CALMAC Study ID CPU0035.01
Volume 13 of 15
Appendix L

Embedded Energy in Water Studies
Study 1: Statewide and Regional Water-Energy Relationship

Prepared by
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Prepared for the
California Public Utilities Commission
Energy Division

Managed by
California Institute for Energy and Environment

August 31, 2010

Appendix L Literature Review – Annotated Bibliography

L.1   Water Energy

California Climate Change Research Center
http://climatechange.ca.gov/research/index.html
Source type: Database, so any references would be quoted directly
Document Type: Compilation of PDFs
Data Range: Historical through Present

This website is the home of the California Climate Change Research Center and has links to various models, studies, and inventory methods that deal with climate change and greenhouse gases in particular.   This database is broken down into three parts: historical climate and key variable data, regional climate models, and developing climate scenarios for California.
This site can be used to get a historical outlook on the climate in California, how it has changed and which of these changes are the results of natural causes. It also includes information on how to model regional climate changes affecting California which will allow climate scenarios to be developed.

California Sustainability Alliance, 2008
The Role of Recycled Water in Energy Efficiency and Greenhouse Gas Reduction
California Sustainability Alliance
Source type: Report
May 2008
http://www.sustainca.org/files/FINAL%20RECYCLED%20WATER%20MAY%202%202008a.pdf

The California Sustainability Alliance gathered senior water and wastewater agency managers throughout the state to brainstorm about opportunities for significantly reducing the water sector's energy and carbon footprint. The purpose of this study is to compute the energy value of recycled water. Recycled water was selected as a high potential area that is becoming increasingly important as a means of reserving limited potable water supplies for potable uses. This study developed an approach for attributing energy and carbon values to recycled water; estimated the magnitude of energy and carbon values achievable by accelerating and increasing use of recycled water in Southern California; and recommended remedies to primary barriers. The authors selected four agencies for detailed study: the Inland Empire Utilities Agency (IEUA); its customer, the City of Ontario; the Los Angeles Department of Water and Power (LADWP); and the City of San Diego. The authors point out that recycled water is resource that is available now in significant quantities, but is largely being discharged without any benefit. The study also concludes the energy and carbon benefits achievable by increasing use of recycled water instead of more energy intensive options such as seawater desalination are significant.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions:

1. Appendix B: Water Agency Profile: Inland Empire Utilities Agency (IEUA). This section documents detailed availability of recycled water in the IEUA region. Data on water supply makeup is summarized from the IEUA's 2005 Urban Water Management plan and other sources authored by the utility. Summary data on water energy intensity calculated jointly by the IEUA and Dr. Robert Wilkinson (author of *Methodology for Analysis of the Energy Intensity of California's Water Systems*) is presented.

2. Appendix C: Water Agency Profile: The City of Ontario. This section documents detailed availability of recycled water in Ontario. Data on water supply makeup and projected demand is summarized from Ontario's *2005 Urban Water Management Plan*. Summary data on water energy intensity is presented sourced from a compilation of sources including the City of Ontario, IEUA, personal communications with the city staff, and other sources.

3. Appendix D: Water Agency Profile: The City of San Diego. This section documents detailed availability of recycled water in San Diego. Data on water supply makeup and projected demand is summarized from the *2005 City of San Diego Urban Water Management Plan* and *City of San Diego Water Reuse Study*. Summary data on water

energy intensity is presented from data provided by these two reports. Energy required to pump recycled water is estimated in this appendix.

4. Appendix D: Water Agency Profile: The City of Los Angeles. This section documents detailed availability of recycled water and current use in Los Angeles. Data on water supply makeup and projected demand is summarized from the LADWP's *2005 Urban Water Management Plan*. Summary data on water energy intensity is calculated from data provided by the LADWP and the MWD.

This study collected and compiled data from the water and wastewater agencies being studied. Some of these data may be used for both Studies 1 and 2, if better sources are not located.

CDWR (Andrew), 2007
Climate Change and California Water Management
First Western Forum on Energy and Water Sustainability 2007
California Department of Water Resources
John Andrew
Source type: Speech
March 22-23, 2007
http://www2.bren.ucsb.edu/~keller/energy-water/first_forum_abstracts.htm

Abstract (direct quote)

Climate change will significantly impact California's water supply and other natural resources, perhaps reducing by 40% the Sierra snowpack and the seasonal water storage it provides by 2050. Climate change will also cause more variable and intense storms, more floods and droughts, rising sea levels, higher water temperatures, and increased water demand in all sectors. While climate change impacts are commonly thought to be long-term in nature, in fact, climate change has already measurably affected California's water supply; the sea level is rising, precipitation is increasing in the north (and decreasing in the south), and the snowpack is melting earlier. In this talk, the Department of Water Resources will present findings from its recent report on climate change, including possible next steps the Department is considering.

This speech can be used to facilitate discussions with key stakeholders about potential climate change scenarios to be evaluated.

CDWR, 2007
Bulletin 132-06 Management of the California State Water Project
California Department of Water Resources
Source type: Bulletin
December 2007
http://www.water.ca.gov/swpao/bulletin.cfm

The California Department of Water Resources Bulletin 132 series began in 1963 and has been prepared annually through 2005, reporting on the planning, construction, financing, managing, and operating activities of the State Water Project. The Bulletin discusses significant events and issues that affect SWP management and operations. Bulletin 132 is available from 1995 through 2006. The most recent Bulletin 132-06 covers the period from January 1, 2005, to December 31, 2005. Bulletin 132-06 also discusses water supply and delivery; Delta resources and environmental issues, including the CALFED Bay-Delta Authority; Oroville facilities relicensing; financial analysis of the SWP; and the update of business systems in the Department.

The two chapters that appear most relevant to the Embedded Energy in Water Studies are Water Contracts and Deliveries and Power Sources, summarized individually below:

Water Contracts and Deliveries
Information for this chapter was provided by the State Water Project Analysis Office

Data included in this chapter is commonly referred to Table A water. SWP contractors with long-term water supply contracts with DWR from the SWP are allotted annual amounts of water in Table A.

DWR approves Table A requests based on hydrologic conditions, current reservoir storage, and combined requests from the SWP water contractors. Table A water includes a portion or all of the annual Table A requested by contractors and approved for delivery by DWR. DWR is not always able to deliver the quantity of water requested by the contractors, and must allocate and deliver a lesser amount under certain conditions.

Brief descriptions of the various agreements and amendments executed during the year are included in this chapter.

SWP volumes of water delivered are tabulated by month to contracting agencies and services. Total amounts of Table A water (acre-ft) and water conveyed by type from 1962 through 2005 indicating initial fill water and losses, and storage changes are also included in this chapter.

Chapter 10 – Power Resources
Information for this chapter was provided by the State Water Project Analysis Office

The SWP provides power sources to deliver water to long-term SWP contractors. The DWR has developed and administers a comprehensive power resources program. Key elements of the program include the strategic timing of generation and pumping schedules, purchase of power resources and transmission services, short-term sales of power surpluses, and studies of power resources for future needs (pg. 179).

A figure showing the names, locations, and nameplate capacities of primary power facilities is included in this chapter.

Data included in this chapter are tabulations of energy used at pumping plants and power plants by month, energy generated and purchased by month, power, transmission, and other services purchased and costs of purchases by area, and energy sold and revenue from sales by area.

This bulletin contains data collected and compiled by the State Water Project Analysis Office. These data in this document may be relied upon as an authoritative source.

CDWR-CDEC
Reservoir Information
California Department of Water Resources
California Data Exchange Center
Updated 1/28/2008
http://cdec.water.ca.gov/misc/resinfo.html

The California Department of Water Resources California Data Exchange Center web page for Reservoir Information includes a tabulated list of State dams, the associated lake and stream names, and the capacity for each reservoir. A unique ID is associated with each dam and provides a link to additional information particular to that dam. Additional online data types are listed and links provided for download of data if available. Additional types of information available may include dam information, precipitation averages, and reservoir information.

These data will be used to populate the model with data about water storage.

CDWR, 2008
Bulletin 120 Water Conditions in California
Source type: Bulletins
California Department of Water Resources
Last Publication May 2008
http://cdec.water.ca.gov/snow/bulletin120/

Bulletin 120 is a publication prepared by the California Department of Water Resources. It is issued four times a year in the second week of February, March, April, and May. Bulletins are available starting from the year 1990. The bulletin contains forecasts of the volume of seasonal runoff from the state's major watersheds, and summaries of precipitation, snowpack, reservoir storage, and runoff in various regions of the State. Snow survey maps indicate percent of average snowpack to date and unimpaired snow melt runoff. This website also offers water supply conditions compared with previous years in each of the publication issue months. The data from Bulletin 120 is used to determine the River Index. In addition to the bulletins, forecast links are also available on the web site to access the latest data.

