems in an Interim Report.

5.4 Task 4: Compile Water Delivery and Energy Data

The purpose of this task is to identify the key drivers of energy used for wholesale water deliveries for both the agricultural and urban water sectors of the state.

5.4.1 Determine population of water agencies to be included

The three largest inter-basin transfer systems (the federal Central Valley Project, the Colorado River Aqueduct, and the State Water Project) form the core of California's wholesale water systems for both agricultural and urban users. However as noted in the Approach section, it is important to include other very large wholesale water systems such as the Metropolitan Water District of Southern California (MWD), the Los Angeles Department of Water and Power (LADWP), the Power and Water Resources Pooling Authority (PWRPA), and various other significant urban and agricultural wholesale water providers that have substantial surface and/or groundwater supplies. The Study Team will confer with water stakeholders that have significant knowledge about California's water systems to agree upon the set of water agencies that will be included in this study. Energy data is expected to be available directly from water agencies for corresponding water supply quantities. It is not anticipated that the Study Team will need to obtain information from IOUs, since the very large water agencies tend to keep good records of their energy consumption, typically their largest operating cost.

5.4.2 Collect Data

By this point, the Study Team will have vetted its study approach and key data with water and energy stakeholders. The purpose of this task is to collect the data. As discussed previously, the key data that will be collected are river indices, storage (surface reservoirs and groundwater basins), and water deliveries and associated energy consumption (including groundwater bank pumping).[7] (Data would include DWR land and water use information, which provides groundwater and surface water sources for agriculture.) Where available, the Study Team will also collect the monthly volume of water requested by primary customers of the wholesale water agencies during the study period. Data will be stored in a way that can be accessed and shared by others at the conclusion of the study.

5.5 Task 5: Analyze Water Deliveries

The purpose of this task is to analyze and "scrub" water delivery data, as deemed necessary.

- The Study Team will review and analyze water delivery data collected from the major wholesale water suppliers identified under Task 4.

[7] Energy consumption will be computed net of in-conduit hydropower production generated as a by-product of water deliveries. There are two primary types of power produced by water systems: power produced through the process of delivering water (in-conduit hydropower) and power production that is independent of the water delivery system (i.e., would produce power whether or not water is transported). Power produced during the process of delivering water which, were it not for the transport of the water, would not otherwise be produced, will be netted from water conveyance energy consumption.

- The Study Team will also adjust or note where historical data has been influenced by non-hydrology factors and suggest corrections to allow the data to be used as a basis for the predictive model.
- The Study Team will present a report summarizing available water information.

5.6 Task 6: Analyze Energy Use (kWh and MMBTUs)

As discussed previously, the energy analysis will focus on energy needed for conveyance, net of energy produced through conveyance (in-conduit hydropower). For purposes of this study, any in-conduit hydropower that is produced as the direct result of delivering wholesale water supplies will be applied to reduce total conveyance energy. This important consideration will influence which data are requested and how they are compiled for analysis.

- The Study Team will review and analyze energy data related to water delivery data from the Statewide, Utility Service areas and major and added wholesale water suppliers in order to select which data should be used for what purpose. Conveyance energy consists of both electricity and natural gas pumping.
- The Team will adjust or note where historical energy data has been influenced by non-hydrology factors.
- The Team will present a report summarizing energy information and documenting the key drivers of energy used for wholesale water supplies and the types of impacts.

5.7 Task 7: Analyze Energy Intensity (kWh and MMBTUs/MG of Water)

This Task combines the results of Tasks 5 and 6 to produce a picture of annual water energy intensities for the test years (Wet, Dry, Average, Critically Dry, and Very Wet).

- The Study Team will combine data from the previous Tasks to produce annual energy intensities of water for the Statewide, Utility Service areas and the water wholesalers.
- The Team will adjust or note where historical energy data has been influenced by non-hydrology factors.
- The Team will present a report summarizing energy intensity information for each wholesale water system included in the study for each of the 5 types of water years, along with a description of the types and magnitudes of impacts of significant non-hydrology factors on the energy intensity of various sources of wholesale water supplies.

