Central Valley Drinking Water Policy Workgroup Synthesis Report

February 21, 2012

Executive Summary

This report documents and synthesizes the results of the technical studies conducted by the Central Valley Drinking Water Policy Workgroup (Workgroup) to support the development of a Central Valley Drinking Water Policy. The Workgroup is comprised of stakeholders who have worked closely with Central Valley Regional Water Quality Control Board (Central Valley Water Board) staff over the past nine years to address and evaluate issues of concern to drinking water agencies that derive their water supply from the Central Valley and Sacramento-San Joaquin Delta (Delta).

Drinking water agencies have long been concerned that water quality will deteriorate over time due to population growth in the Central Valley. These agencies have been concerned that deterioration in water quality could result in the need to upgrade drinking water treatment facilities, increased treatment costs, increase operational difficulties, and create other problems. Drinking water agencies are also interested in maintaining source water quality as the first barrier to contaminants that could endanger public health and because drinking water treatment requirements are increasingly based on the levels of constituents present in source water.

In July 2010, the Central Valley Water Board adopted Resolution No. R5-2010-0079 titled *Establishment of a Drinking Water Policy for the Sacramento-San Joaquin Delta and Upstream Tributaries*. The Resolution directed Central Valley Water Board staff to work with the Workgroup to develop an outline for the content of a proposed drinking water policy, and to develop a work plan and funding proposal for completion of that work. Staff was directed to complete this work in 2011 and to complete the Drinking Water Policy no later than 2013.

Early in the process for developing the Drinking Water Policy the Workgroup identified a list of prioritized water quality constituents of concern:

- Disinfection by-product precursors (DBP): organic carbon, bromide
- Dissolved minerals: total dissolved solids, salinity, conductivity
- Nutrients: nitrogen species (total, total Kjeldahl, organic, nitrate, nitrite, ammonia) and phosphorus species (total, orthophosphate)
- Pathogens and indicator organisms: *Giardia*, *Cryptosporidium*, total coliform, fecal coliform, *Enterococcus*, *E. coli*

Conceptual models for each of the prioritized constituents of concern were developed to gain an improved understanding of sources, transformations, transport processes, and associated impacts. These models are useful tools to identify data gaps as well as to direct future investigations and management practices. Recommendations drawn from these conceptual models can serve as a guide for more refined work to be completed later. After reviewing the conceptual models developed for the constituents of concern a more detailed analytical model was deemed necessary by the Workgroup to draw conclusions on sources and downstream effects.

The Workgroup identified three major loading sources of the prioritized water quality constituents of concern: publically owned treatment works (POTW), urban runoff, and irrigated agriculture. For the urban runoff and POTW source loading categories the Workgroup evaluated current loading regimes and also projected future scenarios for the year 2030. For agriculture current loading scenarios were evaluated but future scenarios included arbitrary reductions of loads rather than loading estimates based upon predicted changes in management practices or regulatory constraints. Cost estimates were developed for the implementation of the future scenarios for urban runoff and POTWs. Cost estimates were not developed for agriculture. The future scenarios projected the current regulatory climate forward to 2030 with modified land use and population (2030 Present), imposed a realistic projection of regulatory constraints (2030 Plausible), and projected ‘limit of technology’ regulatory requirements (2030 Outer Boundary). The source evaluations indicated that combined loads of drinking water constituents of concern from POTWs, urban runoff, and irrigated agriculture will likely decrease in the future as a result of changing land use and regulatory actions already taken by the Central Valley Water Board.

The future scenarios developed as part of the source evaluations were modeled numerically to evaluate the impact of changes in source loading on water quality at drinking water intakes. The numerical modeling effort included salinity, nutrients, and organic carbon. Pathogens were not quantitatively modeled. The modeling was undertaken using a combination of WARMF, DSM2, and CALSIM II. The WARMF, CALSIM II and DSM2 models were successfully linked to develop a comprehensive set of flow and water quality modeling tools for the watershed upstream of representative Central Valley and Delta drinking water intake locations. However, complications with initial runs of the upstream WARMF watershed models make quantification of the current version of DSM2 model results unreliable. Subsequent updated WARMF model runs have corrected some of the technical problems, but these results have not yet been used as DSM2 model boundary conditions and have not been reviewed by the Workgroup. The primary unresolved issue with the WARMF model is that it is simulating significantly less agricultural runoff in the Sacramento River watershed than was observed in historical data as a result of the coefficients used in the model, in particular the applied water rate.

Although the WARMF and DSM2 modeling results provided to the Drinking Water Policy Workgroup should not be used to quantitatively predict organic carbon concentrations at drinking water intakes, the source control scenarios that were evaluated indicate that organic carbon concentrations at drinking water intakes in the Sacramento River and the Delta will not likely increase in the future.

An evaluation of drinking water treatment facilities was conducted to determine the effects of a changing regulatory environment under future water quality conditions at water treatment plants that utilize surface waters from the Delta and Delta watersheds. The Water Treatment Plant Model can be used to predict the impacts of changing water quality conditions on treatment processes needed to comply with DBP and pathogen drinking water standards. It cannot be used to evaluate the impacts of nutrients and associated algal blooms on taste and odor and other operational problems.

Projected future changes in organic carbon concentrations were considered too small to be considered in the Water Treatment Plant Model. The model was therefore run with existing water quality conditions and with both existing drinking water regulations and plausible future drinking water regulations to determine if water treatment plant upgrades would be needed. The virtual water treatment plants were based on existing water treatment plants that were designed to meet all drinking water standards with existing water quality conditions. The MPI report identifies the changes in water quality conditions that would result in the need to upgrade water treatment plants. Those results are not included in this Workgroup Synthesis Report because the source control scenarios indicate that water quality will likely stay the same or improve slightly in the future.

In the plausible future regulatory scenario that evaluated more stringent future drinking water regulations, the model predicted that water treatment upgrades would be needed for water treatment plants treating water from the upper watershed (Sacramento River), the Delta, and at some locations along the California Aqueduct. The analysis did not consider future changes in water quality based on other sources of organic carbon (e.g. conversion of agricultural land in the Delta to tidal wetlands) nor did it consider changes caused by ongoing projects such as the Bay Delta Conservation Plan (BDCP).

The Workgroup has determined that sufficient information has been developed to proceed with the development of the Drinking Water Policy. There are other ongoing efforts to address some of the constituents of concern identified by the Workgroup. The Workgroup has deferred addressing salinity and nutrients to the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS) and Nutrient Numeric Endpoint projects. It is anticipated that this report will be used by the Central Valley Water Board to help formulate the Drinking Water Policy.

Section 1. Introduction and Background

This report documents and summarizes the history and accomplishments of the Central Valley Drinking Water Policy Workgroup (Workgroup). The Workgroup is comprised of stakeholders who have worked closely with Central Valley Regional Water Control Board (Central Valley Water Board) staff over the past nine years to address and evaluate issues of concern to drinking water agencies that derive their water supply from the Central Valley and Sacramento-San Joaquin Delta (Delta).

The Delta provides drinking water to more than 25 million people in the Southern California, Central Coast, and San Francisco Bay regions, and several million people obtain their water supply from the tributaries of the Delta. The tributaries of the Sacramento and San Joaquin Rivers that originate in the Cascades and Sierra Nevada Mountains generally have high quality water; however, as the tributaries flow into lower elevations, they are affected by urban, industrial, and agricultural land uses, natural processes, and a highly managed water supply system.

Drinking water agencies have long been concerned that water quality will deteriorate over time due to population growth in the Central Valley. These agencies have been concerned that deterioration in water quality could result in the need to upgrade drinking water treatment facilities, increased treatment costs, operational difficulties, and other problems. Drinking water agencies are also interested in maintaining source water quality as the first barrier to contaminants that could endanger public health and because drinking water treatment requirements are increasingly based on the levels of constituents present in source water. As part of the Basin Plan Triennial review process, these agencies, in 1998, asked the Central Valley Water Board to develop a drinking water policy to provide additional protection for drinking water uses.

In August 2000, CALFED issued the Record of Decision (ROD) for the Programmatic Environmental Impact Statement/Environmental Impact Report, which required the California Bay-Delta Authority (CBDA), with the assistance of the Department of Public Health, to establish a drinking water policy for the Delta and upstream tributaries by 2004.

In a May 2002 Implementation Memorandum of Understanding for the CALFED Drinking Water Quality Program, the Central Valley Water Board, in consultation with California Department of Public Health (DPH), State Water Resources Control Board (State Water Board) and United States Environmental Protection Agency (USEPA), was given primary responsibility for development of a State drinking water policy for the Delta and its tributaries.

The Workgroup was formed to provide a stakeholder-based platform for development of the Drinking Water Policy. In 2003, California Urban Water Agencies (CUWA) and Sacramento Regional County Sanitation District (SRCSD) entered into a contract to reimburse Central Valley Water Board staff costs for one half of a staff person per year to lead the Workgroup in the development of the Drinking Water Policy. This contract has been amended several times to provide funding assistance for the Workgroup effort.

In July, 2004, the Central Valley Water Board adopted Resolution No. R5-2004-0091 which formally recognized that it would not meet the completion date specified in the CALFED ROD, but communicated the Board's continued support for development of a comprehensive drinking water policy.

The Central Valley Water Board released a Scoping Document in July 2008 seeking input from interested parties regarding alternative regulatory approaches to improve protection of drinking water uses. The document described the existing regulatory objectives and policies that are in place in the Basin Plan and outlined several alternative directions that a drinking water policy may take in the future, including adoption of new water quality objectives and increased point and non-point source regulation to maintain or improve source water quality, increased monitoring with no additional regulation of sources, or no action. A premise in the scoping document was that population increases would lead to water quality degradation and increased risks to public health. This premise was the subject of evaluation in the technical studies that have been performed by the Workgroup. A complete timeline of work performed by the Workgroup is presented in Appendix 1.

In July 2010, the Central Valley Water Board adopted Resolution No. R5-2010-0079 titled *Establishment of a Drinking Water Policy for the Sacramento-San Joaquin Delta and Upstream Tributaries*. This Resolution was adopted as a means of documenting progress to date and to set deadlines for completion of future work needed in the development of a Central Valley Drinking Water Policy. The Resolution stated that

> "The degree of treatment for drinking water required by state and federal regulations depends on the quality of source water for certain parameters."

Those parameters are organic carbon, bromide, and pathogens. Salt and nutrients are also a concern to drinking water agencies.

The 2010 Resolution also stated that there is

> "Considerable concern that population growth in the Central Valley could impact the high quality of [drinking water] source water. Drinking water purveyors are concerned about future treatment requirements and increased costs for treatment."

The Resolution identified the need for development and refinement of analytical water quality and watershed models.

> "The models would predict how constituents of concern move from their sources to the drinking water intakes, under present and projected future conditions, accounting for different treatment options, management practice application and population growth."

The Resolution recommended that the focus of the Workgroup, in terms of Drinking Water Policy development, should be on organic carbon and pathogens (*Cryptosporidium* and *Giardia*). This recommendation was made because there are ongoing regulatory efforts underway to address salts and nutrients. The Central Valley Water Board is leading the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS), a stakeholder-based effort to develop solutions for salinity and nitrate problems in the Central Valley. The State Water Board is leading the nutrient numeric endpoints (NNE) effort to regulate nutrient levels in various waters of the State. The Central Valley Water Board directed staff to coordinate with these ongoing efforts.

Central Valley Water Board staff was directed to work with the Workgroup to develop an outline for the content of a proposed drinking water policy, and to develop a work plan and funding proposal for completion of that work. Staff was directed to complete this work in 2011 and to complete the drinking water policy no later than 2013.

PURPOSE OF THIS REPORT

The purpose of this report is to provide the Central Valley Water Board and other interested parties with a concise summary of the important findings and recommendations developed to date by the Workgroup. It is anticipated that this report will be used by the Central Valley Water Board to help formulate the Drinking Water Policy.

HISTORY OF WORKGROUP PROCESS

Initial efforts to address drinking water agency concerns regarding source water quality commenced in the 1990's. Since the beginning, the major concerns have focused on the potential effects on public health associated with increased levels of organic carbon, bromide and pathogens. The concerns have also focused on the impacts of these constituents, salt, and nutrients on drinking water treatment operations and costs. As noted above, an ongoing concern has existed that water quality in the Delta watershed will degrade over time due to population growth and urbanization of the Central Valley.

After several attempts, the current Workgroup was created in 2002. Key participants in the Workgroup formation were the Central Valley Water Board, CUWA, SRCSD, California Bay-Delta Authority, and the Department of Health Services (now the Department of Public Health). A number of other stakeholders have been heavily involved in the Workgroup process, including:

- Central Valley Clean Water Association
- California Rice Commission
- Northern California Water Association
- USEPA
- City of Sacramento Storm Water Quality Improvement Program
- County of Sacramento Storm Water Quality Program
- City of Vacaville
- California Department of Water Resources

An early step by the Workgroup was to develop a technical work plan, which included a description of technical tasks to be completed, a budget and a schedule. The technical work plan, titled *Work Plan, Development of Drinking Water Policy, Central Valley Region Basin Plan*, was finalized in January 2003 and has been used by the Workgroup throughout the process to guide its activities.

The 2003 technical work plan included the following tasks which were described as necessary to support the development of a drinking water policy: (a) identification of constituents of concern, (b) examination of regulatory goals, objectives and programs for those constituents in other areas of California, the United States and other countries, (c) water quality and watershed modeling, including both conceptual and analytical modeling to link source control measures to changes in ambient water quality, (d) identification of water quality monitoring needed to fill important data gaps, (e) description of potential source control measures, effectiveness and costs, and (f) an evaluation of drinking water treatment and cost associated with existing and future Delta water quality. The primary focus in the formulation of the work plan was to develop information that would be needed to support new numeric or narrative water quality objectives for drinking water constituents of concern should the determination be made that such new objectives were necessary.