This data may be used to supplement inputs for rainfall-runoff modeling and scenario development.

CDWR, 2008
Complete Urban Water Management Plans
California Department of Water Resources
Source type: Reports
Updated November 2008
http://www.owue.water.ca.gov/urbanplan/uwmp/uwmp.cfm

The California Urban Water Management Planning Act requires that each urban water supplier, providing water for municipal purposes either directly or indirectly to more than 3,000 customers or supplying more than 3,000 acre-feet of water annually, shall prepare, update, and adopt its urban water management plan at least once every five years. These plans are required to be filed with DWR.

This website contains links to folders for various agencies who have submitted completed Urban Water Management Plans (UWMPs) to the DWR. These data constitute the best available information about current, historical, and projected water demand and water supplies at the individual water agency level. UWMPs will be used in Study 1 to evaluate current and historical water issues and operations, and also to help develop scenarios.

CDWR, 2009
Bulletin 160 California Water Plan Update 2009
California Department of Water Resources
Source type: Report and Data Report
January 2009
http://www.waterplan.water.ca.gov/cwpu2009/index.cfm

The California Department of Water Resources updates the state's water plan every five years. The California Water Plan Update 2009 is currently available for public comment and review, with a deadline of June 5, 2009 to submit comments. The California Water Plan Update 2009 is organized into five volumes:

Volume 1 – Strategic Plan
Volume 2 – Resource Management Strategies
Volume 3 – Regional Reports
Volume 4 – Reference Guide
Volume 5 – Technical Guide

Due to the large size of the document, each volume has sub-sections that are available for individual download from the CDWR website. There is a Highlights document that summarizes the content of the five volumes and directs the reader to where more detailed information can be found within the larger text. The Draft Assumptions and Estimates Report and CD are available on the same web page and will be finalized in February 2009.

In summary, Update 2009:

- Provides an investment guide for state, federal, Tribal, and regional strategies to reduce water demand, improve operation efficiency, increase water supply, improve water quality, advance environmental stewardship, and improve flood management;
- Integrates objectives and strategies from numerous state agencies and initiatives and offers more than 90 near- and longer-term actions to achieve them;
- Describes 27 resource management strategies that each region can select from to develop a unique and diverse water portfolio suitable for managing an uncertain future; and
- Outlines new analytical methods and tools to help plan for future effects of climate change, population growth and development patterns, economic change, and other factors outside the water community's control.

Draft Assumptions and Estimates Report
The Draft Assumptions and Estimates Report (A&E) for the California Water Plan Update 2009 provides background on the measures the State is taking to improve data, the analytical tools used to develop the Water Plan, descriptions of the most significant data, and the data sources used to prepare the Water Plan Update 2009 (pg. 3).

The data used to prepare the Water Plan Update 2009 are available on CD and for download from the internet. The data are presented geographically, in a drill down fashion, according to the major quantitative deliverables such as water portfolios, future scenarios, and response packages that were developed for the Water Plan (pg. 3). Data are provided for the following areas: the entire state, each of 10 hydrologic regions, the Sacramento-San Joaquin Delta including Suisun Bay and Marsh, and the Mountain Counties Area, which includes foothills and mountains of the western slope of the Sierra Nevada and a portion of the Cascade Range.

Multiple scenarios of California's future water conditions were developed to evaluate various resource management strategies for a range of water demand and supply assumptions, including climate change. Scenarios were developed using 2050 as the planning horizon with 2005 as the initial condition. A joint study by DWR with Montgomery-Watson-Harza, the Stockholm Environment Institute, the national Center for Atmospheric Research, and the RAND Corporation to quantify scenarios and evaluate potential future water management responses has been conducted. The Water Evaluation and Planning (WEAP) model was used for the study.

The two primary sources of data for climate change to the Water Plan are the California Climate Change Center studies from 2006 and 2008 Biennial Climate Science Reports required by Executive Order #S-3-05, signed by Governor Schwarzenegger on June 1, 2005. (pg. 7)

The Water Plan contains 12 regional reports summarizing California's hydrologic regions. These reports provide information on the water supplies and uses in each region or area, discussion of water issues, accomplishments, and challenges specific to each region. The information in these reports is based on Integrated Regional Management and local water and flood planning efforts. (pg. 8)

Twenty-five resource management strategies are outlined in the Water Plan. The data used to develop these strategies are available on the CD.

The Water Plan employs water portfolios to estimate and present actual water uses, supplies, and quality. Water portfolios for water years 1998 through 2005 were used for the Water Plan and are available on the CD. Data are presented in tables, flow charts, and in illustrations.

This is a comprehensive data report for the state of California. This resource may be used in Study 1 to help develop scenarios for analysis and may be used an authoritative data source.

CDWR – CDEC, varies
River Schematics and Maps
California Department of Water Resources
California Data Exchange Center
Source type: Maps
Dates Varied
http://cdec.water.ca.gov/riv_flows.html

The River Stages/Flow tab at the California Data Exchange Center web site, hosted by the Department of Water Resources includes a River Schematics and Maps section. There are links to seven different river schematics or maps; the references are listed below:

Department of Water Resources – Division of Flood Management – Flood Operations Branch, 2003, Sacramento and San Joaquin River Systems Schematic, January 2003.

Department of Water Resources – Division of Flood Management – Flood Operations Branch, 2003, Flood Control Projects and Agencies, revised October 2003.

Department of Water Resources, no date, The Sacramento River and the San Joaquin River Flood Control System – Project Levees and Channels, no date.

Department of Water Resources, 2003, Sacramento River Flood Control System, November 2003.

Department of Water Resources, 2003, Sacramento Valley Flood Control System – Estimated Channel Capacity (in cubic feet per second) – Reclamation and Levee Districts (Vertical Layout), November 2003.

Department of Water Resources, 2003, Sacramento Valley Flood Control System – Estimated Channel Capacity (in cubic feet per second) – Reclamation and Levee Districts (Horizontal Layout), November 2003.

Department of Water Resources, 2003, Sacramento and San Joaquin Valley Flood Control System – Reclamation and Levee Districts, November 2003.

CEC, 2005
California's Water-Energy Relationship
California Energy Commission
CEC-700-2005-011
Source type: Report
November 2005
http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF

This report, prepared by California Energy Commission (CEC) staff in support of the 2005 Integrated Energy Policy Report, integrates input from multiple public and private stakeholders, including water and wastewater agencies, about the interdependencies of California's water and energy resources and infrastructure. The report includes information about the amount of water that can be saved by certain types of water conservation measures, and then estimates the amount of energy embedded in avoided water consumption by computing a proxy for the amount of energy used in various parts of the water use cycle. The numbers used in this report were obtained from other sources and were not documented in detail. The values of embedded energy by type of water measure were provided to illustrate a conceptual methodology. Different assumptions were used for water saved in northern California vs. southern California, to account for the significantly different mixes of water resources and energy embedded in those resources.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions.

1. Appendix B: 2001 California Energy Consumption by End Use was based on information provided by the state's energy utilities to the CEC for use in demand forecasting. Assumptions were made by members of the study group as to whether that end use sector was related to water consumption. If the group agreed that most of the energy was water related, it was assigned a factor of 1. If it was believed that there might be a relationship but the magnitude was not readily determinable, the group assigned it a factor of 0.05. Presumed "intermediate" relationships became 0.5. Categories where there did not appear to be a relationship were assigned a zero value.

2. Appendix C: Energy Impact Analysis of Existing Water Management Practices presented estimated ranges of energy intensities for various portions of the water use cycle in kWh/MG. Wide varieties of sources were used to develop this table and are cited in this appendix. The data used to prepare this table are based on compilations by other individuals and organization's reports from 2000 through 2005. These sources include: LBNL, EPRI, PG&E, DWR, and Navigant Consulting.

3. Appendix C then provides information about the amount of water savings achievable through various "BMPs" (Best Management Practices, a term used by the California Urban Water Conservation Council (CUWCC) for water savings measures) and proposes a methodology for computing the energy intensity of water saved by type of measure and by region (northern vs. southern California). All data about the amount of water savings

attributable to each measure were provided by the CUWCC or its member water agencies from 2004.

4. Appendix C then provides a comparison of the cost-effectiveness of energy savings achievable by saving water (i.e., to avoid the amount of energy embedded in that unit of saved water). The data used for comparing these data with California's energy efficiency programs was obtained from regulatory filings at the California Public Utilities Commission for the 2004-2005 program period.

While this study was very important to helping frame water-energy issues and opportunities for consideration by California policymakers, data was very lean at the time and order of magnitude estimates were employed. Consequently, Study 1 will not be relying upon this report for any data.