5.8 Task 8: Develop a Model(s) Relating Water Use and Energy Use in the Water Sector

The purpose of this task is to develop one or more models relating water use and energy use in the water that predicts the range of possible energy intensities of wholesale water supplies to support analyses of various scenarios and policy issues and options. In this Task, the results of Task 7 (water-energy intensities) and the environmental, population, hydrological, and other statewide information collected in Task 4 and refined in Tasks 5 and 6 will be used to model the relationship between water use in California and the energy used for wholesale water deliveries. The model's expected output is embedded energy use by the state's wholesale water delivery systems. (Hereinafter, we refer to this effort as "a model", with the understanding that it may consist of more than one module, and may be designed to work in concert with other existing models – see Section 5.8.2 Detailed Model Design below.)

5.8.1 Develop Conceptual Model Approach

Upon completion of Tasks 1-7, the Study Team will recommend the type of predictive model (regression, hybrid, structural, econometric, other) that it believes will most effectively achieve the project goals. The Study Team will review its recommendations with CIEE and CPUC staff and consultants. The Study Team will also seek input from knowledgeable water and energy stakeholders.

5.8.2 Detailed Model Design

The Study Team will then design the model, documenting the key variables and the algorithms that define their relationships and interactions. Again, the Detailed Model Design will be reviewed with CIEE, CPUC and knowledgeable water and energy stakeholders. In developing the model, the Study Team will first consider how existing models developed by others might be leveraged for this work. For example, the University of California at Davis developed an economic-engineering optimization model for the entire water system of California named "CALVIN." The model operates facilities and allocates water so as to maximize statewide agricultural and urban economic values from water use. In addition, there are a variety of other models, such as Professor Robert Wilkinson's energy intensity model and Pacific Institute's "Water-to-Air" model that could be used to either provide some baseline data and information, or perhaps to work in concert with the model produced through this effort. These decisions will be deferred until data collection has been completed and the strengths and weaknesses of various types of data that are available for use in the model have been determined.

5.8.3 Program Model

Once the final model design has been reviewed and approved, the Study Team will commence programming and testing. Testing will include calibration to assure that the model is yielding expected results. The calibration process will involve running the model with actual events from the nine most recent water years: 2000 through 2008. Significant variations between model outputs and historical energy data will be documented and analyzed; and if deemed appropriate, will provide input to model refinements. Calibration is an iterative process. Model refinement will continue until the calibration process is deemed complete.

When complete, the model and its documentation (including pertinent development data sets) will be provided in an Interim Report.

5.9 Task 9: Conduct Scenario Analysis

Upon completion of the Model, the Study Team will work with CIEE, CPUC and knowledgeable water and energy stakeholders to examine the relationships between water deliveries and energy use for a range of future conditions in California.

- The Study Team will consult with CIEE and CPUC staff and consultants to formulate a specific set of possible future California conditions that will be examined under this task. The Study Team will also solicit input from water and energy stakeholders to select the scenarios for evaluation, especially any official forums that have been specifically established to support implementation of state policy goals such as the Climate Action Team's Water-Energy Technology sub-committee ("WET-CAT") that is helping to develop the water sector's response to greenhouse gas emissions reduction in support of AB32.
- The Study Team will then conduct the scenario analyses and prepare an Interim Report summarizing the results. Deliverables will include documented analysis datasets on CD.

5.10 Task 10: Analyze Water-Related Policy Issues

The purpose of this task is to analyze water-related policy issues to examine possible regulatory and policy decisions inside and outside California that could affect the amount of water available in areas of California.

- Again, in conjunction with CIEE, CPUC, and knowledgeable water and energy stakeholders, the Study Team will develop a set of possible policy and regulatory issues both inside and outside of California that could influence future water supply California conditions.
- Upon approval of the scenarios, the Study Team will evaluate these possible policy and regulatory conditions with the Model.
- The Team will prepare an Interim Report summarizing the scenario results. Deliverables will include documented analysis datasets on CD.

5.11 Task 11: Prepare Interim Reports and a Draft and Final Technical Report

This Task provides for the writing and production of interim reports for each task as well as the final report that summarizes the work of the previous tasks. The final report will be produced shortly after closure of the public review period and in conjunction with CIEE and CPUC staff and consultants.