In the early stages of work plan implementation, the Workgroup received assistance from USEPA, who provided funding assistance to a contractor (Tetra Tech) for development of conceptual models for organic carbon, pathogens and nutrients. The California Bay-Delta Authority developed a conceptual model for salinity for the Workgroup. These conceptual models, which identified and summarized available information regarding ambient levels, source loadings, fate and transport considerations, and effects for each of the constituents of concern were completed in 2007 and are posted on the Central Valley Water Board's website.

In 2004, CUWA, acting on behalf of the Workgroup, received a Proposition 50 grant that was used to fund technical studies that were scoped by the Workgroup to fulfill the intent of the 2003 work plan. A total of $970,000 was received under the grant. Using this funding, the Workgroup hired several contractors to complete specific tasks under the work plan, as follows:

- Brown and Caldwell — Database Development
- Starr Consulting — Water Quality Goals and Objectives Review
- Malcolm Pirnie — Drinking Water Treatment and Cost Evaluation
- West Yost Associates — Wastewater Effluent Source Control Evaluation
- GeoSyntec — Urban Runoff Source Control Evaluation
- NewFields — Agricultural Source Control evaluation and land use assessment
- Systech — Watershed modeling for San Joaquin and Sacramento River basins
- Resource Management Associates — Water quality modeling of Delta using DSM2

Work on these specific tasks was interrupted in December 2008 by a stop work order issued by the Governor on all proposition funded projects. Work was restarted in December 2009 but then halted again in March 2010.

Later In 2010, the Workgroup and its contractors resumed work under a compressed time schedule. Work by all contractors was completed in the spring of 2011. This Workgroup report describes the results of these studies and recommends further work, including continued refinement and use of the modeling tools developed by the Workgroup.

Section 2. Constituents of Concern

Early on in the drinking water policy development process, the Workgroup recognized that it would be important to focus on a workable number of priority water quality constituents of concern, so the Workgroup initiated a process to identify and prioritize constituents on which to focus future drinking water policy work (i.e., conceptual models, source control evaluations, etc.). The Workgroup developed an initial list of constituents of interest, and developed an inventory of existing water quality databases, water quality reports, sanitary surveys, discharger reports, and other information sources for the initial list of constituents (Larry Walker Associates, 2004). This inventory was used to inform the Workgroup evaluation of the availability of water quality data for the constituents of interest.

The initial list of constituents was evaluated through three tiers of evaluation criteria to develop the prioritized list. The three tiers of evaluation criteria included the following:

- The Workgroup assessed each constituent for presence at drinking water intake locations and if that occurrence is at concentrations that pose a public health or aesthetic concern for drinking water;
- The Workgroup then used the data inventory report to determine if available data for the list of tier 1 constituents was sufficient both temporally and spatially to support drinking water policy technical work. The Workgroup also consolidated the constituents into categories of constituents where it made sense to do so.
- Finally, the Workgroup reviewed the tier 2 list to determine if Basin Plan objectives already exist, and if so, whether the objectives are adequate to protect drinking water supplies. The constituents for which no adequate Basin Plan objectives exist were included on the tier 3 list of constituents.

The Workgroup documented the constituents of concern prioritization in a technical memo (Larsen, 2005). Table 2 in the technical memo summarizes how the tier 2 and 3 criteria were applied to the tier 1 list of constituents. Through this process the Workgroup identified the following prioritized list of constituents:

- Disinfection by-product precursors: organic carbon, bromide
- Dissolved minerals: total dissolved solids, salinity, conductivity
- Nutrients: nitrogen species (total, total Kjeldahl, organic, nitrate, nitrite, ammonia) and phosphorus species (total, orthophosphate)
- Pathogens and indicator organisms: *Giardia*, *Cryptosporidium*, total coliform, fecal coliform, *Enterococcus*, *E. coli*

EVALUATION OF WATER QUALITY GOALS

Task 7 of the 2003 technical work plan called for the identification of a range of potential water quality goals and policy elements for the priority constituents of concern. The Evaluation of Drinking Water Quality Goals work products prepared by Starr Consulting are organized as a series of technical memoranda and a summary table.

Technical Memo No. 1 (Starr Consulting, 2007a) includes a review of procedures used by the California Office of Environmental Health Hazard Assessment (OEHHA) and the California Department of Health Services (now known as the California Department of Public Health) to protect drinking water quality. The memo also includes a summary of the basis for the targets established by CALFED Bay-Delta Program for total organic carbon and bromide. The purpose of developing this information was to identify the process and risk evaluation procedures used by state agencies to develop public health goals, drinking water standards, recycled water criteria and water quality planning targets.

Technical Memo No. 2 (Starr Consulting, 2007b) includes a review of the U.S. Environmental Protection Agency (USEPA) procedures and guidance for establishing ambient water quality criteria for the protection of drinking water supplies, and a review of existing USEPA water quality criteria for nutrients, bacteria and dissolved solids. The memo also includes a review of the USEPA methodology used to establish source water quality concentrations of organic carbon in the Stage 1 Disinfectants/Disinfection Byproducts Rule (D/DBR) and *Cryptosporidium* in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) that trigger additional treatment at water treatment plants.

Technical Memo No. 3 (Starr Consulting, 2007c) includes a review of the water quality protection policies for other states and selected countries to determine if there are examples of adopted ambient water quality criteria, objectives, or goals for the Workgroup drinking water constituents of interest, or adopted policies to protect drinking water supplies.

Technical Memo No. 4 (Starr Consulting, 2007d) includes a review of each of the Water Quality Control Plans (Basin Plans) prepared by the nine Regional Water Boards to determine if any of the Regional Water Boards have adopted, or are planning to adopt, numerical or narrative objectives for the constituents of concern, and to better understand how the drinking water beneficial use is designated in each Region.

The final work product for this task was a summary table (Starr Consulting, 2007e). The table provides a summary of the key information found related to the drinking water quality goals research conducted for the Workgroup. For the disinfection by-product precursors, a couple of examples were noted. The Santa Ana Regional Board is developing a total organic carbon (TOC) objective related to groundwater recharge and the California Department of Public Health (DPH) is developing a groundwater recharge reuse regulation that includes limits for TOC in recharge water. The Province of British Columbia in Canada has also developed guidelines for TOC and bromide for water sources used as drinking water supplies. For the dissolved minerals constituents, most Regional Water Boards and USEPA have established water quality objectives to protect drinking water beneficial use based on the secondary maximum contaminant levels.

Some Regional Water Boards and other states do not allow discharges to increase the salinity of the source water, which in some cases results in the implementation of site-specific objectives. For nutrients, protection of drinking water beneficial use is largely addressed through the nitrate and nitrite drinking water standards and narrative objectives for biostimulatory substances. For pathogens and indicator organisms, no examples of water quality objectives were identified for pathogens, however, water quality criteria/objectives were identified for several indicator organisms for the protection of drinking water and body contact recreation beneficial uses. More detailed information is provided in the four technical memos described earlier. It should be noted that the technical memos were prepared for the Workgroup in 2007 and only reflect information available at that time. The Summary Table is included as Appendix 2.

Overall, these work products were informative for the Workgroup because they provided detailed information regarding how the priority constituents of concern are currently being addressed in water quality and drinking water regulations of other Regional Water Boards, other states, and in a few countries. However, the project resulted in the identification of few examples where agencies were developing numeric water quality objectives for the constituents of concern to the Workgroup to protect the drinking water beneficial use.

Section 3. Conceptual Models

CONCEPTUAL MODELS

Conceptual models of various constituents of concern were developed to gain an improved understanding of sources, transformations, transport processes and associated impacts. Conceptual models synthesize available data and describe key processes of constituent fate and transport with structured relationships and mass balances. These models are useful tools to identify data gaps as well as to direct future investigations and management practices. The conceptual models presented in this section provide a preliminary analysis based on data available at the time of their development. Recommendations drawn from these conceptual models serve as a guide for more refined work to be completed later. Analytical models, presented in Section 5, provide more detailed estimates of water quality concentrations and loadings, but require significantly more effort to develop input data and the modeling framework. Summaries of the conceptual model studies are discussed in this section for the drinking water constituents of concern as identified by the Workgroup (pathogens and pathogen indicators, nutrients, organic carbon, and salinity.)

PATHOGENS AND PATHOGEN INDICATORS

The Conceptual Model for Pathogens and Pathogen Indicators in the Central Valley and Sacramento-San Joaquin Delta study (Tetra Tech, 2007) assessed sources and spatial trends of pathogen and pathogen indicators in the Central Valley and Delta.

The study area covered 43,300 square miles encompassing the Sacramento and San Joaquin watersheds and the Delta. Water quality data for fecal indicators such as total coliform, fecal coliform, *Escherichia coli* (*E. coli*) and pathogens such as *Cryptosporidium* and *Giardia*, was compiled from the Drinking Water Policy Workgroup (2004-2005) database, Natomas East Main Drainage Canal (NEMDC) Studies, North

Bay Aqueduct Sampling, and the United State Geological Survey (USGS) National Water Information System (NWIS).

The Tetra Tech study synthesized a large amount of data; however, rapid die-off rates and low detection of pathogens prevented a detailed quantification. The quantitative analysis was not as extensive as the analysis that was performed with the organic carbon and nutrient conceptual model studies (see sections below). Though coliform were the most prolific data-type, the rapid die-off rates make coliform an indicator of local sources but a less reliable indicator of watershed sources with longer transport times. Some agricultural discharges, runoff from urban land, wastewater effluent discharges, and terrestrial wildlife (except aquatic wildlife which was not quantified) were all considered as potential sources.

No correlation was found between coliform concentrations and flow rate, though most high concentrations were observed in wet months indicating a potentially important contribution from storm water. High coliform and *E. coli* concentrations were observed in waters affected by urban and agricultural runoff, wastewater treatment plant effluent was not found to be a significant coliform source. Levels of coliform were also high in wetland areas, probably due to aquatic wildlife activity. The Lower Sacramento River had low pathogen levels (equivalent to levels produced by excretion from one calf).

Data for true pathogenic organisms was available primarily for *Cryptosporidium* and *Giardia* along the Sacramento River. Where monitored, concentrations were generally very low, and when detected counts were typically less than one organism per liter. These relatively low detection rates could be due to natural and/or artificial barriers as well as analytical method limitations.

Despite the limitations of coliform as a pathogen indicator, the study recommended continued coliform monitoring to maintain historical consistency while evaluating new analysis techniques such as molecular and immunological methods versus traditional culture methods. The study also cautioned that large-scale modeling of pathogens and pathogen indicators may not be appropriate due to data limitations. Characterization of fecal coliform loading from small watershed and surface water areas would allow for more accurate characterization and modeling of fecal coliform loading.

Another key recommendation of this study is to gather additional data on *Cryptosporidium, Giardia,* and other pathogens, including bacteria and viruses. The study recommended monitoring of the Sacramento and San Joaquin rivers and potential sources such as urban runoff and wastewater effluent as well as Delta intakes.

NUTRIENTS

The objective of the nutrient study (Nutrient Conceptual Model, Tetra Tech, 2006a) was to evaluate sources, transformation processes and transport of nitrogen and phosphorous in the Central Valley.

This study area encompassed 43,300 square miles over the Sacramento and San Joaquin watersheds and the Delta, which were divided into 22 sub watershed areas. Most data was from the main stem of the Sacramento and San Joaquin rivers, with limited data on tributaries and upper portions of the watersheds. Flow data was obtained via the USGS National Water Information System, and the California

Department of Water Resources (DWR) model DAYFLOW. Water quality data for nitrogen and phosphorous concentrations was obtained from a database of constituents compiled by the Drinking Water Policy Workgroup in 2004-2005, the Municipal Water Quality Investigations (MWQI) program, USGS and the United States Environmental Protection Agency (EPA). CDF-Fire Resource Assessment Program provided land-use data. Data from in-delta nutrient sources, reservoir sources, upstream tributaries, and land use data used to calculate export rates was limited and not well quantified

This study evaluated total nitrogen and total phosphorus average concentrations and distribution over time, average loads over time for each watershed, and differences in loading rates between wet seasons and dry seasons. Contributions from different land use types were also estimated for both wet and dry water year types. Ambient water concentrations were estimated via averaged time-series data at various river and stream sampling locations. Loads were calculated by multiplying average monthly concentration data by average monthly flow data, which were then summed to obtain seasonal or annual loads. The total nutrient load contribution from each watershed was assumed to be the sum of land uses weighted by export rates (mass or organic carbon per unit area per year). Though data were limited and estimates from the study are considered preliminary, the loads based on export rates compared favorably with stream loads at key locations such as the Sacramento River at Hood/Greenes Landing and the San Joaquin River at Vernalis

Based on the study data, levels of nutrients in portions of the Sacramento and San Joaquin Rivers and the Delta were determined to be high enough to cause eutrophic conditions. In general, the San Joaquin River exhibited higher nutrient concentrations than the Sacramento River, though the greater flows in the Sacramento River watershed yielded Sacramento River nutrient loads that were greater than San Joaquin loads by a factor of two. San Joaquin nutrient concentrations (nitrogen and phosphorous) did not exhibit seasonal variability. Sacramento River nitrogen loads varied seasonally, with higher concentrations in the wet months. However, Sacramento phosphorus loads did not exhibit seasonal trends.