CEC, 2005-2006
Refining Estimates of Water-Related Energy Use in California
California Energy Commission, 2006
CEC-500-2006-118
Document Type: Report
Data Range: 2005 through 2006
http://www.energy.ca.gov/2006publications/CEC-500-2006-118/CEC-500-2006-118.PDF

This report, prepared by Navigant Consulting on behalf of the California Energy Commission's Public Interest Energy Research (PIER) division revisits and documents some of the original data sources and assumptions used in the CEC's 2005 white paper, "California's Water-Energy Relationship." The study reviews the estimation methodologies that were developed and used in the CEC's white paper and recommends three important modifications:

1. Differentiate energy intensity values for indoor vs. outdoor use to account for the difference in embedded downstream energy. Specifically, wastewater from indoor uses incur energy for treatment and disposal; outdoor uses such as landscape irrigation are deemed to typically flow into groundwater, thereby avoiding embedded downstream energy associated with wastewater treatment.

2. Energy intensity values should include a factor for system water losses.

3. There is wide variability in the range of energy intensities for certain types of water and wastewater systems and functions. Examples of key drivers of differences in energy intensity were identified and ranges of energy intensity for certain types of systems and functions were illustrated.

This report relies heavily on the original case study data, so any assumptions made during that study has significant influence on these values. The majority of the information for the update comes from a study published in 2002 by EPRI that documented the energy intensity of water and wastewater systems and functions on a national basis.

This study will not be relied upon as a source of data for Study 2. However, the key differentiators of energy intensity provide a start point for development of the Study 2 matrix of primary energy drivers and energy intensity characteristics of California water and wastewater systems. In addition, the guidance with respect to maintaining awareness of the contribution of system losses may be considered in the development of Study 2 energy use profiles and intensities. The issue with respect to differences between energy intensity of indoor vs. outdoor water uses is not included in the scope of Study 2.

CEC, 2008
Water-Energy (WET-CAT) Subgroup of the Climate Action Team
California Energy Commission
Source type: Website
Accessed: February 2009
Date of last update: July 2008
http://www.climatechange.ca.gov/wetcat/

The Water-Energy (WET-CAT) Subgroup is one of fourteen subgroups of the Climate Action Team (CAT). It is tasked with coordinating the study of greenhouse gas effects on California's water supply system. In this group state agencies will work together, under leadership of the Department of Water Resources, to assess the greenhouse gas effects and reductions as a result of water supply development alternatives, including water recycling and conservation. All subgroups of the CAT are tasked to implement GHG emission reduction programs and report on the progress made toward meeting the statewide greenhouse gas targets that were established in the California Global Warming Solutions Act (AB32).

WET-CAT's group published a list of draft strategies and measures to reduce water use in the state. These measures focus on three areas, water recycling, water conservation/efficiency, and reduced energy intensity of water delivery. In March 2008 WET-CAT made available its list of proposed strategies and measures.

WET-CAT has compiled information regarding the effects of climate change on the California water system. The CAT selected four climate change scenarios that reflect greenhouse gas emissions scenarios represented by global climate models and requested that these scenarios be used whenever possible in the climate change reporting efforts. The first product of WET-CAT (*Progress on Incorporating Climate Change into Planning and Management of California's Water Resources.* 2006) was meant to examine the effects of these scenarios on the state's water system. This report examines the changes in reservoir inflows, delivery reliability, and annual average carryover storage due to climate change induced shifts in precipitation and runoff patterns. The effect on the State Water Project, Central Valley Project, and Sacramento-San Joaquin Delta was examined.

WET-CAT is a key stakeholder in the water-energy deliberations and will be invited to help develop scenarios for analysis.

EPRI, 2002
Water and Sustainability (Volume 2): An Assessment of Water Demand, Supply, and Quality in the U.S. - The Next Half Century
Electric Power Research Institute (EPRI)
Source type: Report
March 2002
http://my.epri.com/portal/server.pt

EPRI developed this report to aid in its research and development activities in sustainable development. The report largely focuses on a discussion of issues pertaining to sustainable water resources. The report concludes sustainable development and water quality require a balancing of technology use and management and policy, unlike past developments. Given this need, EPRI researchers were able to identify several R&D focus areas including: advanced water technology, monitoring, integration of economic and meteorological information, and various model development.

The most promising data that can be of use to this study team is a section of the report that is a case study on the California water system. However, this section mostly summarized data from past California Water Plan Updates. More recent data is available to the study team from other sources.

Following are the primary types of data that were either provided or relied upon in the report:

1. California water supply is summarized for average and drought conditions in 1995 and projected in 2020 from the *1998 California Water Plan Update*.

2. California water budget is summarized for average and drought conditions in 1995 and projected in 2020. This information was obtained from the *1998 California Water Plan Update*. It shows the net out-flow of water from California's storage indicating an unsustainable use of resources. The table also highlights how actions such as conservation and local sourcing, can reduce this net outflow in 2020, though further action is still need to achieve a sustainable level.

While this study was very important in helping frame sustainable water issues and opportunities, the results of this report will not be relied upon in Study 1. This study collected and compiled data for two hydrological scenarios in California; however, more detailed data are available from primary sources.

ITRC, California Polytechnic State University, 2003
California Agricultural Water Electrical Energy Requirements
Irrigation Training and Research Center, California Polytechnic State University
Burt, C.M., D.J. Howes, and G. Wilson
Source Type: ITRC Report No. R 03-006
2003
http://www.itrc.org/reports/energyreq/energyreq.pdf

The Irrigation Training and Research Center as Cal Poly State University, San Luis Obispo, working under agreement with the California Energy Commission as part of its Public Interest Energy Research Program, conducted an analysis of the energy used to supply water to California's agriculture and examined potential future trends in the agriculture water community to predict future energy requirements.

Following are summaries of the primary sections in the report.

1. Section A: Water Currently Destined for Agricultural Irrigation
   Agricultural water demand varies by location throughout the state. The study area for this project was split into thirteen zones based on the DWR ETo Zone Map, and total electrical energy requirement for agricultural destinations by sector in California has been tabulated in this report. The ITRC gathered most of the data to determine regional estimations for annual agricultural water uses.
2. Section B: Transfer of Historical Agricultural Water to MWD
   The MWD has transfer agreements and purchases with agricultural water users in the northern part of the state, and the one-year (2003) water transfer options exercised by MWD have been tabulated in the report. The energy consumption resulting from these transfers depends on what the MWD decides to do with the water. The energy requirements for the various scenarios have been tabulated in this report.
3. Section C: Potential Future Energy Requirements
   Ten scenarios were analyzed, including ranchettes, to predict future impacts of energy requirements.
4. Section D: Reservoir Sensitivity to Global Warming
   The results of the reservoir sensitivity to global warming were developed through a spreadsheet application, employing general predictions of the reservoir storage levels and outflows when inflows into the reservoir were changed.
5. Impact of Water Policies
   This study indicates that water-related policies by state and national governments can have an impact on energy consumption and on peak load demand, and proceeds to include various examples.
6. Section F: Future Research
   This report concludes that further research is necessary and has recommended four research tracks based on a 2004 document entitled, “Technology Roadmap – Water Use Efficiency in California Agriculture,” by Carles Burt and Ricardo Amon. The four research tracks include hardware improvements, reductions in water demand, enhanced utilization of surface water, and assess policy impacts.

This report will help establish the amount of agricultural water demand and related energy. In addition, this report will help facilitate discussions with key stakeholders about potential climate change and policy scenarios to be evaluated through this Study.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions.

1. Attachment A: Irrigation District Pumping
   This attachment explains the methodology and procedures used to estimate the amount of surface and groundwater pumping by irrigation districts by region throughout the state.
2. Attachment B: On-Farm Pumping
   Annual volumes of on-farm groundwater pumping were estimated from crop irrigation demands and on an estimation of uniformity and the availability of surface irrigation water deliveries. The on-farm pump efficiency and total dynamic head data were used to estimate the energy required to pump the water by region based on the estimated volume of water applied.
3. Attachment C: Irrigation District Pump Efficiency
   This attachment includes data focusing on the irrigation district overall pumping plant efficiency that has been collected by ITRC through the Agricultural Peak Load Reduction Program (APLRP).
4. Attachment D: On-Farm Pump Efficiency
5. This attachment includes data focusing on the irrigation district overall pumping plant efficiency that has been collected by the Center for Irrigation Technology (CIT) through the Agricultural Peak Load Reduction Program (APLRP).
6. Attachment E: Analysis of Irrigated Areas in Ranchettes
   This attachment includes a discussion and investigation using GIS imagery on ranchettes, and how the amount of applied water is affected, the source of the water, and how energy is impacted.
7. Attachment F: Groundwater Banking Case Studies
   Three case studies are included in this attachment with a discussion on the energy component associated with each case history.
8. Attachment G: Net Energy Cost of a Groundwater Banking Program
   An example calculation is included to demonstrate the net energy cost of a groundwater banking program.
9. Attachment H: Glossary of Groundwater Banking Terms
10. Attachment I: Interbasin Transfers
    Includes portions of Robert Wilkinson's report, "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", 2000.