- Upon completion of Tasks 1-10, the Study Team will compile the Draft Report.
- The Draft Report will be reviewed by CIEE and CPUC staff and consultants, and the Draft Report revised as necessary.
- The Revised Draft Report will be presented and reviewed with stakeholders at a Public Workshop.
- The Study Team and CIEE and CPUC staff and consultants will collectively review stakeholder/public comments to determine revisions to the report, if any.
- Agreed upon revisions will be incorporated into the Final Technical Report that will be issued by the Study Team.

5.12 Study Coordination Efforts with CIEE Water Studies

As noted previously, the data and methods used in this study will be provided to other CPUC studies that are being performed in parallel. These include the measurement and evaluation study being conducted by ECONorthwest for the water-energy pilots that were approved pursuant to the CPUC's Decision 07-12-050 and a third study being conducted by CIEE on behalf of the CPUC with regard to the time-of-use profile of water consumption by various types of water users, agricultural and urban. All of these studies are also being relied upon to provide input to the revision of the CPUC's water-energy calculator.

The Study Team will work closely with the CIEE and their consultants to ensure that the outputs of this research are consistent with what is being developed in the other CIEE studies. The Team will also refine our research plan for this study as needed to provide inputs for the CIEE studies as directed by the CPUC. The Study Team will also coordinate with these other studies to ensure that definitions and data analytical approaches are consistent, to the extent appropriate to the objectives of Study 1. Currently the CIEE studies are still in the development stage and additional details on how the Embedded Energy in Water Studies will merge with the other CPUC studies and other CPUC efforts will be provided once the CIEE studies are underway.

5.13 Study 1 Deliverables

Deliverable	Due Date
1) Draft Study Plan	*November 1, 2008*
2) Final Study Plan	*January 1, 2009*
3) Interim Report: Literature Review	*January 15, 2009*
4) Interim Report: Water Delivery & Energy	*March 1, 2009*
5) Interim Report: Analyze Water Deliveries	*April 1, 2009*
6) Interim Report: Analyze Energy Use	*May 1, 2009*
7) Interim Report: Analyze Energy Intensities	*June 1, 2009*
8) Interim Report: Develop Working Predictive Model of Water-Energy Relationship	*July 1, 2009*
9) Interim Report: Scenario Analysis	*August 1, 2009*
10) Interim Report: Policy Issues Analysis	*September 1, 2009*
11) Draft Final Report	*September 15, 2009*
12) Final Report	*October 31, 2009*
13) Monthly Reports	*Monthly*

5.14 Study 1 Schedule

Milestones	Deliverables	Schedule Duration	Month											
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Kickoff Meeting		1 day	X											
Study Plan	Draft Study Plan	3 weeks	X											
	Review with CIEE/CPUC	1 day	X											
	Stakeholder Review + Workshop	4 weeks			X									
	Review Public Input w/ CIEE/CPUC	1 day			X									
	Final Study Plan - Interim Report	1 week			X									
Literature Review	Interim Report	2 weeks				X								
Compile Water Delivery & Energy Data	Water & energy data ready for analysis - Interim Report	10 weeks					X							
Analyze Water Deliveries	Water delivery data in Statewide (ag-urban), SWP, CVP, CR categories - Interim Report	3 weeks						X						
Analyze Energy Use	Energy data for water in Statewide (ag-urban), SWP, CVP, CR categories - Interim Report	3 weeks							X					
Analyze Energy Intensities	Energy intensities for water in Statewide (ag-urban), SWP, CVP, CR categories - Interim Report	3 weeks								X				
Develop Model	Working Predictive Model of Water-Energy Relationship - Interim Report	4 weeks									X			
Conduct Scenario Analysis	Scenario Results - Interim Report	3 weeks										X		
Analyze Policy Issues	Policy Scenario Results - Interim Report	3 weeks											X	
Final Report	Draft Final Report	2 weeks											X	
	Review with CIEE/CPUC	1 day											X	
	Stakeholder Review + Workshop	4 weeks												X
	Review Public Input w/ CIEE/CPUC	1 day												X
	Final Report	2 weeks												X

Embedded Energy in Water Studies
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