The nutrient conceptual model indicated that, based on estimated export rates, key nitrogen sources appeared to be from forest/rangeland and wastewater effluent (Sacramento Basin) and agriculture (San Joaquin Basin). Key phosphorus sources were forest/rangeland and wastewater effluent (Sacramento Basin) and wastewater effluent (San Joaquin Basin). Wastewater effluent appeared to be an important source in dry years (Sacramento and San Joaquin), accounting for a significant portion of the total nutrient loads, and possibly in wet years in the San Joaquin Basin. In-Delta loads were generally small compared to tributary loads. Nutrient loads in water diversions were not determined to vary annually. Increasing developed land, population and the resulting increases in wastewater effluent and urban runoff discharges were factors expected to have the biggest impact on nutrient levels.

The study recommended additional data collection and targeted monitoring to improve estimates of export rates, up-stream tributary data, in-Delta sources of nutrients, and loads from urban runoff, wastewater effluent, fish hatcheries and upstream reservoirs. Targeted monitoring of small indicator watersheds could be an effective way to improve estimates of export rates for different land uses.

ORGANIC CARBON

The objectives of the organic carbon study (Organic Carbon Conceptual Model, Tetra Tech, 2006b) were to identify data needed to better understand sources of organic carbon, to evaluate the relationship between drinking water and ecosystem concerns, and to recommend measures that could result in improved control of organic carbon in the Central Valley watersheds.

This study included the same area as the pathogens and nutrients study (see previous sections for details) encompassing the Sacramento and San Joaquin watersheds. Most data was from the main stem of the Sacramento and San Joaquin rivers, with limited data on tributaries, upper portions of the watersheds and reservoir releases. Flow data was obtained via the USGS NWIS, and the DWR model DAYFLOW. Water quality data was obtained from a database compiled by the Drinking Water Policy Workgroup in 2004-2005, the MWQI program, the USGS and EPA. CDF-FRAP provided land-use information.

The conceptual model for organic carbon was constructed in much the same way as the nutrient conceptual model with concentrations estimated via averaged time-series data at various sampling locations and loads calculated by multiplying average monthly concentration data by average monthly flow data, which were then summed to obtain seasonal or annual loads. The total organic carbon load contribution from each watershed was assumed to be the sum of land uses weighted by export rates (mass or organic carbon per unit area per year), although data was too limited to provide useful estimates of export rates for all but a few locations. The loads based on export rates compared favorably with stream loads at key locations such as the Sacramento River at Hood/Greenes Landing and the San Joaquin River at Vernalis.

Based on the conceptual model, organic carbon concentrations were determined to fluctuate due to seasonal and annual climatic variation. Anthropogenic sources such as agricultural drainage were determined to have the most impact in dry and critically dry years. Concentrations in the San Joaquin watershed were generally higher than the Sacramento watershed, but as with nutrient loading, the higher flows yielded higher organic carbon loads in the Sacramento River. In wet years, loads from the Sacramento River were greater than San Joaquin loads by a factor of two. In dry years, the San Joaquin River load was only slightly lower than the Sacramento River load. In the Sacramento River basin, most of the organic carbon load came from the upper forested portions of the watershed due to the high flows generated in the upper watershed. Agricultural land generated most of the organic carbon load in the San Joaquin River basin. In-Delta organic carbon loads were less than tributary loads, and represent a lower percentage of total source loading of organic carbon in wet years than in dry years.

This study identified several data gaps and recommended solutions to improve the conceptual models. The limited data on export rates for each land use could be improved through focused flow and concentration data collection in small, relatively homogeneous watersheds. Additional recommended data collection included quantification of reservoir exports, improved quantification of wastewater sources, improved cataloging of data from existing monitoring projects, and continued monitoring of Delta Island and tidal marsh inputs. Future modeling efforts should consider the dry and critically dry years, as well as the effects of restoration in the Delta tidal wetlands, changes in standards for disinfection byproducts, additional regulated compounds, and effects of levee failures.

SALINITY

The objectives of the salinity study (Harader, 2006) were to evaluate the sources of salinity in the Central Valley water supply, to identify locations in the watershed where salinity data was lacking and to recommend measures that could result in improvements to water quality related to a reduction in salinity.

The study area covered the Sacramento and San Joaquin watersheds, and the Delta. Flow and salinity data (EC and TDS measurements) were obtained from DWR sampling locations via the California Data Exchange Center (CDEC). Some pre-1975 salinity data was available, though data was heavily weighted toward the period 1975 to the present. Salinity data was widely available for the Delta and San Joaquin areas but limited for the Sacramento watershed. Additional data was extracted from a database compiled by the Drinking Water Policy Workgroup in 2004-2005.

Hydrology (precipitation and stream flow), water operations (e.g. reservoir releases), hydrodynamics (e.g. channels, levees), and watershed sources (e.g. irrigation, wastewater effluent and industrial discharges) were incorporated into the conceptual model of salinity movement to the intake pumps in the Delta. Daily average values of salinity were computed and evaluated over time.

Salinity was determined to vary seasonally and from year-to-year, with lowest salinity concentrations occurring during high flow as in the winter seasons and wet years. In dry years, water operations and hydrodynamics were determined to be dominant controls on salinity concentrations. The conceptual model indicated that key watershed sources of salinity at the Delta intake pumps include 1) salinity derived from seawater and 2) salinity due to mobilization of naturally occurring minerals in the San Joaquin watershed from agricultural and wetlands drainage. Point-source discharges from wastewater treatment plants and industrial sources did not appear to be key salinity sources.

Additional data collection at upper San Joaquin tributaries was recommended by the study along with continued monitoring of wastewater effluent and industrial point-source discharges. Watershed management recommendations to reduce salinity and improve water quality at the intake pumps include reducing tidal pumping of seawater into the Delta at crucial times (i.e. low-flow), reducing irrigation in the San Joaquin watershed, and separating high quality flows from low-quality flow through conveyances such as the Delta Cross Channel and temporary barriers.

WORKGROUP INTERPRETATIONS AND CONCLUSIONS ON CONCEPTUAL MODELS

Key conclusions from the conceptual models on sources and trends of the constituents of concern are outlined below:

- **Pathogens and Pathogen Indicators** – Limited available data prevented a full watershed-scale quantitative analysis of sources and transport, but qualitative analysis indicated that wastewater effluent, and urban, agricultural and wetlands runoff are likely sources of pathogens and fecal indicator loads. Actual pathogen data were more limited to the Sacramento River, where detection was infrequent although there were analytical limitations.
- **Nutrients** – Greater runoff volumes produce nutrient loads in the Sacramento River that were greater than San Joaquin River loads by a factor of two, even though concentrations were generally greater in the San Joaquin watershed. In all years key nutrient sources include forest/rangeland and wastewater effluent (Sacramento watershed) and agricultural runoff and wastewater effluent (San Joaquin watershed). Wastewater effluent contributed a significant fraction of nutrient loads to the Sacramento and San Joaquin watersheds in dry years.
- **Organic Carbon** – As with nutrients, the Sacramento River yielded the larger organic carbon load by comparison, while the San Joaquin watershed generally has higher concentrations by comparison. Organic carbon varied seasonally and year-to-year, with the most impact from anthropogenic activities occurring in dry years.
- **Salinity –** Primary sources of salinity in the Central Valley were derived from seawater mixing into the Delta as well as agricultural and wetlands drainage in the San Joaquin watershed. Salinity varies seasonally and year-to-year. In dry years, water operations and hydrodynamics (reservoir releases, diversions) have significant impacts on salinity levels.
- **Need for Analytical Modeling –** The Workgroup developed conceptual models to understand system interactions and to identify types of sources. A more detailed analytical model was deemed necessary by the Workgroup to draw conclusions on sources and downstream effects.

WORKGROUP IDENTIFIED FUTURE USES FOR CONCEPTUAL MODELS

By identifying constituent sources, watershed management decisions targeting those key sources can be evaluated to determine the ability to more effectively manage drinking water quality in the Central Valley. For example, the conceptual models indicate that management tools utilized in urban development and growth may help to manage nutrient levels whereas measures such as reducing tidal pumping of seawater into the Delta at crucial times, reducing irrigation in the San Joaquin watershed, and separating high quality flows from low-quality flow through conveyances would be most effective in managing salinity levels.

The results of the conceptual models can be used to improve future analyses. For example, future analyses should address dry and critically dry years, which are especially important constituents, such as organic carbon and salinity, with sources that vary year-to-year.

In the course of these studies, key data gaps and conceptual model improvements were identified. For example, the creation of large watershed-scale conceptual models was found to be inadequate for modeling of pathogens and pathogen indicators due to data limitations. Targeted monitoring of small watersheds and surface waters was proposed as an alternative to aid in creation of more refined pathogen models and also as a means to improve the land use export rates for organic carbon and nutrients. All constituent conceptual models could benefit from additional upstream tributary and reservoir monitoring programs.

Section 4. Source Control Evaluations

PUBLICALLY OWNED TREATMENT WORKS EFFLUENT

Overview of Approach

The DWP Workgroup commissioned a publically owned treatment works (POTW) Study (West Yost Associates, 2011) to evaluate the current and predicted 2030 loads for drinking water constituents of concern that are discharged by POTWs within the Sacramento River, San Joaquin River and tributary watersheds to the Sacramento San Joaquin River Delta. The Study identified population increases projected through 2030, compiled POTW information, developed alternative regulatory scenarios and treatment levels, and estimated loads, changes in loads, and costs to upgrade wastewater treatment plants under different regulatory scenarios.

POTW Compilation

The loading and cost estimates presented in the POTW Study were for “major” dischargers (i.e., average dry weather flow ≥ 1 million gallon per day or MGD.) In addition, all POTWs that discharge within the legal boundary of the Delta were included regardless of ADWF. The major POTWs (43 of the identified total of 62 POTWs) comprise 98.6% of the total wastewater effluent flow discharged to surface waters in the Sacramento-San Joaquin River watersheds. Information compiled for each of the major POTWs included agency and facility name, receiving water name, current facility treatment level and disinfection process, planned/mandated facility treatment level and disinfection process, estimated service area population, current permitted ADWF, recent ADWF, and available data describing average effluent concentrations for constituents of concern. Much of this information was obtained from current NPDES permits and/or monitoring data collected by the discharger. Not all data used in the report was reviewed by each POTW.

Projected 2030 Scenario Development

Projected discharges in 2030 considered anticipated growth of the POTW service areas, treatment that is required to meet current regulatory requirements, and both planned and possible treatment scenarios that may be required to meet possible future regulations. The analysis effectively “bookended” a range of future conditions from existing treatment levels to outer boundary levels of advanced treatment. The Study was not intended to describe specific elements of a Drinking Water Policy, but rather was a means to develop information on potential reductions in loads of key drinking water constituents and the estimated costs associated with those load reductions.

Projected growth rates were determined for each POTW sphere of influence using Department of Finance (DOF) historic population data, the US Census Bureau, NPDES permits, General Plans, Development Plans, and other readily available local documents.

Several flow reduction scenarios were incorporated to encompass former Governor Schwarzenegger's 2008 initiative to "achieve a 20% reduction in per capita water use statewide by 2020." While most of these reductions are likely to be seen in irrigation, some reductions in flow to POTWs are expected. Therefore, four flow reduction scenarios were considered due to conservation efforts, reflecting 0%, 2%, 5%, and 10% flow reductions. These reductions were not incorporated into the 2030 constituent load predictions, because a reduction in flow due to future water conservation efforts would likely not translate into corresponding load reductions.

In the POTW Study, the major POTWs were categorized into five treatment levels for evaluation defined as:

Treatment Level a: Secondary Treatment (includes POTWs with pond treatment systems);

Treatment Level b: Secondary Treatment with nitrification (includes POTWs with data demonstrating that complete nitrification is occurring; partial denitrification may also be occurring);

Treatment Level c: Tertiary Treatment (POTWs with filtration facilities in addition to secondary treatment. May or may not include POTWs with advanced disinfection facilities.);

Treatment Level d: Tertiary Treatment with nitrification (includes POTWs with data demonstrating that complete nitrification is occurring; partial denitrification may also be occurring); and

Treatment Level e: Tertiary Treatment with nitrification and denitrification (NDN).

The following three control strategy scenarios were evaluated for the major POTWs.

2030 Planned Changes - The Planned Changes scenario includes mandated improvements that were required under NPDES permits by the end of 2010. Current NPDES permits include requirements stemming from State and Federal water quality-related policies which necessitated the construction and operation of treatment processes such as tertiary filtration, UV disinfection, nitrification and denitrification for compliance.

2030 Plausible – The Plausible scenario includes 2030 Planned Changes for mandated requirements plus enhanced biological nutrient removal, followed by chemical phosphorus removal with tertiary clarification, tertiary filtration (if not currently mandated) and ultraviolet (UV) disinfection (if not currently mandated). This scenario focuses on providing the highest level of nutrient removal using currently available technologies and advanced (full Title 22) UV disinfection, but does not include microfiltration or reverse osmosis. Enhanced biological nutrient removal includes two primary components: biological nitrogen removal and enhanced biological phosphorus removal. While the effectiveness of phosphorus removal purely by chemical addition is not always consistent, chemical addition followed by two-stage filtration has been demonstrated to consistently achieve phosphorus levels of less than 0.1 mg/L (USEPA, 2010). Filtration will also reduce total organic carbon, another constituent of concern, and will likely provide reductions in effluent concentrations of other priority pollutants, such as metals and organic compounds that are adsorbed to solid particles in wastewater effluent. UV disinfection was identified due to the concern that *Cryptosporidium* oocysts are resistant to chlorine disinfection, as well as the potential for harmful chlorine disinfection byproducts.