LADWP, 2008
Lower Owens River Project Monthly Reports
Los Angeles Department of Water and Power
Source type: Monthly Data Report
July 2007 to November 2008
http://www.ladwp.com/ladwp/cms/ladwp009817.jsp

The Lower Owens River Project Monthly Reports prepared by the Los Angeles Department of Water and Power (LADWP) include a brief summary of the maintenance and operation activities for the month, a description of their quality assurance and calibration procedures, and the bulk of the report consists of extensive compilations of hydrological data. Reports are readily available from July 2007 through November 2008. Data are collected at sixteen locations at ten minute intervals twenty-four hours per day via SonTek area velocity flow meters. A daily summary tabulating the daily average flow, the fifteen day average, and the number of days of the last fifteen days at forty or greater cfs for each site, and total river flows and pumpback data are included at the beginning of the report. Following the summary table are the daily flow report summaries for the project. The LADWP has developed a quality assurance program and calibration procedures to maintain high quality data. Some of the LADWP's quality assurance measures include utilizing SonTek software to automatically check the quality of the data, visiting the site regularly, and using "ViewArgonaut" software to check the performance of the meters. The remainder of the report includes the monthly data readings for each metered location. Each dataset includes a summary page which shows the general data and geometry, and it also includes some statistical data. The summary page is followed by a series of three tables showing the hydrological data collected over the course of the month.

This is an authoritative source of data, and it will be used in developing the model and scenarios.

LBNL, 2009
Water Energy Technology Team
Lawrence Berkley National Lab
Source type: Website
Accessed: February 2009
Date of last update: February 2009
http://water-energy.lbl.gov/

The mission of the Water and Energy Technology Team (WETT) at Lawrence Berkeley National Laboratory (LBNL) is focused on a better understand the fundamental science, applied technology, and economics of the water/energy nexus. Research includes: the interaction between human and natural systems; and development, economic analysis, and optimization of new technologies, practices, and approaches for working with the water/energy interrelationship. Below are the key areas of WETT's research that are of interest to this study team:

Agriculture
WETT is constructing models to forecast climate change trends and effects on the agricultural sector, WETT is also developing tools to assist farmers in irrigation and pumping management.

Climate change
The WETT researchers are examining the effects of climate change on California's water supply. The WETT is collecting California water district data and using models to measure the current reliability of water supplies. The research staff has assembled a detailed database of California household- and district-level water use though this work.

Energy Production
The WETT staff is developing conceptual and planning models of reservoir and aquifer management. The models will be used to evaluate options for efficiently supplying water and generating electricity.

Urban Water Use
Quantitative estimates were made of water and energy use by residential end-use and industrial sector, each disaggregated by hydrologic region. Although this research topic is of interest to this study group, all related publications are from 1977. Further contact with the WETT staff may be needed to see if a more recent study has been performed.

Wastewater Treatment
The WETT researchers are collecting process-specific and system-integrated data regarding energy use and energy intensity of wastewater treatment technologies. These data will assist in comparison of processes and technologies and will also improve energy management by identifying opportunities for energy conservation.

WETT is a key stakeholder in the water-energy deliberations and will be invited to help develop scenarios for analysis.

MWD, 2007
A Status Report on the Use of Groundwater in the Service Area of the Metropolitan Water District of Southern California
The Metropolitan Water District of Southern California
Source type: Report No. 1308
Data Range: 1985 to FY 2004
September 2007
http://www.mwdh2o.com/mwdh2o/pages/yourwater/supply/groundwater/GWAS.html

This report, sponsored by the Metropolitan Water District of Southern California, discusses the current status of the groundwater basins that are used as a source for water for their service area. This report goes over the process in which the data were compiled that included an initial data gathering followed by a review from each of the various groundwater basin managers. This report showed that over a twenty year period from FY 1985 to FY 2004 that for the Metropolitan Water District, roughly 40% of their water use came from groundwater basins, and that the majority of the basins levels were either stable, in recovery, or increasing in their water levels. This report also emphasizes the need for the ground water basin managers to keep the water levels sustainable over the long term and the possible implications of using these basins for future storage. This report also covers aspects of basin management, existing facilities, current and historic water levels.

Information for this study came from member agencies, basin managers, and water purveyors when it was available. The data collected from this report were collected from the member agencies of the MWD and included the following: physical descriptions of the basin, water quality, facility descriptions, management practices, groundwater production, and recharge. When information was not available from the member agencies, a literature review was performed and other sources cited to help supplement the information. Some of the sources that were used in the literature review were: urban water management plans, water management plans, engineering reports, hydrogeologic reports, and modeling reports.

This study will be used to develop assumptions as to the capacity and operations of groundwater basins within MWD's service area.

NRDC, 2007
In Hot Water: Water Management Strategies to Weather the Effects of Global Warming
Natural Resources Defense Council
Source type: pdf
July 2007
http://www.nrdc.org/globalWarming/hotwater/hotwater.pdf

This report, put out by the Natural Resource Defense Council, stresses that global warming will have significant impact on water management strategies. It defines four main goals: increase awareness, prevent future impacts by the reduction of greenhouse gases, consider the changes that global warming will have on water management strategies, and to evaluate the current policies in place to see how they fare against the changes that global warming will have. Under each of these goals there are suggestions on how to go about accounting for some of the issues in dealing with global warming such as: how to handle earlier spring runoff, watershed restoration, urban water management strategies, etc and the potential qualitative energy savings generated from these activities. This report also details what the effects of global warming will be on current water management strategies and how to incorporate the most effective strategies into future plans. The report stresses that now is the time to think and begin to plan for the effects of global warming and how communication amongst the various agencies will play a key role in developing a water management strategy that will serve us all in the future.

This report will be used to help frame discussions with key stakeholders about potential climate change and policy scenarios for evaluation. The NRDC *Energy Down the Drain* published in 2004 and the International Panel on Climate Change's 4th Assessment Report released in 2007 are two examples of sources of climate change data from this report. This report addresses those water management strategies that will not be impacted significantly due to climate change and those that will. It offers guidance as to future water management strategies and some of the necessary issues to consider in developing these plans.

Natural Resources Defense Council and the Pacific Institute, 2004
Energy Down the Drain: The Hidden Costs of California's Water Supply
Natural Resources Defense Council and the Pacific Institute
Source type: Report
August 2004
http://www.nrdc.org/water/conservation/edrain/contents.asp

The NRDC and Pacific Institute report present a model to show policy makers how to calculate the amount of energy consumed in water use. The model is applied to three case studies in the western United States, two of which are in California. The authors suggest that integrating energy use into water planning can save money, reduce waste, protect the environment, and strengthen the economy. This report utilizes the Pacific Institute's Water to Air Model. See our review of the Water to Air Model for more details.

In examining San Diego County's urban water use, the authors estimate the energy intensity of water use broken down by the amount of energy consumed at five different steps (source and conveyance, treatment, distribution, end use, wastewater treatment). The authors then calculate the energy intensity of available options to satisfy an incremental demand of 100,000 af/yr including: conservation, recycling, desalination, and various water transfer options. While the study finds conservation is the best option, other options are ordered in the energy intensity from low to high.

The report also examines agricultural water use in the Westlands Water District in California specifically focusing on land retirement. In this case study, the authors evaluate three alternatives for the disposition of the water formerly used to irrigate retired lands in the district: enhance environmental flows in the delta, use on other land within the district, or transfer to other agricultural or urban uses.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions.

1. Appendix A: Description of model used for San Diego urban water case study. This model was derived from the methodology described in the CIEE report *Methodology for Analysis of the Energy Intensity of California's Water Systems*. Although no data lie in this section, model documentation and explanation are present.

2. Appendix B: Sources for San Diego urban water case study. The authors rely on the CIEE report *Methodology for Analysis of the Energy Intensity of California's Water Systems* as a source for pumping energy used by the State Water Project and the Colorado River Aqueduct. Another primary source for data was personal communication in 2003 with the SDCWA for information on: energy intensity of desalination plants, groundwater pumping data, energy used for recycling, energy used in water treatment, and several demographic data sets. Other data sources, less imperative to this study team's work, are also sourced in Appendix B.

3. Appendix C: Description of model used for agricultural water use analysis. This model was derived from the methodology described in the CIEE report *Methodology*

for Analysis of the Energy Intensity of California's Water Systems. Although no data lie in this section, model documentation and explanation are present.

This study relied upon other studies for data. Consequently, this study will be used to help develop scenarios for analyses but will not be relied upon as an authoritative data source.

The Pacific Institute
Climate Change and California Water Resources: A Survey and Summary of the Literature
The Pacific Institute
Michael Kiparsky and Peter H. Gleick
Source type: Paper
July 2003
http://www.pacinst.org/reports/climate_change_and_california_water_resources.pdf

This paper, by The Pacific Institute, begins to summarize some of the consequences of climate change for water resources and water systems in California and encourages a more comprehensive assessment be conducted by a larger pool of state agencies and stakeholders. This paper acknowledges that more than 150 peer-reviewed scientific articles on climate and water in California have been published (as of 2003) addressing a spectrum of topics from improvements in downscaling of general circulation models to understanding how reservoir operations might be adapted to new conditions. As a result of this research, a multitude of focused areas in need of further research have been identified.

This study will be used to help facilitate discussions with key stakeholders about potential climate change scenarios to be evaluated.

Pacific Institute, 2005
California Water 2030: An Efficient Future
Pacific Institute
Source type: Report
September 2005
http://www.pacinst.org/reports/california_water_2030/ca_water_2030.pdf

This study presents an alternative projection to the May 2005 California Water Plan issued by the California Department of Water Resource (DWR). The DWR routinely prepares water scenarios and projections as a part of long term water planning. In the 2005 the DWR presented three scenarios (current trends, more resource intensive, less resource intensive) to provide some sensitivity; the authors of this report present another scenario, high efficiency. In this scenario, the authors assume the potential for efficiency increases is higher than that assumed by the DWR for their "less resource intensive" scenario. The model used to estimate water use is the same model that is used by the DWR in its analysis. The authors changed some of the elasticity assumptions and projected a larger increase in water prices over the period of the study. The authors use a bottom up approach to estimate technology improvements in the agricultural sector (as opposed to the top down method used by the DWR). The report estimates total water consumption in the state by the agricultural and urban end use. Although estimates were made separately for California's 10 hydrological regions, the authors are not confident of the results at this level, thus results are disaggregated only by 3 geographic regions (north, central, south). The authors do not perform a sensitivity analysis of their own "high efficiency" scenario.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions.

1. Table 3 and Table 4: The model utilizes price elasticity factors in all sectors to model the response of water consumption on prices. The authors present their sources for elasticity factors and take an aggregate average value. The author's average value is compare to the default values found in the DWR model. Tables 3 and 4 present the elasticity factors for the urban sector (residential and commercial/industrial), the authors find that water is more elastic to price than the DWR report assumes. Data are compiled from reports published between 1991 and 1999.

2. Figures 2 and 3: The authors compare past water projections by the DWR's Bulletin 160 (1964-2005) to actual water use. This exercise is helpful in validating the accuracy of the model development. Figures 2 and 3 provide an accessible summary of past water projections and how they compare to actual consumption and other water use projections.

3. Appendix A: The authors use a bottom up approach to determine efficiency improvements in the agricultural sector. To do so, the authors have summarized data from primary sources listed that show the growing trend of drip and sprinkler irrigation over the last several decades among various farm types. The authors offer

their own projection of how these will continue in trend over the next several decades. Historic data used to project irrigation trends ranges from 1972 to 2001.

This study will be used to facilitate discussions with key stakeholders about potential climate change and policy and water demand scenarios to be evaluated.

UCSB (Tellinghusen, Dennen Lee, and Larson), 2007
Water-Use Intensity of Renewable Energy vs. Conventional Sources
First Western Forum on Energy and Water Sustainability, 2007
University of California, Santa Barbara
Stacy Tellinghusen, Bliss Dennen, Cheryl Lee, James Lee, Dana Larson
Source type: Speech
March 22-23, 2007
http://www2.bren.ucsb.edu/~keller/energy-water/first_forum_abstracts.htm

Abstract (direct quote)

Energy and water are inextricably linked. Although water supplies and energy supplies are thought of by the general public as two separate systems, it is often overlooked that the production of energy itself consumes significant quantities of water. Likewise, it is also overlooked that the distribution of water requires large amounts of energy. This interdependence of energy and water is known as the energy-water nexus. In California, where water supplies are already limited, the effects of climate change and regional population growth threaten the future available supply of water for energy production. Meanwhile, rising prices of fossil fuels and concern over greenhouse gas emissions have led to broader interest and investment in renewable energy sources. Renewable energy technologies not only reduce dependence on fossil fuels which emit the greenhouse gases linked to climate change, but typically reduce the amount of freshwater required for energy generation. In turn, reducing the amount of freshwater consumed in energy production keeps more water in the natural environment to relieve pressure on ecosystems stressed by human water withdrawals, ensure base flows of rivers to preserve wildlife, and maintain natural habitats. The analysis quantified the amount of freshwater required to produce energy for different types of power generation technologies. This information is used to compare the water use impacts of several different energy portfolios using California as a case study.

This speech will be used to facilitate discussions with key stakeholders about potential scenarios to be evaluated.

USBR, 1985 to current
Report of Operations Monthly Delivery Tables
U.S. Bureau of Reclamation
Central Valley Operations Office
1985 to Current
http://www.usbr.gov/mp/cvo/deliv.html

This web site, hosted by the United States Department of the Interior Bureau of Reclamation, and run by the Central Valley Operations Office includes Report of Operations Monthly Delivery Tables from 1985 to current. Delivery Tables from 1985 to 1992 are scanned hardcopies and have been compiled into single PDF files by year.

Tables are available for the following systems:

- Central Valley Project Diversions (Table 21)
- Friant-Kern Canal Deliveries (Table 22)
- Madera Canal and Millerton Lake Deliveries (Table 23)
- San Joaquin River and Mendota Pool Deliveries (Table 24)
- Delta-Mendota Canal Deliveries (Table 25)
- San Luis and Cross Valley Canal Deliveries (Table 26)
- Tehama-Colusa Canal Deliveries (Table 27)
- Sacramento River Deliveries (Long-term contracts) (Table 28)
- Sacramento-San Joaquin Valley Streamflow Data (Table 29)

Each table includes the canals, projects, tunnels, creeks, and/or water users in the system and the deliveries per month to each component.

This is an authoritative source of data.

USBR, 2008

Lower Colorado River Accounting System Evapotranspiration and Evaporation Calculations – Calendar Year 2007

United States Bureau of Reclamation

Source type: Data Report

September 2008

[http://www.usbr.gov/lc/region/g4000/4200Rpts/LCRASRpt/2007/Report07.pdf]

<u>Summary (paraphrased from USBR)</u>

This document outlines the process for the Lower Colorado River Accounting System (LCRAS) Evapotranspiration and Evaporation Calculations for the 2007 calendar year. Arizona, southern California, and Nevada utilize the Colorado River as a principle water source. The LCRAS provides the USBR the following information to use as water management tools:

1. Estimates of evapotranspiration (ET) from irrigated areas for monitoring of agricultural water use
2. Estimates of ET from riparian vegetation for environmental resources assessment and management
3. Estimates of evaporation from the channel and reservoirs of the lower Colorado River, and evaporation from canals, lakes, lagoons, and other open-water areas along the river for river system resource assessment and management

The USBR uses these tools to monitor the current state of the river system, to assess potential impacts of changes to the river system, and as inputs to management decisions involving the administration of the laws, compacts, and U.S. Supreme Court decree which govern the diversion and use of Colorado River water.

<u>Results (direct quote from USBR)</u>

Table 1 shows the ET from agriculture2 and riparian vegetation; and evaporation from the open-water surfaces of lakes, ponds, lagoons, and other open-water surfaces that are not part of the river channel or reservoirs of the lower Colorado River between Hoover Dam and Mexico for calendar year 2007. Table 1 includes areas irrigated with water diverted from the lower Colorado River which are not on the river itself, specifically the Wellton-Mohawk Irrigation and Drainage District on the Gila River in Arizona, and the Imperial Irrigation and the Coachella Valley Water districts in California. Detailed calculations and values used to develop the results presented in Table 1 can be found in, "Lower Colorado River Accounting System Appendix: Part 1, Evapotranspiration-Rate."

This information will probably not be used directly in the development of the Study 1 model since other water demand sources are available.