2030 Outer Boundary - The Outer Boundary scenario adds microfiltration and reverse osmosis (MF/RO) and advanced UV disinfection treatment, if not already part of 2030 Planned Changes. MF/RO are physical treatment processes that involve the use of membranes to separate constituents from the wastewater. MF filters have a pore size around 0.1 to 10 microns and can remove many particles, but cannot remove monovalent ions such as salts, ammonium and nitrate. However, it is necessary to provide MF filters with a pore size of 5 microns or less as a pre-treatment step ahead of RO. RO membrane filters have a pore size around 0.0001 microns. After wastewater passes through RO filters, it is essentially pure water. Disposal of the brine from RO is a concern, and an expensive consideration. Studies have concluded that zero liquid discharge (ZLD), where the brine waste is disposed of within the plant boundary and/or at a landfill site, may be the only option for the majority of major inland POTWs. While the 2030 Plausible scenario includes advanced nutrient removal, MF/RO removes additional nutrients.

Load Reductions

Concentrations and loadings for the 2030 Planned Changes scenario were estimated using actual effluent quality for the major POTWs, in most cases and where available. Otherwise literature-based values were assumed. For the 2030 Plausible and 2030 Outer Boundary scenarios, published literature was reviewed to develop typical values for average effluent concentrations of TOC, TDS, nitrogen species, and total phosphorus. The resultant reductions in loading for each scenario and each discharge area are illustrated in Table 1 below for TOC, total nitrogen, total phosphorus, ammonia, TDS, and nitrate as nitrogen. The loads developed in this study were used as inputs to the WARMF analytical model for the Sacramento and San Joaquin basins and as inputs to DSM2 for the Delta. The analytical modeling results are described later in this report.

The loads of TOC and nutrients (with the exception of nitrate and nitrite) are expected to decrease by 2030 as a result of the upgrades that are planned for several of the major POTWs. The observed increases in nitrate between the current 2010 and planned 2030 scenarios are reflective of the future addition of nitrification (conversion of ammonia nitrogen to nitrate nitrogen) at some facilities. Although it is also anticipated that denitrification (conversion of nitrate to nitrogen gas) will occur at some facilities, the conversion of nitrate is typically less complete, resulting in a net increase in nitrate loads in effluent.

Table 1: Current and Projected Average Daily Discharge Loads for Existing Major POTW Dischargers, pounds per day (based on WYA 2011, Tables 11 through 13)

	POTW Estimated Discharge Load (lb/day)						
	TOC	**Total Phosphorus as P**	**Total Nitrogen as N**	**Ammonia**	**Nitrate as N**	**Nitrite as N**	**TDS**
2010	47,800	7,200	57,500	29,320	15,400	270	1,350,000
2030 Planned	37,300	6,100	51,000	6,650	33,400	380	2,050,000
2030 Plausible	21,200	220	12,700	1,240	6,300	380	2,050,000
2030 Outer Boundary	1,230	14	7,700	740	5,900	380	170,000

Note: Considers all POTWs > 1MGD in the Sacramento and San Joaquin River watersheds and the Delta.

Cost Estimates

Cost estimates for the Plausible and Outer Boundary scenarios were prepared as part of the Study (Table 2). Costs were generalized, not specific to treatment plant locations, and are considered Class 5 estimates per the Association for the Advancement of Cost Engineering International (AACE). Class 5 estimates are generally prepared based on limited information and subsequently have wide accuracy ranges. Typical Class 5 estimates range from -20 to -50% up to +30 to +100% (AACE, 2005). In developing the cost estimates, it was necessary to identify which components needed to be added at each POTW so that previously mandated upgrades were not included in the cost estimate. The basis for the cost estimates included the process component, the Engineering New Record Construction Cost Index applicable to the project, the capacity for each component (either ADWF or peak flow), and an economy of scale "power factor" applicable to each process component. The cost estimates summarized below in Table 2 are the totals for all discharge areas (Sacramento Basin, San Joaquin Basin, Delta, Eastern Delta Tributary, and Northern Delta Tributary) and/or all treatment levels. Estimates provided in the full study report also include the breakdown for each of the five discharge areas and five levels of treatment.

Table 2: Cost Estimates for 2030 Plausible and 2030 Outer Boundary Scenarios after Previously Mandated Upgrades (based on WYA 2011, Tables 16 and 17)

	Estimated Construction Costs, $ million				Estimated Capital Costs, $ million		Capital Cost per Gallon ADWF, $/gallon	Annual O&M Costs, $M	O&M Cost per Gallon Treated, $/MG
	Nutrient Removal	**Title 22 Filtration**	**UV Disinfection**	**Total Construction Cost**	**Capital Cost Allowances**	**Total Project Capital Costs**			
2030 Plausible	880	65	130	1,080	700	1,800	3.6	95	526
2030 Outer Boundary	1,900[1]	3,700 [2]	130	5,900	3,800	9,600	19.2	400	2,216

Notes: [1] includes microfiltration; [2] includes reverse osmosis

The cost estimates developed in the Study focused on the costs of constructing, operating, and maintaining new treatment processes. Potential additional costs not included in the analysis could include expansion of power distribution systems, additional flow equalization storage and/or associated odor control, issues specific to MF/RO cost estimating, pH adjustment and re-mineralization, and laboratory, maintenance and administrative facilities.

Workgroup Conclusions and Wastewater Effluent Study Interpretations

A robust assessment of Central Valley POTWs was performed in this study, covering more than 98% of the effluent flow volume to the Delta and upstream tributaries. Changes to minor dischargers were not considered because they would have a negligible effect on Delta water quality.

The POTW Study is limited to developing source quantification and projected "bookend" regulatory and treatment loading scenarios from major POTWs in the Central Valley watersheds and Delta. These loading scenarios are intended as model inputs for WARMF modeling of the Sacramento River and San Joaquin River watersheds to 'I' Street and Vernalis, respectively and within the DSM2 modeling of the Delta, which also uses WARMF outputs as boundary conditions at these locations. The planning level loading and cost scenarios should not be used outside of this intended use.

POTWs contribute a portion of the overall organic carbon, phosphorus, nitrogen and ammonia loadings to the Delta. Using the WARMF and DSM2 models allows interpretation of the effect of wastewater effluent loads on ambient water quality in comparison to other loads such as natural, agriculture, and urban runoff in the Sacramento and San Joaquin Rivers and the Delta.

In recent years, the Central Valley Water Board has mandated more advanced treatment at many of the POTWs in the watershed. This will result in a reduction in TOC, total P, and total N loads discharged to the Delta watershed by 2030 despite population growth in the watershed, as illustrated in Table 1. This is a significant finding because one of the major concerns expressed by drinking water agencies at the inception of this effort was that population growth in the watershed would result in substantially higher loads of constituents of concern discharged by POTWs.

As described in the Analytical Modeling section, the results of the Wastewater Effluent Study can be used to make a quantitative assessment of the cost of a range of POTW upgrades and the resulting downstream water quality and drinking water supply benefit. The Study can be used as a basis for flow and concentration inputs into both the WARMF and DSM2 models for 2030 projections of water quality changes over a range of current and future treatment scenarios.

Workgroup Recommendations for Future Wastewater Effluent Evaluations

There are several issues that the Study did not examine that could be considered in more detail in future studies:

- The Study did not forecast water reuse changes in 2030. Additional wastewater effluent reuse would directly reduce loads of constituents discharged to surface waters. Future analyses could examine reuse feasibility and cost effectiveness and impacts to water quality.

- The impacts of water conservation on future flows and loads could be evaluated to determine if wastewater effluent loads are substantially reduced due to water conservation efforts.
- The Study did not examine the increasing preference for surface drinking water sources over groundwater sources in the Central Valley. While this may marginally decrease net downstream flows, it might also result in changes to salinity loads.
- Portions of a number of the NPDES permits issued to POTWs in recent years have been appealed by the permitees and other interested parties. This Study assumed permit conditions as of the end of 2010. Future analyses could evaluate 2030 projected loads of constituents of concern if these permit conditions are not maintained.

URBAN RUNOFF

The DWP Workgroup commissioned a Study (Geosyntec Consultants, 2011) to evaluate the current and predicted 2030 urban runoff loads of drinking water constituents of concern discharged to surface waters within the Sacramento River and San Joaquin River tributary watersheds. The Urban Runoff Study evaluated projected urban land area changes, compiled urban runoff source information on drinking water constituents of concern, projected regulatory scenarios, compiled urban runoff control measures and best management practice performance characteristics, and estimated costs of the regulatory scenarios.

Source Identification

The Urban Runoff Study examined available literature to summarize previously identified sources and pathways. Sources are activities that introduce constituents into the environment, whereas pathways refer to the means by which constituents are mobilized and transported from a source to the surface water.

Urban sources of organic carbon include soil disturbance and erosion, leaf and plant litter, fecal matter pollution from pet wastes, leaks from failing septic systems, combined and separated sewer overflows, atmospheric deposition of combustion related emissions, and spills of oil and gasoline. Urban sources of nutrients include landscaping fertilization, septic system leaks, combined system outflows, animal wastes and atmospheric deposition associated with fuel combustion or industrial emissions. Sediment and plant matter may also contain nitrogen and phosphorus sources.

Urban sources of dissolved solids or salts include dissolution of naturally occurring salts in soil and rock (CVRWQCB, 2008a). Land application of fertilizers and urban irrigation runoff also introduce salts that may reach surface waters. Other applied compounds contribute to salt loading.

Urban sources of pathogens (bacteria, viruses, and protozoa) include domestic animals, wildlife, septic systems, combined sewer overflows, illicit sewer connections, creekside homeless encampments, illegal RV discharges, and leaky sanitary sewer systems. The Urban Runoff Study summarized available drinking water constituents of concern characterization data for urban runoff from the Sacramento Stormwater Quality Partnership and the National Stormwater Quality Database land use summaries for data from Alabama, Arizona, California, Colorado, Georgia, Kansas, Kentucky, Massachusetts, Maryland, Minnesota, North Carolina, Oregon, Pennsylvania, Tennessee, Texas, and Virginia When compared to the data in the national database, Sacramento organic carbon medians were substantially lower, nutrients and salts medians were slightly higher and fecal indicator bacteria (FIB) medians were substantially higher.

Treatment and Control Approaches Identified

Municipal separate storm sewer systems (MS4) programs include different types of control strategies including development standards for new or retrofit construction; source control through public awareness or use restrictions; and constructed controls or best management practices (BMP) such as runoff retention, biofiltration, and treatment controls. The Urban Runoff Study focused on retention and biofiltration constructed controls, as there are more performance data for these facilities. Treatment controls were also included in some future scenarios for industrial facilities. Non-structural control programs (e.g. public outreach, waste minimization, etc.) were not considered for future conditions.

Research suggests that effluent quality rather than percent removal is a more reliable indicator of BMP performance for modeling (Strecker, et. al., 2001). Generally, percent removal in a BMP is higher with increased BMP inlet concentrations, and in some cases there is a minimum achievable concentration (Schueler 2004; Minton 2005). The Study summarized various BMP median values from the International Stormwater Best Management Practices (ISW BMP) Database.

Filtration systems such as media filters are the most effective at removing organic carbon (media effluent total organic carbon is 7.6 mg/L). Retention ponds, detention ponds, and biofilters (swales) provide a medium level of treatment with effluent TOC ranging from 10 to 12 mg/L. The least effective BMPs for TOC treatment are wetland basins where plant material can contribute to effluent TOC.

Filtration including media filters, bioretention, and biofilters are the most effective BMPs for removing nutrients. The median total nitrogen effluent concentrations for these BMPs range from 0.5 to 0.8 mg/L. Detention basins and retention ponds (wet ponds) are less effective with media total nitrogen concentrations that range from 1.2 mg/L to 1.7 mg/L. Phosphorus tends to associate with particulates so BMPs that rely on settling or filtration tend to perform better. The median effluent quality for media filters and retention (wet) ponds are in the range of 0.06 to 0.08 mg/L, whereas biofilters (swales) exhibit a median concentration of 0.320 mg/L.

There are no traditional BMPs that reduce salinity concentrations. However, low impact development (LID) measures that infiltrate runoff on site or otherwise reduce urban runoff discharge volumes are effective in reducing surface water loads of all constituents.

The ISW BMP Database does not include BMP effluent information on protozoa or viruses, but does include considerable data for fecal indicator bacteria.

Filtration/infiltration unit processes such as retention ponds, media filters and bioretention BMPs are the most effective at removing fecal indicator bacteria. Media filters are the most effective at removing fecal coliform (150 MPN/100 mL median), followed by detention basins (465 MPN/100 mL median) and biofilters (2,300 MPN/100 mL median).

There are additional cases of advanced or active treatment whereby traditional wastewater treatment is applied to urban runoff through a diversion of runoff to the sanitary sewer or localized treatment facilities. The most recent Construction General Permit includes a provision requiring high risk construction sites to implement active treatment for the term of construction activity, and the City of Santa Monica constructed a 0.5 MGD dry weather runoff treatment and reuse facility that includes screening, dissolved air flotation, degritting, microfiltration, and ultraviolet disinfection.

Projected Regulatory Scenarios

The Urban Runoff Study included development of potential future regulatory scenarios to guide a range of future conditions and provide bookends on potential future water quality changes. The regulatory "forecasting" included a summary of current MS4, Federal, and general permit requirements known as the "planned changes" scenario, and then proposed a "probable" and "outer bound" scenario as summarized in Table 3. These scenarios include assumptions for dry weather flow reduction through water conservation, BMP design storm size, on site retention, treatment standards, retrofitting requirements and numeric effluent limitations (NELs) for nutrients. The dry weather flow reduction assumptions are significant for those constituents which are more concentrated during dry weather and assume that urban landscape irrigation practices can provide the reductions ranging from 20% to 60%. However, it should be noted that many of the bioretention BMPs include landscaping that requires summertime irrigation, increasing water use and the potential for dry weather urban runoff. The outer bound scenario is the only scenario that includes retrofit of existing sites (industrial facilities).