USBR, 2008

Reclamation – Managing Water in the West – Colorado River Accounting and Water Use Report Arizona, California, and Nevada - Calendar Year 2007

U.S. Bureau of Reclamation
Lower Colorado Region
Source type: Annual Report
September 2008
http://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2006/2006.pdf

This annual data report, prepared by Paul Matsuka, BC00-4222 of the Lower Colorado Regional Office, Boulder Canyon Operations Office, is a compilation and summary of storage and delivery data for the Colorado River. Annual reports are available from 1964 through 2007. The basis for this report is the Article V of the Consolidated Decree of the United States Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006) (Consolidated Decree). As a result, the United States is responsible for preparing and maintaining annual reports and making them publically available and accessible with detailed and accurate records of the following:

(A) Releases of water through regulatory structures controlled by the United States;
(B) Diversions of water from the mainstream, return flow of such water to the stream as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation, and consumptive use of such water. These quantities shall be stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California and Nevada;
(C) Releases of mainstream water pursuant to orders therefore but not diverted by the party ordering the same, and the quantity of such water delivered to Mexico in satisfaction of the Mexican Treaty or diverted by others in satisfaction of rights decreed herein. These quantities shall be stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California and Nevada;
(D) Deliveries to Mexico of water in satisfaction of the obligations of Part III of the Treaty of February 3, 1944, and, separately stated, water passing to Mexico in excess of treaty requirements;
(E) Diversions of water from the mainstream of the Gila and San Francisco Rivers and the consumptive use of such water, for the benefit of the Gila National Forest.
(pg. 4)

Each of the five records above is further described in their respective sections of the report, where the tabulated records are presented.

This report also includes information supplemental to the records required by the Article V of the Consolidated Decree of the United States Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006). Information tabulated in this section of the report presents a broader range of activities relating to federal management of the Colorado River, specific to various agreements or requirements. This section is designed to provide the reader with supplemental data to make connections between the records of diversions and consumptive uses and the various conservation, transfer and exchange agreements that exist.

The data for the 2007 calendar year are summarized in tables on pages 2 and 3. The Summary table on page 2 summarizes the lower division states consumptive use, the Lower Colorado Water Supply Project (LCSP) wellfield pumping summary, and the reservoir contents summary, by month for the 2007 calendar year. The offstream interstate storage summary is also summarized on page 2 per state. The monthly storage contents of the Colorado River system reservoirs are summarized on page 3.

This is an authoritative source of data, and it will be used in developing the model and scenarios.

USGS, 1995
Ground Water Atlas of the United States – California, Nevada
United States Geological Survey
HA 730-B
Michael Planert and John S. Williams
Document Type: HTML with figures as GIFs
Data Range: early 1900s to 1995
http://pubs.usgs.gov/ha/ha730/

This website contains information about the nation's groundwater system. It is broken down into thirteen distinct regions of which California and Nevada are Segment 1. Under Segment 1, a background history is provided about the region's groundwater system and is discusses in more depth as sub-regions. Each sub-region is broken down into eight distinct elements and analyzed. The eight elements include: geologic setting, groundwater flow system, post development groundwater flow system, well depths and yields, water budget of the aquifer system, fresh groundwater withdrawals, land subsidence, and ground water quality. Each heading covered historical facts and information and if applicable had information on current and future projections.

This document will provide the background information for the groundwater basins in California that will be incorporated in writing the report. It contains information on the groundwater basins in California prior to development and the various methods and problems that occurred as these basins were developed.

USGS, 2007
Ground-Water Recharge in the Arid and Semiarid Southwestern United States
United States Geological Survey
Source type: USGS Professional Paper 1703
2007
http://pubs.usgs.gov/pp/pp1703/

This professional paper by the United States Geological Survey presents the coordinated efforts to develop a better understanding of ground-water recharge in the arid and semiarid southwestern United States. This eleven chapter (426 pages) volume begins with an overview of climatic and hydrogeologic framework (chapter A) and narrows to a regional analysis of ground-water recharge across the entire study area (chapter B). Chapter C presents an overview of site-specific case studies representing different subareas of the southwestern United States. Chapters D through K include the individual case studies. Chapter G Ground-Water Recharge from Small Intermittent Streams in the Western Mojave Desert, California is the only case study in this paper in California.

Appendices 1 and 2 discuss two different methods for investigating groundwater recharge, thermal methods and geophysical methods, respectively. Geophysical methods used in this study consist of using heat as a tracer and applying computationally intensive geophysical imaging tools to characterize hydrologic conditions in the unsaturated zone. The modeling-based techniques employed spatially distributed water-budget computations using high-resolution remotely sensed and ground-based geographic data. These techniques were applied to the study area and revealed distinct patterns of recharge which corresponded to geologic setting, climatic and vegetative history, and land use.

As a result of the analysis of recharge patterns, this study revealed large expanses of alluvial basin floors are drying out under current climatic conditions, with little to no recharge to underlying groundwater. This study also found that Ground-water recharge occurs mainly beneath upland catchments in which thin soils overlie permeable bedrock, ephemeral channels in which flow may average only several hours per year, and active agricultural areas.

This document will provide the background information for the groundwater basins and recharge in California that may be incorporated in the report.

Wilkinson, 2000

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

Ernest Orlando Lawrence Berkeley Laboratory
California Institute for Energy Efficiency
Agreement No. 4910110
Source type: Report
January 2000
http://www.es.ucsb.edu/faculty/Wilkinson.pdfs/Wilkinson_EWRPT01%20DOC.pdf

This exploratory study report, prepared by Dr. Robert Wilkinson of the Environmental Studies Program at University of California, Santa Barbara for the California Institute for Energy Efficiency examines the energy intensity of water used in specific geographic areas of the state and it estimates the potential energy benefits of efficiency improvements of water use. The study developed a methodology to account for total energy requirements for water used within a specific service area, created a spreadsheet tool to apply the methodology, and incorporated a geographic information system (GIS) application to present the data geographically.

The analysis was focused on the two most energy-intensive water conveyance systems in the state, the State Water Project (SWP), and the Colorado River Aqueduct, with the focus on the municipal and industrial (M&I) sector as the users. The M&I sector has both greater energy intensity and availability of data than the agricultural sector. The study found that the energy intensity of water varies considerably by geographic location of both end-users and sources. Water use in certain parts of the state is highly energy intensive due to the combined requirements of conveyance over long distances with significant elevation lifts, local treatment and distribution, and wastewater collection and treatment processes. The analysis also indicates that significant potential *energy* efficiency gains are possible through implementation of cost-effective *water* efficiency improvements. This study also identifies potential cost-effective energy efficiency benefits from integrated energy, water, and wastewater efficiency programs and acknowledges work undertaken by others in the realm of combined end-use strategies.

This exploratory research project includes a well-documented review of previous work addressing energy elements of water and wastewater processes and systems, the goal of which is to provide a platform and to facilitate further research. Further research priorities were identified and form the basis of the recommendations from this study.

Energy inputs included (and excluded) in the analysis:

Energy inputs for extractions from natural systems through end-uses to ultimate disposal or re-use are included. Power generated by water systems separate from the delivery and conveyance systems is not included. Power generated as a part of conveyance systems is counted because it relates directly to the volume of water pumped through the system. The data used for this analysis were provided by MWD.

Data for Specific Geographic Locations
Geographic factors such as the sources of water and the location of end-use are usually used to determine the energy intensity; however, due to overlaps or inconsistencies in jurisdictional boundaries, the geographic boundaries must be accounted for and the appropriate energy factor for each element of the system must be attributed to the area. The author suggests the use of geographic information systems (GIS) to delineate the boundaries and record energy and other data as a next step in this research project. (pg. 17)

Energy Inputs to Water Systems
State Water Project Energy Inputs to Water Systems
SWP energy requirements for the MWD region were obtained from MWD. (pg. 25)

The figure illustrating names, locations, and generating capacity of primary power facilities includes data provided by MWD (pg. 26).

The kilowatt-hours per acre foot pumped (including transmission losses) for each facility on the SWP shown on a flowchart, was based on data obtained from the California DWR, State Water Project Analysis Office, Division of Operations and Maintenance, Bulletin 132-97, 4/25/97. (pg. 27)

Water delivered in calendar year 1995 and delivery locations was shown geographically, with data obtained from MWD.

The Colorado River Aqueduct

Water volumes and energy required to import water to Southern California from the Colorado River Aqueduct were provided by the MWD. (pg. 30)

Local Sources (surface and groundwater)

Water Processes
A national average for estimates of electricity use in wastewater treatment was obtained from Burton, Franklin L., 1996, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. (Burton Engineering) Los Altos, CA, Report CR-106941, Electric Power Research Institute Report, p.2-45. (pg. 43)

Water Reuse
Trends in water reuse were identified in a 1999 case study for the Pacific Institute titled, "Use of Reclaimed Water in Urban Settings: West Basin Recycling Project and South Bay Water Recycling Program" for the years of 1987, 1989, and 1993 by Arlene Wong in Lisa Owens-Viani, Arlene Wong, and Peter Gleick, Eds., *Sustainable Use of Water: California Success Stories*, Pacific Institute, January 1999, based on data from : The 1987 and 1989 data are from

Water Recycling 2000, 1991. The 1993 data are from *Survey of Future Water Reclamation Potential*, 1993. (pg. 43)

Energy Analysis
A spreadsheet tool was developed as a part of this exploratory project to assist in analyzing the energy intensity of water used at a given location.

Groundwater, surface water, and reclaimed water data inputs are provided by the agency in the form of total volume of water pumped and total amounts of energy (kWh of electricity and/or therms of gas) used. (pg. 47)

The imported supply energy is calculated based on a stated kWh/acre-ft factor, from DWR, MWD, or other source (available input choice), and the total amount imported for each source. (pg. 47)

The spreadsheet tool does not provide a refined methodology for calculating the marginal difference between wastewater treatments required under applicable standards and the level of treatment required for reuse. This is an area in which the author recommends further research. (pg. 48)

The regional distribution energy inputs are reportedly difficult to secure and according to the author, further research is needed to quantify the appropriate energy figures. Real-time data on MWD pumping facilities throughout its service area were provided by MWD. The user also inputs the sources of water delivered to each member agency including the associated energy intensities. (pg. 49)

Energy inputs for potable treatment and the energy required to pressurize and deliver supplies to customers is obtained from the individual agencies.

End-use factors may be included, however this study did not attempt to place values on these energy uses.

This spreadsheet applies a percentage factor to total water inputs for wastewater collection and treatment that can be adjusted and customized based on a specific facility, or it can be averaged for a service area.

The results can be viewed at each stage of the process, and a summary table of total energy and energy intensity is the final product.

This study provides a fundamental framework for calculating the energy intensity of water at specific locations and this methodology may be used as a starting point to develop scenarios for the embedded energy study.

Wilkinson, 2006

Rethinking Water Policy Opportunities in Southern California – An Evaluation of Current Plans, Future Uncertainty and Local Resource Potential

Robert Wilkinson, Ph.D

Director, Water Policy Program, Bren School of Environmental Science and Management, University of California, Santa Barbara

David G. Groves, Ph.D, RAND Corporation, Santa Monica, California, June 2006

http://g.icess.ucsb.edu/rtmime/1168389566-18330/Socal%20Project%20Report%20v07%2024%202006-FINAL.pdf

This study report, prepared by Dr. Robert Wilkinson and Dr. David G. Groves, was developed to provide a mechanism and tool for considering water management options. The study used the Water Scenario Evaluation Model (WASEM), developed by Dr. Groves, incorporated with the water management forecasts and strategies presented in the 2005 Urban Water Management Plans to generate seven water supply and demand scenarios for Southern California. The study also incorporated management approaches from the California Water Plan Update, 2005, such as urban water use efficiency, groundwater conjunctive management and storage, and recycled municipal water use, to develop four different management strategies. All of the scenarios were applied to each of the strategies using the WASEM in the analysis.

The results of the analysis suggest that the state's three top water supply options, stated above, may be understated in regional and state-wide plans. The study team recognizes that Southern California water agencies are actively planning and pursuing greater amounts of water from these three sources, however the analysis indicates that even more aggressive development of local supplies should be considered as opposed to the more conventional means of meeting the region's water needs.

Following are the primary types of data that were either provided or relied upon in the report to develop its conclusions.

1. Appendix 1: Water Scenario Evaluation Model (WASEM)
   The WASEM for this study utilizes two input modules. The Urban Demand Module has six subsections with various inputs required to calculate urban demand, population, housing, employment, water use coefficient, and losses and other water demands. The Supply Module has ten input categories including groundwater, groundwater recovery, surface water, total recycling, ocean desalination, Los Angeles Aqueduct, other imported supplies, Colorado River Aqueduct, State Water Project Aqueduct, and in-basin storage. The study team has devised a demand calibration process to calibrate the model with the 2005 RUWMP, the results of which are also included in Appendix 1.
2. Appendix 2: Water Management Strategies
   This section describes how efficiency projections from the Comprehensive Evaluation of the CALFED Water Use Efficiency Element (CBDA, 2005) can be used as a benchmark for alternative levels of policy-induced efficiency in the WASEM.

This study will be used to facilitate discussions with key stakeholders about potential climate change and policy scenarios to be evaluated.

Wilkinson, 2007

Integrating Water and Energy Resource Management: Progress and Opportunities

Bren School of Environmental Science and Management, University of California, Santa Barbara

Dr. R.C. Wilkinson

Source type: Conference Proceeding Paper

2007

http://cedb.asce.org/cgi/WWWdisplay.cgi?0705621

Abstract (direct quote)

Integrated policy, planning, and management of water resources and energy systems can provide important opportunities. While both energy and water managers have used integrated planning approaches for decades, the broader integration of water and energy management is a relatively new and exciting policy area. Water and energy systems are interconnected in several important ways. Developed water systems provide energy (e.g. through hydropower), and they consume energy, primarily through pumping and thermal processes. Many energy systems require energy for cooling and other purposes. The focus of this paper is on energy inputs to water systems. Critical elements of water infrastructure systems and certain uses are energy intensive. Moving water over distances and elevation gains, treating and distributing it, meeting end-uses for various purposes, and collecting and treating the resulting wastewater, accounts for one of the largest uses of electrical energy in some areas. For example, estimates by the California Energy Commission indicate that 19% of the state's electricity use, and 33% of natural gas use (excluding power plants), is devoted to water use. Examples of new approaches to the integration of water and energy planning, including policy processes at the California Energy Commission, Public Utilities Commission, and Department of Water Resources are discussed. Current methodologies for accounting for embedded energy, from initial extraction through treatment, distribution, end-use, wastewater treatment and discharge, are reviewed. New approaches to institutional collaboration between energy and water management authorities and providers are also discussed.

This paper will be used to facilitate discussions with key stakeholders about potential policy scenarios to be evaluated.

L.2 Model References

<u>Description of Individual Models</u>

CalSim-II
http://www.usbr.gov/mp/cvo/ocap_page.html

CalSim-II was developed using the Water Resources Integrated Modeling Software (WRIMS), that solves for an optimal set of decisions for each time period given a set of weights and system constraints. The physical description of the system is expressed through a user interface with tables outlining the system characteristics. The priority weights and basic constraints are also entered in the system tables. The programming language used, Water Resources Engineering Simulation Language (WRESL), serves as an interface between the user and the LP/MILP solver, time-series database, and relational database. CalSim-II uses described optimization techniques to route water through a CVP-SWP system network representation. The network includes over 300 nodes and over 900 arcs, representing 24 surface reservoirs and the interconnected flow system. The model operates on a monthly time step from water year 1922 through 2003. Using historical rainfall and runoff data, which have been adjusted for changes in water and land use that have occurred or may occur in the future, the model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period. Included in this operation are agricultural and municipal & industrial water demands, environment water requirements, regulatory conditions, (e.g., water rights, water service contracts and deliveries, coordinated operation agreements, CVPIA 3406(b)(2) operations, joint point of diversion, D-1641 operations, and others). In the model, the reservoirs and pumping facilities of the SWP and CVP are operated to assure the flow and water quality requirements for these systems are met. The model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development.

CalSim-II does not simulate embedded energy. However, CalSim-II contains a large database that can be accessed and used as part of this study. CalSim-II simulates the state-wide system at a level-of-detail not needed in Study 1. As such, CalSim-II is not appropriate for Study 1.

CALVIN

www.waterplan.water.ca.gov/docs/tools/descriptions/CALVIN-description.pdf

CALVIN is a statewide model of economic and engineering aspects of California's integrated water supply system. The model spans nearly the entire state and it incorporates over 90% of the estimated 2020 urban water demand and almost 90% of estimated 2020 irrigation water demands. The model integrates a wide variety of aspects of this complex system, including surface and groundwater hydrology, water management facilities and their capacities, environmental regulations, economic values for water deliveries, and economic costs of operations. The model integration is simulated within a framework of economic optimization within an engineering and planning context. The model outputs provide an economic and engineering view of promising integrated management strategies, in an optimization, rather than a simulation context.

CALVIN relies on a lot of data that are incorporated from a variety of sources which has been extensively documented. Postprocessors are used extensively to visualize complex output data. Following is a general list of input data to CALVIN: surface and groundwater hydrology, facilities and capacities (storage and conveyance), urban water use, agricultural water use, environmental flow constraints and operating costs. Output data include water allocations and delivery reliabilities, willingness to pay for water and reliability, economic benefits, conjunctive use operations, value of flexible operations, and values of increased capacities.

To be applicable for this study, CALVIN would need to significantly modified. CALVIN is designed to represent the entire Central Valley, Bay Area, and Southern California water systems in an integrated manner. Embedded energy is not an explicit component of CALVIN and this would need to be added to CALVIN. However, CALVIN approaches the level of detail needed in Study 1 and will be further evaluated.

DHI – MIKE Water Resources Family

http://www.dhigroup.com/Software/WaterResources.aspx

MIKE 11 river and channel hydraulics

MIKE 11 is a popular river model. It simulates in a one-dimensional hydrodynamic environment the solution of St.Venant equations, plus many process modules for advection-dispersion, water quality and ecology, sediment transport, rainfall-runoff, flood forecasting, real-time operations, and dam break modeling.