Projected Urban Land Area

Land use types are a key input to WARMF modeling as wet weather urban runoff and applied water is routed through the soil and soil surface systems to streams and rivers. WARMF land use mapping databases were developed as part of the Study for the Sacramento and San Joaquin basins, but not for the in-Delta areas that were modeled by DSM2. Regional planning map data were obtained for the Sacramento (SACOG, 2010) and San Joaquin (Harnish 2010) valleys that project expected land uses in 2050. These data were then scaled to 2030 based on interpolation of the Farmland Mapping and Monitoring Program historical data published by the California Department of Conservation. The Urban Runoff Study projected an increase in urban area of 50% by 2030 as shown in Table 4.

Table 3: Comparison of the 2030 Regulatory Scenarios (Source: Geosyntec 2011, Table 4-2)

Regulatory Program	Regulatory Requirement	Regulatory Scenario		
		Planned Changes	*Probable Scenario*	*Outer Boundary Scenario*
New Development	Dry weather flow reduction	20% reduction	40% reduction	60% reduction
	BMP design storm event standard	85th percentile storm event	85th percentile storm event	95th percentile storm event
	On-site retention of runoff from design storm event	Assumed applicable on 5% (Sac) and 10% (SJV) of area	Assumed applicable on 10% (Sac) and 25% (SJV) of area	Assumed applicable on 20% (Sac) and 50% (SJV) of area
	Treatment Standard	MEP	MEP	MEP
Retrofitting	Industrial Permit requires retrofitting to meet best available technology economically achievable (BAT) and best control technology (BCT) criteria	None	None	Implement BMPs on existing industrial areas to BAT/BCT (assume phased implementation such that 20% of industrial land use retrofitted by 2030)
NELs	NELs for nutrients in San Joaquin Valley (SJV)	None	TN = 2 mg/L TP = 0.2 mg/L (SJV only)	TN = 1 mg/L TP = 0.1 mg/L (SJV only)

Table 4: Projected 2030 Increase in Urban Land Uses in Central Valley (Source: Geosyntec 2011, Table 5-1)

Land Use	Sacramento Valley (Acres)[1]		San Joaquin Valley (Acres)[2]		Total (Acres)	
	Existing	*Projected Increase*	*Existing*	*Projected Increase*	*Existing*	*Projected Increase*
Residential	302,041	173,460	102,272	82,141	40,4314	255,601
Commercial	57,217	70,860	27,470	14,232	84,687	85,092
Industrial	42,507	31,621	15,803	6,029	58,310	37,649
Paved Areas	21,379	495	3,533	-	24,912	495
Landscape/Open Space	208,001	75,317	64,529	-	272,529	75,317
Total	**631,145**	**351,752**	**213,607**	**102,402**	**844,752**	**454,155**

References:

[1] Sacramento Council of Governments (2010) include Sacramento, El Dorado, Placer, Sutter, Yuba, Yolo counties.

[2] Council of Governments in San Joaquin Valley includes eight counties in San Joaquin County (Harnish, 2010). Note that the WARMF model domain only includes that portion of the San Joaquin Valley upstream of Lander Avenue Bridge in Turlock and in that portion, the projected increase in urban land uses by 2030 used in the WARMF model was approximately 40,000 acres.

Future Scenario Implementation

The Urban Runoff Study provided the WARMF modeler with calibration targets (flows and concentrations) for existing conditions and a simulated deployment of control measures in the new urban areas, dry weather runoff flow reductions, and retrofit deployment in the outer bound scenario only. For the San Joaquin River urban drainage area, nutrient NELs were imposed under the probable and outer bound scenarios.

Load Reductions

Changes in urban runoff loading were calculated by the WARMF model and were not presented as part of the Urban Runoff Study. With the projected 50% increase in urban area between 2011 and 2030, it would be expected that urban loadings would increase. However, the area of projected urban growth was offset by decreases in natural land cover and agricultural areas that can have higher per acre loadings of organic carbon, nutrients and total dissolved solids (FIB were not examined in the WARMF model) than urban areas. Net decreases in loads were predicted in the WARMF modeling.

Cost Estimates

The Urban Runoff Study estimated costs for implementation of the regulatory scenarios based on guidance from the Water Environment Research Foundation (WERF, 2009). The guidance provides spreadsheets for planning level costs. The Study based costs on an assumed mix of representative BMPs including curb-contained bioretention, rain gardens, and retention ponds. The centralized retention basin BMP is most cost-effective per acre, but is not suitable for all locations (e.g., small and dense developments) and is not considered low impact development because it does not necessarily reduce runoff volumes on site. The cost estimating does not include consideration of the infrastructure costs necessary to convey runoff from the source to retention ponds. LID BMPs are distributed throughout the service area and require fewer to no conveyance structures. Table 5 summarizes the unit costs for construction of the assumed BMPs. Table 6 summarizes the estimated costs of BMP implementation for future scenarios. These cost estimates are intended as a range of future possible conditions and do not specifically address compliance with a water quality objective.

Table 5: Summary of Estimated Unit Costs for Selected New Development and Redevelopment BMPs in Study Area (Source: Geosyntec 2011, Table 6-4)

BMP Type	Drainage Area (acres)	Capital Cost	Maintenance Costs[1] (Annual)	Total Cost[2] (present value)	Cost/Acre (present value)
Rain Garden	0.25 acres	$8,930	$300	$18,000	$72,100
Curb-Contained Bioretention	1	$64,500	2700	$114,000	$114,000
Retention Pond	500	$3,170,000	$6,600	$3,340,000	$6,680

Note:
[1] Maintenance costs include routine annual costs and non-routine non-annual maintenance costs that have been annualized in this table.
[2] Total costs are present value 2011 dollars based on assumed 50 year design life and 3% discount rate.

Table 6: Cost Summary for Urban Runoff Control Measures Applied Across Study Urban Area (taken from Geosyntec 2011, Table 6-11)

BMP Type	Cost Estimate (Wet Weather)	Cost Estimate (Dry Weather)	Total Cost
Planned Changes	$12,000,000,000	$547,000,000	$12,500,000,000
Probable	$13,700,000,000	$1,200,000,000	$14,900,000,000
Outer Boundary	$17,100,000,000	$1,900,000,000	$19,000,000,000

Workgroup Conclusions and Urban Runoff Study Interpretations

The Urban Runoff Study developed land use, regulatory, implementation, and cost scenarios to provide a range of possible urban runoff water quality and implementation cost conditions in 2030. The Study did not quantify the benefit of the control measures in the form of water quality changes. Benefits from these measures will need to be derived from loading assessments or downstream water quality monitoring. The Workgroup provided the following additional considerations and interpretations of the Study:

- The Urban Runoff Study was limited to developing source quantification and projected "bookend" regulatory and source control scenarios in the Central Valley watersheds. These scenarios are intended as model inputs for WARMF modeling of the Sacramento River and San Joaquin River watersheds to 'I' Street and Vernalis, respectively and within the DSM2 modeling of the Delta, which uses WARMF outputs as boundary conditions at these locations. The planning level water quality and cost scenarios should not be used outside of this intended application without considering and disclosing the context and intended scope of the Study.
- Approximately 450,000 acres of new urbanization was projected in the modeled tributary area by 2030. Urban loads would be expected to increase with the projected 50% increase in urban area between 2011 and 2030. However, the area of projected urban growth was offset by decreases in natural land cover and agricultural areas that can have higher per acre loadings of organic carbon, nutrients and total dissolved solids than urban areas; fecal indicator bacteria (FIB) were not examined in the WARMF model. In this way net decreases in loads were predicted in the WARMF modeling. This is a significant finding because one of the major concerns expressed by drinking water agencies at the inception of this effort was that population growth in the watershed would result in substantially higher loads of constituents of concern due to urban runoff.
- There are limited data on the effectiveness of urban runoff BMPs in removing drinking water constituents of concern. Information is needed on the effectiveness of BMPs being installed in the Central Valley. Previous analyses of the National Stormwater Quality Database indicate that geographical location and land use are the most important factors affecting most constituent concentrations[1]. Data from the ISW BMP Database indicate that filtration systems are most effective at removing organic carbon and nutrients. Wetland basins may actually contribute organic carbon due to plant material generated in the basins. The BMP database does not contain information on removal of protozoa or viruses but there is substantial information that filtration systems are effective at reducing fecal indicator bacteria.

1 Storm Water Panel Recommendations to the California State Water Resources Control Board. *The Feasibility of Numeric Effluent Limits Applicable to Discharges of Storm Water Associated with Municipal, Industrial and Construction Activities*. Page 6. June 19, 2006 .
<http://waterboards.ca.gov/water_issues/programs/stormwater/docs/numeric/swpanel_final_report.pdf>

- The control measures examined in the Urban Runoff Study primarily apply to areas of new development (i.e., growth) and only the outer boundary scenario includes implementation of BMPs at industrial facilities in older development.
- The Urban Runoff Study assumes water use reductions in new development will result in equivalent dry weather runoff reductions for each of the future scenarios. However, there are no local studies that confirm this relationship. Furthermore, existing urban areas were not considered with regard to water conservation and runoff reductions.

Workgroup Recommendations for Future Urban Runoff Evaluations

There are several areas that could be addressed in future studies:

- Information is needed on the removal of drinking water constituents of concern by BMPs that are being implemented in the Central Valley.
- Additional study of water conservation and implementation of irrigation control in existing areas, through retrofit, should be evaluated to quantify the load removal benefit.
- A more detailed examination of the sources of organic carbon in urban runoff, including the relative percentages of types of organic carbon, is necessary to better identify sources.

AGRICULTURE

Overview of Approach

The DWP Workgroup commissioned a study (NewFields, 2011) of agricultural sources of constituents of concern (Ag Study) within the Sacramento River, San Joaquin River and tributary watersheds to the Sacramento-San Joaquin Delta.

The Ag Study was comprised of the following components as inputs to the WARMF model:

- Development of land cover maps for all land-based source categories.
- Estimation of modal irrigation, fertilization, impervious surface, and crop removal model input parameters for each class.

Due to resource and time limitations, the following aspects of agricultural sources were not investigated, but rather deferred pending additional future funding opportunities:

- Inventory of potentially influential management practices, along with estimates of their costs and influence on specific water quality constituents.
- Inventory of existing applications of potentially influential management practices and their performance.
- Additional sensitivity analysis and prioritization of possible model parameter refinements.
- Further refinement of elements developed in the Ag Study, which might be based on additional sensitivity analysis and prioritization.

As previously described, the Ag Study was judged to be a helpful step and component of the larger set of studies performed by the Workgroup to provide a basis for the Drinking Water Policy. Future refinement and expansion of the work was understood to be deferred during this phase, and potentially developed as part of later phases, as necessary.

Source Identification

The Ag Study examined available literature to summarize potential land-based sources of the drinking water constituents of concern into surface waters. Specifically, agricultural and other land cover classes were developed, and the following assigned to each class:

- Proportions of impervious and irrigated surfaces
- Applied water
- Applied ammonium, nitrate, and other salts
- Removed biomass and nitrogen

Thirty one land cover classes were mapped on the 12.3 million acres of study area landscapes based on data from DWR, the National Land Cover Database (NLCD), Central Valley Water Board's Diary WDRs, and SACOG. Mapping was hierarchical, as follows:

- DWR mapping was used first. The period mapped for counties within the study area varied but reflected the most recent available data from this source.
- NLCD data were used to fill in non-agricultural, non-urban/commercial areas with greater detail.
- Data from Dairy General Waste Discharge Requirement program (DWDRs) were used to identify lands and loading rates for dairies and areas receiving dairy waste.
- SACOG and UC Davis data were used to overlay more detailed information regarding urban/commercial land areas and their expansion during the study period.
- As urban/commercial areas expanded, agricultural and other rural lands were replaced.

The result is probably the most thorough data set yet developed to represent land cover parameters affecting water quality in this region. In conjunction with state-of-the-art modeling tools, these input data served as an excellent starting point to analyze the influence of land cover patterns on raw drinking water quality.

Additional refinements in land cover data are possible. As with other parts of the modeling effort, the best method to identify high-value refinements is to study the sensitivity of the model to individual parameters, and to focus effort on parameters with the greatest influence on key model outputs.

Aspects of land cover that are not reflected in the current land cover input data, primarily due to lack of available resources (source data sets, time, and/or budget) include the following:

- Projections of other future changes in non-urban/commercial land use patterns were unavailable and are not reflected. That is, land use model inputs for these areas are static throughout the study period). The Ag Study reminds us that real agricultural landscapes evolve over time in response to various factors, such as markets, technology, climate, and regulation. An exception is that removal of agricultural land cover due to urban land cover expansion is reflected in the current land cover input data set.
- Storage and land application of other animal waste (beef cattle, poultry, swine, sheep, and dairy solids) is not quantified or located spatially. To the extent that these materials are applied as fertilizer at agronomic rates, or exported in some form from the watershed, they are accounted for fully in land cover class nitrate and ammonium application rates. Applications in excess of this amount would not be reflected. Taking Stanislaus County as one extreme, according to the Ag Study, each of these sources (except for sheep) is estimated to produce more nitrogen than dairy.
- Year-to-year dynamics of land cover changes that occur in all classes of land use are not represented. The best agricultural examples are crop rotation or other changes (such as installation of new permanent crops).
- Types of irrigation systems on agricultural lands are not mapped. Different irrigation systems result in differing surface and subsurface hydrologic conditions, and thus can influence water quality.
- Field-to-field differences in management (e.g., cultural practices, irrigation scheduling, fertilizer application rates), crop yield, and (on non-agricultural lands) impervious surfaces and plant communities are not represented. The estimated parameters reflect an estimated, modal condition for each class. Exceptions to this are the variable nitrogen rates for dairy manure land application fields. These were derived from ratios of herd size to land application acreage, as reported in response to the DWDRs.
- Evaluation of the accuracy of specific analytical (e.g., modeling) processes in reflecting the fate and transport of specific constituents in agricultural portions of the landscape and hydrologic system is not represented.

Treatment and Control Approaches Identified

As mentioned previously, specific agricultural management practices were explicitly excluded from the Ag Study, and were deferred for potential inclusion during future efforts, as needed.

Projected Regulatory Scenarios

The influence of existing and planned regulatory programs on agricultural water quality was generally considered, including the following:

- Irrigated Lands Regulatory Program
- Long-term Irrigated Lands Regulatory Program
- DWDRs
- Rice Pesticide Program
- CV-SALTS

Projected Agricultural Land Area

The projected 50% increase in urban area (Table 4) results in a reduction of agricultural and other rural land area, since these lands are generally the sites of urban development. This is one of the reasons that agricultural sources decline in the future. Land cover and regulatory assumptions dictate that on a unit-land-area basis, constituent loads from agriculture should not increase, and may in some cases decrease.

Future Scenario Implementation and Load Reductions

Study of management practices that would be necessary to project future land cover parameters from agricultural land cover classes was deferred. However, the Workgroup desired to examine, as part of the modeling effort, sensitivity to potential load reductions from these areas. Although no specific agricultural BMP implementation was incorporated into modeling assumptions, it was assumed that 2%, 6%, and 10% reductions in loading of nitrogen, phosphorus, and organic carbon would reasonably capture the sensitivity of surface water quality to agricultural load reductions. To implement these reductions in WARMF simulations, the Future Planned, Plausible, and Outer Boundary simulations respectively included reductions in ammonia, nitrate, phosphate, and organic carbon concentrations of 2%, 6%, and 10%. Irrigation rate and field hydrology were unchanged. The reductions were only applied to agricultural land cover classes (orchards, row crops, rice, vineyards, farmsteads, fallow land, confined animal feeding operations, and dairies).

Cost Estimates

As previously discussed, cost estimates were explicitly excluded from the Ag Study, and deferred to future phases of similar work, as may prove necessary.

Workgroup Conclusions and Agricultural Study Interpretations

At the time the Ag Study was completed, modeling was well under way. As modeling was completed, calibrations suggested that some parameter inputs ought to be reviewed and refined, notably applied irrigation water and fertilizer. In areas where land cover (crop type) data are old, they should be updated with newer data as it becomes available. If such reviews emerge as priorities from this phase of the work, they can be taken up during later phases. This type of dynamic interchange is normal during model calibration.

Although land cover data extend into the Delta region, model representation of in-Delta agriculture differs from areas outside the Delta. This is because WARMF has been employed to model hydrology outside of the Delta, and DSM2 was employed within the

Delta. As tools for considering agricultural sources interior to the Delta evolve, the influence of in-Delta agricultural sources will be accounted for more accurately.

The Ag Study developed land cover, regulatory, and load sensitivity scenarios to represent a range of possible agricultural conditions throughout the study period. Specific management practices' cost and efficacy were not part of these scenarios. As such, no cost-to-benefit analysis of agricultural management practices can be performed without additional work. Additional considerations for interpretation of DWPTWG work to date relative to policy and future efforts are as follows:

- The Ag Study provides the best set of land cover input data yet to characterize the influence of agricultural and other land cover on water quality in the study area.
- The current conditions analyzed in this modeling effort reflect (contain) historic, voluntary reductions in pollutant loads due to past changes in crop and water management, including improved efficiency in agrochemical use, by agriculture. Based on anticipated future land cover and regulatory conditions, constituent loads from agriculture will likely decline. These declines are not explicitly estimated for use as model inputs. Rather, this general trend is represented by hypothetical load reduction percentages as discussed previously (in the preceding "Future Scenario Implementation and Load Reductions" section).
- Despite the quality of the modeling and inputs, this is a planning level water quality study. Results indicate ranges of future conditions, and are most helpful when interpreted at a regional scale. Field- and crop-specific interpretations, while potentially helpful for calibration, are not otherwise appropriate, given the scale and nature of input data.

Workgroup Recommendations for Future Agricultural Evaluations

There are several issues that could be considered in future studies:

- Review and refine applied irrigation water and fertilizer inputs for the WARMF model.
- Prioritize future work, and focus on efforts that will meet identified analytical needs to answer key questions related to the Drinking Water Policy.
- Refine agricultural and other land cover input parameters according to priorities that emerge from calibration and sensitivity analysis.
- Inventory and characterize agricultural BMPs as necessary, including:
  - cost and efficacy in reducing load and concentration of constituents of concern
  - locations where BMPs currently exist
  - criteria to guide location and timing of future implementation
  - potential synergies or conflicts among BMPs

Section 5. Analytical Models

Analytical modeling refers to numerical modeling performed by the Workgroup to quantify numerical changes in ambient water quality for future (2030) scenarios of urban development and treatment and source control. The modeling quantifies ambient concentrations of organic carbon, nutrients, and salt. Pathogens and fecal indicator bacteria were not considered in the analytical modeling. The output of the analytical modeling is used to assess the impact of changes on drinking water supply and water treatment requirements. The analytical models build on the Workgroup conceptual modeling and data compilation, and can also be used to identify data gaps, guide monitoring programs and provide information to other efforts such as CV-SALTS.

The Delta and the Delta watersheds up to controlled reservoir locations were modeled using the Delta Simulation Model (DSM2) and the Watershed Analysis Risk Management Framework (WARMF). DSM2 models hydraulic and particle tracking of the tidal Delta system, models transformation and cycling of nutrients, uses the Delta Island Consumptive Use (DICU) model and receives input at its boundary conditions from WARMF at the Sacramento River at 'I' Street, the San Joaquin River at Vernalis, other east Delta rivers and control points at the San Francisco Bay "interface".

The analytical models were calibrated to historic observed conditions based on current (2010) land use conditions, historical flow and water quality data, and historical point source flow and water quality data, where available. Projected 2030 conditions were developed in separate source control efforts for POTWs, municipal separate storm sewer systems (MS4) and agriculture. Future scenarios were developed on planned, plausible and outer boundary conditions to reflect a range of future conditions.

The DSM2 modeling did not consider land use changes within the Delta area as was done with the larger WARMF modeling domain. WARMF outputs were not fully developed until after they were provided to the DSM2 modeler resulting in unreliable analytical results that can be corrected with additional model runs. The WARMF model in the Sacramento River was found to underestimate agricultural return flows in some areas and was not completely calibrated during the period covered by this report. Continued improvement of the models is expected to incorporate additional calibration, new input data and improved model components as they become available to the Workgroup and other water quality planning initiatives with available resources.

WARMF MODELING

WARMF is a GIS based watershed public domain model. WARMF is compatible with other watershed models contained in the EPA "Better Assessment Science Integrating point & Non-point Sources" **(**BASINS) framework. WARMF simulates the watershed processes to calculate hydrology and nonpoint source loads of pollutants from various land uses (urban, native vegetation types, and agricultural areas). The input data includes climatic conditions, the locations of agricultural diversions, daily diversions, and amount of irrigation water applied to the agriculture lands. The model simulates percolation of irrigation water through soil, evapotranspiration of water through crops, change of groundwater table, agricultural return flow, and groundwater accretion to the river reaches. The model also simulates the nonpoint loads of pollutants due to fertilizer applications, leaching of cations and anions from the soil, and erosion of soils from land.

The San Joaquin WARMF model was developed for the Stockton Deep Water Ship Channel DO TMDL. Additional work in the San Joaquin River watershed was performed for CV-SALTS and the US Bureau of Reclamation for the Westside Salt Assessment project. The Sacramento River WARMF model was developed for the Central Valley

Drinking Water Policy Project with grant funding from the State Water Resources Control Board. Recently, the State Water Contractors funded development of the WARMF model for the eastside streams that drain to the Delta. The models for the Sacramento and San Joaquin rivers and the eastside streams were rerun and recalibrated for the Drinking Water Policy Project in 2011 with additional land use updates, including higher resolution land use data (i.e., additional land use classifications including crop covers). The land use information was developed by another Workgroup contractor (NewFields, 2011).

The WARMF model interfaces with the Delta DSM2 model, providing upstream Delta boundary conditions. The Sacramento River boundary is at the I Street Bridge in downtown Sacramento, which is upstream of the discharge from the Sacramento Regional Wastewater Treatment Plant. There is also a boundary at Lisbon for the Yolo Bypass. The boundaries for the Cosumnes and Mokelumne Rivers are just upstream of where the two rivers meet. The boundary for the Calaveras River is where it meets the San Joaquin River in Stockton. The other model boundary is the San Joaquin River at Vernalis, which is downstream of the San Joaquin's major tributary inflows but upstream of where the river becomes tidally influenced.

Calibration

The WARMF calibration was performed throughout the two watersheds and east side tributary watersheds as described in the two final technical memoranda (Systech Water resources, 2011a, 2011b). Calibration in WARMF assesses both the hydrologic components (flow) and water quality concentrations compared to historic observed concentrations. The WARMF modeler identified data calibration issues affecting the Sacramento River watershed that could not be resolved by refining applied water parameters, as mentioned in the earlier "Agriculture" section, and by employing available calibration tools. In separate communication[2], the modeler has stated that these calibration issues are the most important source of error in the Sacramento River and that the San Joaquin River does not have the same issue with "under-simulation". The modeler also stated that calibration of model inputs would improve nutrient simulation in both watersheds.

Results

The sensitivity analysis (Systech Water Resources, 2011c) primarily examined the differences in model outputs between the projected scenarios. The range of scenarios included variation in many individual model inputs rather than an examination of isolated input changes. This approach accurately reflects the physical nature of the range of management regimes described in the scenario, but is not designed to test specific assumptions regarding control strategies (such as implementation of a specific BMP).

Appendix 3 summarizes loadings of TOC, nitrogen, phosphorus and salinity at the WARMF surface water boundary locations (to DSM2) for each future scenario. Loading is tracked back from the source, accounting for chemical reactions, settling, re-suspension, and diversions which may have attenuated concentrations during transport

[2] Herr, Joel, Systech. Email communication to Brian Laurenson, Larry Walker Associates. June 21, 2011

from sources to the Delta intakes. The resulting downstream load is often markedly different from the sum of loading to surface waters throughout the watershed because of these processes.

As discussed previously, additional data are needed to fully calibrate the WARMF model. Therefore the reported (Appendix 3) load reductions between scenarios should be viewed as general indicators of the effectiveness of the source controls in the projected 2030 scenarios. The WARMF output at I Street reflects the quality of water at drinking water intakes in the lower Sacramento River. Due to the WARMF calibration issue, specific projections of the magnitude of future water quality constituent concentrations cannot be made. The WARMF results do provide reasonably reliable indications of the direction of changes in source loads between the evaluated scenarios.

The quality and quantity of flows from WARMF were the boundary conditions for the DSM2 modeling of the Delta. In-Delta sources (some portion of the Sacramento urban area and the Sacramento Regional County Sanitation District discharge) are considered in WARMF, but are downstream from the DSM2 boundary. The WARMF results for the downstream location on the Sacramento River at Morrison Creek include these urban inputs, and are included in Appendix 3 for comparative purposes.

The WARMF modeler developed outputs to match the location, data period and time step duration to develop usable DSM2 model inputs using CALSIM II (Systech Water Resources, 2011d). CALSIM II performs simulations of the State Water Project and Central Valley Project operations using the Water Resource Integrated Modeling System model engine.

The WARMF-CALSIM II linkage is ideal for simulating changes in external time series inputs to the watershed, not necessarily limited to CALSIM outputs. This includes reservoir management scenarios, future conditions, and climate change. Using the CALSIM linkage can also be used to make WARMF compatible with the Delta DSM2 model, which also uses CALSIM for its model inputs. When using the linkage, inputs from CALSIM must also be compatible with other WARMF model inputs, especially land use and diversion flows. Using the linkage with monthly CALSIM output results in a loss of temporal resolution, but the resulting WARMF simulations are informative when their outputs are compared against other simulations also using the linkage. The comparison between historical and CALSIM linked simulation demonstrated in this document are useful for evaluating the effect of the CALSIM assumptions on WARMF simulation results. Caution should be used when comparing historical simulations with CALSIM linked simulations for any other reason besides assessing the effect of the linkage itself.

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DSM2 MODELING

DSM2 is a one-dimensional (1-D) hydrodynamic and water quality simulation model used to represent conditions in the Sacramento-San Joaquin Delta. The model was developed by the Department of Water Resources (DWR) and is frequently used to model impacts associated with projects in the Delta, such as changes in exports, diversions, or channel geometries associated with dredging in Delta channels. DSM2 contains three separate modules, a hydrodynamic module (HYDRO), a water quality module (QUAL), and a particle tracking module (PTM).

The Delta area and waterways downstream of the WARMF boundaries were modeled using DSM2 (Resource Management Associates, 2011), which includes both DICU and CALSIM II model input components. The objective of the modeling is to examine comparative results (i.e., differences between future 2030 scenarios) rather than absolute results.