MIKE FLOOD - river and floodplain hydraulics

MIKE FLOOD is an integrated tool for detailed floodplain studies. It combines the two numerical hydrodynamic models MIKE 11 (1-D) and MIKE 21 (2-D) with a unified user interface for spatial modeling where needed and one-dimensional calculations where appropriate. MIKE FLOOD is ideal for many types of analyses such as flooding, storm surge, dam break, embankment failure, and more.

MIKE BASIN - water resources modeling

MIKE BASIN is a water resource and environmental modeling package. It provides a framework to address multi-sectoral allocation and discharge issues in a river basin. MIKE BASIN represents all elements of water resource modeling: users, reservoirs, hydropower, surface water, groundwater, rainfall-runoff, and water quality. Its object-oriented and open-ended code allows users to write their own Visual Basic rules, and make their own decision support interfaces in e.g. Microsoft Excel.

This model is for the detailed modeling watersheds and riverbasins. It is not suited for a statewide predictive model of water and energy as needed in Study 1.

HEC-HMS (HEC-1)

http://www.hec.usace.army.mil/software/hec-hms/

HEC-HMS Users Manual

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic drainage basins. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the water cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment.

The HEC-HMS system is for the detailed modeling watersheds and rivers. It is not suited for a statewide predictive model of water and energy.

IWR-MAIN (Institute for Water Resources – Municipal and Industrial Needs)

http://www.iwrmain.com/

The IWR-MAIN is a planning tool for the planning and management of water resources. IWR-MAIN is proprietary software of Camp Dresser & McKee (CDM) and is used in the development of water demand forecasts and the assessment of water conservation savings. The Institute for Water Resources – Municipal And Industrial Needs (IWR-MAIN) model was developed by the Corps of Engineers Institute for Water Resources based upon models of residential water demand, commercial water use coefficients, and industrial water use coefficients. IWR-MAIN includes a conservation routine and a benefit-cost analysis module for conservation measures. These versions continued to operate on the Windows platform. Users of the IWR-MAIN software were required to provide user-specified model parameters, thus giving the software the maximum flexibility as a planning tool. IWR-MAIN has been applied for Phoenix, AZ, Southwest Florida Water Management District, Metropolitan Water Districts of Southern California, City of San Diego, CA, San Diego County Water Authority, Miami-Dade Water and Sewer Department and others.

This model is applicable to demand forecasts for individual water districts and would not be appropriate for the wholesale and statewide predictive Study 1 model

OASIS
www.hydrologics.net/oasis.pdf

OASIS is linear programming software that simulates the routing of water through a water resources system. Users can express all operating rules as operating goals or operating constraints, and can account for both human control and physical constraints on the system. Hydrologic systems are modeled in OASIS by setting goals and constraints. The software solves for the best means of moving water through the system to meet these goals and constraints. Features of the model include:

- OASIS is data-driven. Any operational rules can be included in OASIS, including conditional operations. These rules can be specified without modifying OASIS source code.
- The model simulates routing decisions and simulation rules by representing them as goals or constraints. Goal-seeking algorithms are used in a way that corresponds to the way real-world operators and planners think about a water system.
- The model can be run in parallel with other models. Data from the model can be interchanged with data from other programs while the programs are running. Each program can then react to the information provided by the other.
- OASIS is designed to model the operations of water resources systems, and uses standardized features appropriate to that kind of modeling. For example, OASIS can simulate reservoir operations so that minimum flow targets are maintained.

OASIS is a generic tool that needs to be customized and calibrated to each system's unique characteristics. It is robust at the individual system level, but costly and not applicable to Study 1.

RiverWare
http://cadswes.colorado.edu/riverware/overview.html

RiverWare is a generalized river basin modeling tool and provides for the developing and running detailed, site-specific models without the need to develop or maintain the supporting software. It includes an extensible library of modeling algorithms, several solvers, and a rich "language" for the expression of operating policy. The graphical interface facilitates model construction and execution, and communication of policies, assumptions and results to others. RiverWare allows the user to model any basin by selecting generic basin features from a palette, name the features, and link them together to create your basin topology. The models can be customized by selecting the appropriate physical process equations for each basin feature.

RiverWare is for the detailed modeling watersheds, basins and rivers. It is not suited for a statewide predictive model of water and energy as needed in Study 1.

STELLA

www.iseesystems.com
STELLA_productsheet.pdf

STELLA offers a practical way to dynamically visualize and communicate how complex systems and ideas. STELLA is used to explore and answer endless questions. STELLA models allow you to communicate how a system works - what goes in, how the system is impacted, what are the outcomes. STELLA models provide endless opportunities to explore by asking "what if," and watching what happens. Diagrams, charts, and animation help visual learners discover relationships between variables in an equation.

STELLA is a very generic model/tool that has limited applicability to Study 1.

Water to Air Model
Pacific Institute
Source type: Excel model and report documentation
October 2004
http://www.pacinst.org/resources/water_to_air_models/index.htm

The Water to Air Model was designed by the Pacific Institute to allow water managers to quantify the energy and air quality impacts of their management decisions. The model is designed to simulate a water agency, not the entire state water system. It is a publicly available spreadsheet based model consisting of two sub-models for the urban use and agricultural sectors that are disconnected. The models documentation is well written and walks users though examples for both sectors.

Inputs to the model include six total water sources (five for each sector) including: groundwater, local surface water, reclaimed water, imported water, desalinated water, and tailwater reuse. Within each type of water source, users can identify up to 19 different facilities for the agency and provide specific data on amount of water supplied and energy consumed. If specific facility data are not available aggregate data will suffice. In the urban model data on water treatment, distribution, wastewater collection, and wastewater treatment facilities are also input by users. Once again up to 19 different facilities can be accounted. In the agricultural model, water distribution (non-irrigation) and drainage management can be accounted. The modeling of end use in each sector differs between the sub-models. The urban sector can simulate 5 different residential end uses, 10 commercial end uses, and 2 other end uses. The agricultural sector can simulate 4 irrigation methods and 19 crop uses. Any end uses can be specified by the modeler; input data on percent of water use or crop water intensity are a required input.

In addition to modeling the energy use of water system, the Water to Air Model also quantifies the emissions impacts of water use based on electric utility data.

This model could be of use to the study team to tabulate or estimate embedded energy at the agency or purveyor level. Although this model focuses on water agencies, the accounting methodology for energy intensity and emissions and the methods of scenario analysis could be useful.

Following are the primary types of data that are provided in the model documentation as default assumptions:

1. Table A-1 and A-2: The model developers provide data on the energy intensities of imported water from both the State Water Project (SWP) and the Central Valley Project (CVP). Energy intensities are cited from Dr. Robert Wilkinson (*Methodology for Analysis of the Energy Intensity of California's Water Systems*). SWP intensities are available at 15 different points; CVP intensities are only available at 6 different points.

2. Table A-4: This table documents default assumptions made by the model. These include assumed energy intensity for: imported water, groundwater, reclaimed water, seawater desalination, brackish water desalination, water treatment, water distribution, and

wastewater treatment. These values are defaults in the model and are more or less representative averages. The model developers strongly urge users to define more specific intensities for their region as opposed to relying on these default values. These default values were taken from various sources including Dr. Robert Wilkinson, the San Diego County Water Authority, the California Energy Commission, and several estimates by the model developers themselves.

WEAP (Water Evaluation and Planning System) User Guide
http://www.weap21.org

WEAP is software for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. Integrated approach to water development has emerged which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. WEAP places demand-side issues such as water use patterns, equipment efficiencies, re-use strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g., evapotranspirative demands, runoff, baseflow) and engineered components (e.g., reservoirs, groundwater pumping) of water systems, allowing the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. The result is an effective tool for examining alternative water development and management options.
WEAP operates on the basic principle of a water balance and can be applied to municipal and agricultural systems, a single watershed or complex transboundary river basin systems. Moreover, WEAP can simulate a broad range of natural and engineered components of these systems, including rainfall runoff, baseflow, and groundwater recharge from precipitation; sectoral demand analyses; water conservation; water rights and allocation priorities, reservoir operations; hydropower generation; pollution tracking and water quality; vulnerability assessments; and ecosystem requirements. A financial analysis module also allows the user to investigate cost-benefit comparisons for projects.

WEAP represents the system in terms of its various supply sources (e.g., rivers, creeks, groundwater, reservoirs, and desalination plants); withdrawal, transmission and wastewater treatment facilities; water demands; pollution generation; and ecosystem requirements. The data structure and level of detail can be easily customized to meet the requirements and data availability for a particular system and analysis.

WEAP could be applied to statewide system; however, the system would need to be simplified to accommodate the programmatic limits within WEAP. The level of effort to develop a WEAP application is significant and it is not recommended for Study 1. The WEAP model does not include energy.