DICU values are applied by the modeler on a monthly average basis and are derived from monthly DSM2 input values calculated by the DICU model (DWR, 1995, 2002). DICU flows incorporate channel depletions, infiltration, evaporation, and precipitation, as well as Delta island agricultural use. There are three components to DICU flows – diversions, drains and seeps. The total monthly diversions incorporate agricultural use, evaporation and precipitation, drains incorporate agricultural returns, and seeps incorporate channel depletions. These flows are distributed to multiple elements throughout the Delta. Similarly, the concentrations of DOC and EC in agricultural return flows, called drain flows in DSM2, are applied on a monthly average basis, using the same monthly averages in every year. Nutrient concentrations in agricultural returns and the temperature of these flows are applied as constants. For the future scenarios, the DSM2 modeler used the projected 2030 future scenarios for POTW point sources, but did project changes in land use for 2030 within the modeled Delta area due to budget and schedule constraints.

WARMF development was performed in parallel with DSM2 modeling; inputs at the interface points were provided from the WARMF model and used in DSM2 before they were completely vetted for model performance issues. Issues with the WARMF-provided input files were corrected, as reflected in the WARMF reports, but only after the DSM2 modeling was completed. The DSM2 modeler reported that water quality concentration results from these DSM2 runs had resulting errors, but that the proof-of-concept was successful.

WORKGROUP CONCLUSIONS AND MODEL INTERPRETATIONS

The WARMF, CALSIM II and DSM2 models were successfully linked to develop a comprehensive set of flow and water quality modeling tools for the watershed upstream of representative Central Valley and Delta drinking water intake locations. Key Workgroup questions about relative changes to water quality at drinking water intakes can be quantified through this analytical modeling approach, after the models are refined.

The Sacramento and San Joaquin WARMF models are useful tools that need to be recalibrated with the updated land use information that was developed for the Workgroup and with all available water quality data that the Workgroup has identified as appropriate for use in this model. The WARMF modeler has identified a calibration issue in agricultural areas that has not yet been resolved.

Complications with initial runs of the upstream WARMF watershed models make quantification of the current version of DSM2 model results unreliable. Subsequent updated WARMF model runs have corrected some of the technical problems, but these results have not yet been used as DSM2 model boundary conditions and have not been reviewed by the Workgroup. The primary unresolved issue with the WARMF model is that it is simulating significantly less agricultural runoff in the Sacramento River watershed than was observed in historical data as a result of the coefficients used in the model, in particular the applied water rate.

Organic Carbon

The 2030 future scenarios that were provided to the modelers contained overall reductions in organic carbon loads from wastewater effluent, urban runoff, and agricultural discharges. The wastewater effluent and urban runoff scenarios were based on permitting actions already taken by the Central Valley Water Board (planned future) and expert opinions on plausible and outer boundary future conditions. The agricultural reductions were hypothetical percent reductions and included projected conversion of agricultural to urban land uses.

Although the DSM2 modeling results provided to the Drinking Water Policy Workgroup cannot quantitatively predict organic carbon concentrations at drinking water intakes, the scenarios that were evaluated indicate that organic carbon concentrations at drinking water intakes will not likely increase in the future. However, because the WARMF model reports are based on updated model runs, these results can be used for quantitative assessments with the known limitation that some agricultural return flows and loads may be underestimated. Relative changes in loads and concentrations between scenarios are less affected by this issue.

It should be noted that future changes to organic carbon loadings from other sources (e.g. from newly constructed wetlands in the Delta) were not considered by the Workgroup.

Nutrients and Salinity

Given the modeling issues described above, nutrient and salinity changes resulting from the 2030 future scenarios could not be quantified. If the models are refined in the future, the calibrated models should be rerun to quantify nutrient and salinity changes resulting from the 2030 future scenarios.

Pathogens

Pathogens (*Cryptosporidium* and *Giardia*) were not quantitatively modeled.

WORKGROUP RECOMMENDED MODEL REFINEMENTS FOR WARMF AND DSM2

If funding is available in the future, the Drinking Water Policy Workgroup should further develop the models to refine model calibration and input data. The refined models will be useful tools for both their original purpose and also in other water quality efforts including CV-SALTS, Nutrient Numeric Endpoint evaluations, TMDL development, and other watershed management uses. The models will be useful in predicting water quality, and in designing, coordinating and managing regional monitoring activities. Therefore, adequate time, funding and resources should be allocated for inter-model quality assurance, work sequencing, and coordination.

Due to time and budget constraints, the DSM2 Delta model runs conducted for the Workgroup only evaluated changes in Delta wastewater treatment plant loads in the three future 2030 scenarios that were developed by the Workgroup. Urban runoff and agricultural loads were not modified for in-Delta sources. The urban runoff and agricultural loads could be adjusted in future runs if adequate funding is provided.

Section 6. Water Treatment Evaluation

The objective of the Drinking Water Treatment Evaluation project was to determine the effects of a changing regulatory environment under future water quality conditions at water treatment plants that utilize surface waters from the Delta and Delta watersheds. The impacts on treatment processes and the cost to upgrade drinking water treatment plants were evaluated. This synopsis of the Drinking Water Treatment Evaluation project is based on the Drinking Water Treatment Evaluation Project Report (Malcolm Pirnie, Inc. (MPI), 2011).

SOURCE WATER AREAS AND VIRTUAL WATER TREATMENT PLANTS

The Workgroup identified four source water areas. The source water areas were based on similar drinking water treatment plant intake water quality. The source water areas are:

- Upper Sacramento and Upper-Eastern San Joaquin Watersheds (Upper Watersheds)
- Central Delta and South Bay Aqueduct (Central Delta)
- Coastal Branch and East Branch of the California Aqueduct (CAA)
- West Branch of the California Aqueduct (CAA-West)

Virtual water treatment plants (VWTPs) were developed for each source water area. The VWTPs do not exactly represent any one water treatment plant in the source water area but are a general representation of the treatment plants in the area. Table 8 presents a summary of the VWTPs for each source water area. A detailed discussion of how the VWTPs were selected is presented in Section 4 of the MPI report.

Table 8: Selected VWTPs (Source: Table 4-8 of MPI Report)

Source Water Area	VWTP Identifier	Size (MGD)	Particulate Removal	Primary Disinfection	Secondary Disinfection	pH Adjustment
Upper Watersheds	UW-1	100	Conventional*	Chlorine	Chlorine	Yes
Central Delta	CD-1	40	Conventional*	Ozone + Chlorine	Chloramines	Yes
CAA	CAA-1	40	Conventional*	Chlorine	Chloramines	No
	CAA-2	500	Conventional*	Ozone + Chlorine	Chloramines	Yes
CAA- West Branch	CAAW-1	800	Conventional*	Ozone + Chlorine	Chloramines	Yes

*Conventional particulate removal includes alum coagulation, flocculation, sedimentation, and multi-media filtration.

REGULATORY SCENARIOS

Drinking water regulatory scenarios for the year 2030 were developed by a team of technical experts and advisors, based on the team's experience with the U.S. Environmental Protection Agency and California Department of Public Health, and on best professional judgment. Three regulatory scenarios were evaluated:

- Current – includes contaminants that are currently regulated. This scenario was the baseline against which other scenarios were evaluated.
- Plausible Future – includes contaminants that are considered likely to be regulated in some form.
- Outer Boundary Future – includes the same contaminants at the Plausible Future Scenario; however, the requirements could be more stringent. This scenario was provided to bracket the regulatory possibilities.

Table 9 provides a summary of the regulatory scenarios. The regulatory scenarios are described in detail in Section 2 of the MPI report.

Table 9: Scenarios (Source: Table 2-1 from MPI Report)

Constituent	Regulatory Scenarios		
	Current	**Plausible[1]**	**Outer Boundary[2]**
Disinfection Byproduct Precursors			
Organic Carbon and Organic Nitrogen	Enhanced Coagulation Treatment Technique under the Stage 1 D/DBP Rule	Same as current	Control TOC as a precursor Control DON as a precursor

Constituent	Regulatory Scenarios		
	Current	**Plausible[1]**	**Outer Boundary[2]**
Disinfection Byproducts			
Chlorite	1 mg/L (daily at EPDS, monthly in DS)	Same as current	Same as current
Chlorate	-	700 µg/L (daily at EPDS, monthly in DS)	Same as plausible
Bromate	10 µ g/L(RAA)	5 or 10 µ g/L*	1 to 4 µ g/L*
THMs			
THM4	80 µ g/L(LRAA)	80 µ g/L*	Regulate individual species*
Iodinated THMs	-	-	Regulate iodinated THMs as a group*
HAAs			
HAA5	60 µ g/L(LRAA)	60 µ g/L*	Individual levels for selected species
HAA9	-	80 µ g/L(LRAA), additional species to current regulations	1. 80 µ g/L* 2. Individual levels for selected species*
Iodinated HAAs	-	-	Regulate as a group or individual species*
Nitrogenous Organic Compounds			
Nitrosamines	3 ng/L[3] Public Health Goal (PHG), 10 ng/L[3] Notification Level (NDMA)	NDMA at 3 to 10 ng/L(LRAA)[4]	Regulate select compounds*
Hydrazine	-	-	10 ng/L*
Disinfection Practices and Views			
Chloramination	Accepted technology	Other technologies preferred	Technology prohibited
View of low to no use of disinfectants	View generally not accepted in U.S	Same as current	View begins to be accepted in U.S.
Dissolved Minerals			
TDS	500 mg/L secondary MCL	Same as current	Reduction required to reduce salinity load and recycled water
Nutrients			
Nitrite	1 mg/L (as N) at EPDS	1 mg/L(as N) in DS	Same as plausible
Nitrate	10 mg/L(as N) at EPDS	10 mg/L (as N) in DS	Regulation pending heath data
Algal Toxins			
Microcystin	-	1 µ g/L WHO guideline	Same as plausible
Anatoxin-a	-	-	3 µ g/L (suggested, Australia)

Constituent	**Regulatory Scenarios**		
	Current	**Plausible**[1]	**Outer Boundary**[2]
Saxitoxin	-	-	3 µ g/L (suggested, Australia)
Pathogens and Indicators			
Total coliform (TC), Fecal coliform (FC), and *E. coli*	Monitoring based upon population. TC triggers assessment and corrective action. Failure to take corrective action is considered a treatment technique violation. A violation of E. Coli MCL occurs when routine and repeat TC samples are positive and one is also E. Coli positive. Failure to take repeat sample after E. Coli positive is also considered E. Coli violation. A violation triggers public notice.	Same as current	Same as current
Cryptosporidium	2-log removal credit (IESWTR[6]); Additional inactivation needed based on source water concentration (LT2ESWTR)	Same as current	Additional 1-log
Giardia and enteric viruses	3-log inactivation and/or removal of Giardia cysts and 4-log inactivation and/or removal of enteric viruses.	Same as current	Same as current
CCL3 Pathogens	-	Regulated, but less challenging to remove/inactivate than SWTR and LT2ESWTR standards	Same as plausible

[1]Scenario will be used in treatment selection and future costing.

[2]Scenario will be discussed qualitatively, but not included in future costing.

[3]CDPH regulation.

[4]NDMA is considered by the regulatory agency as an indicator of other nitrosamines' levels

[5]Current regulation represents the proposed revisions to the Total Coliform Rule based on the 2008 Total Coliform Rule/Distribution System Advisory Committee Agreement in Principle.

[6]Interim Enhanced Surface Water Treatment Rule (IESWTR)

*Single sample not to exceed. This could include multiple samples collected instantaneously a given location to average results and avoid an unrepresentative sample or could include re-sampling in the case of an outlier result. Intention is to obtain a sample that is representative of the quality of the water in a particular location at a unique point in time.

VIRTUAL WATER TREATMENT PLANT PERFORMANCE

The EPA Water Treatment Plant Model (EPAWTPM) Version 2.0 was used to evaluate the performance of each virtual water treatment plant under the current and two future regulatory scenarios. The EPAWTPM is an empirical model that simulates disinfection byproduct (DBP) formation (total trihalomethanes, haloacetic acids, total organic halides, bromate, and chlorite) under given treatment conditions.

Existing water quality conditions were evaluated by MPI based on data collected between 1998 and 2008. Future water quality conditions for the Upper Watershed were provided from the WARMF model runs discussed previously. Future water quality conditions for the Delta were provided from the DSM2 model runs discussed previously. The modeling results provided simulations of monthly average dissolved organic carbon, bromide, and temperature for the three future scenarios. Based on input from the modelers, the relative difference between the three modeled future scenarios was used to evaluate if the projected differences would be substantially different from the existing water quality conditions. All three future modeled scenarios showed a slight improvement in total organic carbon (TOC); however, TOC concentration reductions were not large enough to significantly reduce DBP formation in the water treatment process. As a result, the existing water quality conditions were modeled with the three regulatory scenarios to determine the impact of changing drinking water regulations on treatment plant upgrades and costs. Based on the assumed source water quality, the water treatment modeler simulated monthly average dissolved organic carbon, bromide, and temperature within the virtual water treatment plants for the three future drinking water regulatory scenarios.

As discussed previously, the DSM2 model should be rerun using updated WARMF inputs. When those updated results are available, MPI should be asked to determine if the revised modeled differences between the scenarios would have any impact on this evaluation.

The water treatment consultant determined threshold levels or treatment triggers for each VWTP using the EPAWTPM. The baseline water quality “design” conditions (90^{th} percentile historical water quality for each VWTP) were used as inputs to the model. Then TOC, ultraviolet absorbance, and bromide were varied until a trihalomethane, haloacetic acid, or bromate target was exceeded. Treatment targets were defined as 80 percent of the maximum contaminant level. This is a common practice in water treatment engineering, both with respect to design and operation of water treatment facilities.

The Drinking Water Treatment Evaluation Project Report contains matrices showing the TOC and bromide concentrations that would result in treatment targets being exceeded for each VWTP under existing drinking water regulations. Because water quality is expected to slightly improve with the three future scenarios that were modeled, no treatment targets were exceeded with the existing drinking water regulatory environment. Table 10 is an example for the Upper Watershed (UW) of the matrices that were developed for each VWTP and for each regulatory scenario. The 90^{th} percentile box shows the existing water quality conditions that were modeled by MPI. The matrix shows that additional treatment would be needed if TOC increased from 3.0 to 3.5 mg/L or if bromide increased from 0.02 to 0.06 mg/L.

Table 10: UW-1 Treatment Triggers Evaluation Matrix (Current Regulations) (Source: Table 5-2 from MPI Report)

Bromide (mg/L)	**0.20**	T	T	T	T	T
	0.16	T	T	T	T	T
	0.12	T	T	T	T	T
	0.06		T	T	T, H5	T
	0.02				T, H5	T, H5
Influent Temp: 16 °C (average)		**2**	**2.5**	**3.0**	**3.5**	**4.0**
Min Temp: 5 °C		**TOC (mg/L)**				

= 90th percentile water quality
= 2 or more treatment targets exceeded*
= 1 treatment target exceeded *
= no treatment targets exceeded

Treatment target equals 80% of the MCL.

*B= Bromate exceeded, T= THM4 exceeded,

H5= HAA5 exceeded, H9= HAA9 exceeded.

The future drinking water regulatory scenarios contain more stringent maximum contaminant levels for DBPS, causing VWTPs to exceed treatment targets. Under the plausible future regulatory scenario, drinking water treatment targets are exceeded for the Upper Watershed, Central Delta, and CAA under existing water quality conditions.

- UW-1 - This VWTP exceeded the targets for trihalomethanes and haloacetic acids. There are two options for treatment upgrades to meet the targets:
  - Use chloramines as a secondary disinfectant, or
  - Install granular activated carbon contactors and continue to use free chlorine as a secondary disinfectant
- CD-1 and CAA-2 – Both of these VWTPs exceeded the bromate target. The recommended treatment to meet the target is to reduce the ozone dose and add ultraviolet light disinfection

The Outer Boundary scenario includes greater degree of removal of DBP precursors (TOC and dissolved organic nitrogen), regulating individual trihalomethane and haloacetic acid species, regulating new compounds (iodinated DBPs, select nitrosamines, algal toxins), increasing *Cryptosporidium* inactivation, and discontinuing the use of chloramines for secondary disinfection. The current EPAWPM is not capable of predicting water quality parameters under consideration in the Outer Boundary scenario. Since the regulatory scenario for the Outer Boundary could not be defined more specifically, an assumption was made that all plants would move away from ozone and chloramines to avoid bromate and nitrogenous DBPs. As a result it is assumed that in the Outer Boundary scenario that all plants would need to add granular activated carbon contactors and ultraviolet light disinfection in all four source water areas to address current water quality conditions. Table 11 summarizes the treatment plant upgrades that would be needed to meet the Plausible Future and Outer Boundary future regulatory scenarios with existing water quality conditions. A key finding to be derived from the updated water quality modeling is whether source control measures in the watershed would impact the need for these upgrades.

Table 11: VWTP Upgrades Needed to Meet Future Regulations (Source: Table 6-3 from MPI Report)

VWTP	Scenario	Description
UW-1	Current	Conventional particulate removal, free chlorine disinfection
	Plausible	Convert to chloramines or
		Add GAC, free chlorine disinfection remains
	Outer Boundary	Add GAC and UV disinfection, free chlorine disinfection remains
CD-1	Current	Pre-ozonation, conventional particulate removal, chloramines
	Plausible	Reduce ozone dose and add UV disinfection
	Outer Boundary	Add GAC and UV disinfection, eliminate chloramines and use free chlorine
CAA-1	Current	Conventional particulate removal, chloramines
	Plausible*	No upgrades
	Outer Boundary	Add GAC and UV disinfection, eliminate chloramines and use free chlorine
CAA-2	Current	Pre-ozonation, conventional particulate removal, chloramines
	Plausible	Reduce ozone dose and add UV disinfection

	Outer Boundary	Add GAC and UV disinfection, eliminate chloramines and use free chlorine
CAAW-1	Current	Pre-ozonation, conventional particulate removal, chloramines
	Plausible*	No upgrades
	Outer Boundary	Add GAC and UV disinfection, eliminate chloramines and use free chlorine

*No upgrades needed, baseline costs remain.

COST TO MEET FUTURE REGULATIONS

Preliminary cost estimates were developed to upgrade the VWTPs to meet the plausible and outer boundary future scenarios. The cost estimates are considered to be Class 5 estimates based on limited information and have an accuracy of -30% to +50%. Table 12 presents the range of costs associated with upgrading water treatment plants in each of the source water areas to meet the future regulatory scenarios. Capital costs range from $3 billion to $8 billion to meet the Plausible Future scenario and from $9 to $19 billion to meet the Outer Boundary future scenario.

Table 12: Estimated Regional Costs for Upgrades (Source: Table 8-10 from MPI report)

VWTP	VWTP Design Capacity (mgd)	Representative Regional Treatment Capacity/ VWTP Capacity	Scenario	Added Capital Cost ($)	Added Annual O&M Cost ($/yr)
Upper Watersheds- 818 mgd Total Regional Treatment Capacity					
UW-1	100	8.18	Plausible	$10 - $21M	$0.3 - $0.6M
				or	
				$883 - $1893M	$35.3 - $118.5M
			Outer Boundary	$1581 - $3387M	$55.3 – 118.5M
Central Delta- 284 mgd Total Regional Treatment Capacity					
CD-1	40	7.1	Plausible	$270 - $579M	$6.2 - $13.4M
			Outer Boundary	$634 - $1359M	$20.8 - $44.5M
CAA- 2201 mgd Total Regional Treatment Capacity					
CAA-1	40	3.86	Plausible*	-	-
			Outer Boundary	$345 - $739M	$11.3 – $24.2M
CAA-2	500	6.78	Plausible	$2699 - $5783M	$110.0 - $235.8M
			Outer Boundary	$5226 – $11198M	$286.2 - $613.3M

CAA-West - 836 mgd Total Regional Treatment Capacity					
CAAW-1	800	1.04	Plausible*	-	-
			Outer Boundary	$1288 - $2760M	$76.3 – $163.5M
TOTAL			Plausible	$2978 - $6382M	$116.6 - $249.8M
				Or	
				$3852 – $8254M	$151.6 - $324.8M
			Outer Boundary	$9074 - $19443M	$449.8 - $963.9M

*No upgrades needed, baseline costs remain.

All costs in December 2010 dollars, CCI = 8952.

Costs are representative of AACE Class 5 estimates. AACE Class 5 estimates are planning level costs prepared based on 0 to 2% of full project definition with accuracy ranges of -20% to -50% on the low side and +30% to +100% on the high side. The accuracy range for cost estimates presented in this project are -30% to +50%.

WORKGROUP CONCLUSIONS AND WATER TREATMENT PLANT INTERPRETATIONS

The Water Treatment Plant Model can be used to predict the impacts of changing water quality conditions on treatment processes needed to comply with DBP and pathogen drinking water standards. It cannot be used to evaluate the impacts of nutrients and associated algal blooms on taste and odor and other operational problems.

Although the WARMF and DSM2 modeling results provided to the Drinking Water Policy Workgroup should not be used to quantitatively predict organic carbon concentrations at drinking water intakes, the source control scenarios that were evaluated indicate that organic carbon concentrations at drinking water intakes in the Sacramento River and the Delta will not likely increase in the future.

Projected future changes in organic carbon concentrations were considered too small to be considered in the Water Treatment Plant Model. The model was therefore run with existing water quality conditions and with both existing drinking water regulations and plausible future drinking water regulations to determine if water treatment plant upgrades would be needed. The virtual water treatment plants were based on existing water treatment plants that were designed to meet all drinking water standards with existing water quality conditions. The MPI report identifies the changes in water quality conditions that would result in the need to upgrade water treatment plants. Those results are not included in this Workgroup Synthesis Report because the source control scenarios indicate that water quality will likely stay the same or improve slightly in the future.

In the plausible future regulatory scenario that evaluated more stringent future drinking water regulations, the model predicted that water treatment upgrades would be needed for water treatment plants treating water from the upper watershed (Sacramento River), the Delta, and at some locations along the California Aqueduct. The analysis did not consider future changes in water quality based on other sources of organic carbon (e.g. conversion of agricultural land in the Delta to tidal wetlands).

WORKGROUP RECOMMENDATIONS FOR FUTURE WATER TREATMENT PLANT MODEL EVALUATIONS

If the WARMF and DSM2 models are rerun in the future, the results should be evaluated to determine if the predicted changes in organic carbon concentrations at the drinking water intakes are substantial enough to warrant additional runs with the Water Treatment Plant Model.

Section 7. Summary and Conclusions

SUMMARY

The high quality of water flowing out of the major reservoirs on the Sacramento and San Joaquin Rivers and their tributaries is changed as it flows through the Central Valley and the Delta. Drinking water agencies taking water from the Delta must provide more advanced and costly water treatment than agencies taking water upstream. This change in water quality, combined with projected population growth in the Central Valley and the fact that drinking water agencies were facing several significant and costly drinking water regulations in the late1990s led California Urban Water Agencies (CUWA) to conclude that a Drinking Water Policy was needed. Dischargers in the watershed were interested in having regulatory certainty and expressed a desire to work with the Central Valley Water Board and CUWA on the Drinking Water Policy. The primary initial objective of the workgroup was to ensure that the key drinking water constituents of concern were being adequately addressed in water quality monitoring programs and regulatory efforts.

Since 2002, the Central Valley Water Board, in cooperation with the Department of Public Health, State Water Board, and United States Environmental Protection Agency, has been working to develop a Drinking Water Policy for the Delta and its tributaries. Central Valley Water Board staff has coordinated with a Workgroup composed of stakeholders including both public and private entities to complete technical studies and research required to support the development of a Drinking Water Policy for surface waters of the Delta and its tributaries. The Drinking Water Policy is intended to address constituents of concern to drinking water agencies identified as highest priority by the Workgroup: disinfection byproduct precursors (organic carbon, bromide), salts (dissolved minerals), nutrients, and pathogens. The Central Valley Water Board adopted a resolution in July, 2010 supporting the development of the Drinking Water Policy and directing the Workgroup to focus on organic carbon and pathogens (*Cryptosporidium* and *Giardia*) since the remaining constituents of concern would be addressed through other ongoing, regulatory efforts (CV-SALTS, Nutrient Numeric Endpoints, State Recycled Water Policy).

Conceptual models were developed by the Workgroup for the drinking water constituents of concern: pathogens and pathogen indicators, nutrients, organic carbon, and salinity. Conceptual models for these constituents were developed to document the understanding of sources, transformations, transport processes, and impacts. The conceptual models provided a compilation and evaluation of available data and qualitatively described the key processes of constituent fate and transport. The conceptual models identified seasonal, inter-annual, and spatial trends in ambient levels of the constituents of concern. The conceptual models served as a valuable precursor to subsequent evaluations of the sources of the drinking water constituents of concern and also informed later analytical modeling efforts involving both WARMF and DSM2.

In 2009, the Workgroup retained contractors to perform source evaluations of wastewater effluent, urban runoff, and irrigated agriculture for the constituents of concern. These source evaluations included identification of the constituents present in each of the source categories and identification of pathways for the constituents to enter surface water supplies.

The source evaluations also included investigations of planned and potential control measures for the constituents of concern and 2030 projections of loading contributions from each of the three source categories. The future loading projections were developed in the form of the scenarios; identified as ‘2030 Planned’, ‘2030 Plausible’, and ‘2030 Outer Boundary.’ The ‘2030 Planned’ scenario included mandatory improvements already included in permits or otherwise required by regulations, the ‘2030 Plausible’ scenario was based on regulatory thresholds that might be present at that time, and the ‘2030 Outer Boundary’ scenario was based on the most extreme regulatory requirements that could be envisioned, i.e. treatment and controls carried out at the current limit of technology.

For both wastewater effluent and urban runoff, the future scenarios included projected regulatory thresholds (e.g. effluent limits or percent reduction goals) as well as estimated costs for possible best-management-practice implementation. The agricultural source evaluation did not explore specific future regulatory requirements or specific best-management-practice implementation. Due to resource and time limitations and the complexity of analysis, these subjects were deferred pending the availability of future funding for such work. The agriculture source evaluation examined available literature to summarize potential land-based sources of drinking water constituents of concern and from that information defined and mapped thirty one unique land cover classes present in the Central Valley. For each land cover class the following properties were assigned: proportions of impervious and irrigated surfaces, applied water, applied ammonium, nitrate and other salts, and removed biomass and nitrogen. The land cover data set developed under the agriculture source evaluation greatly improved the existing representation of the Central Valley in the WARMF model and supported the analytical modeling analysis to assess the influence of land cover patterns and changes on ambient raw drinking water quality.

The source evaluations completed for wastewater effluent, urban runoff, and agriculture informed a tiered modeling exercise that attempted to quantify the changes to raw drinking water quality caused by changes to the source loading of constituents of concern. The Sacramento and San Joaquin River watersheds, the primary tributaries to the Delta, were modeled using WARMF. The results of the WARMF modeling work, at ‘I’ Street on the Sacramento River and Vernalis on the San Joaquin River, were applied as boundary condition input for the Delta model, DSM2. Both of the analytical models were calibrated to historic observed conditions based on available information, including recent (2010) land use conditions, historical flow and water quality data, and historical point source flow and water quality data. The future scenarios developed in the source evaluations were used as input to the analytical water quality models WARMF and DSM2 to allow a comparison to current conditions to judge the magnitude of change associated with the different future source loading scenarios.

For this modeling exercise, the WARMF and DSM2 Delta models were successfully linked to develop a comprehensive flow and water quality model for the watershed upstream of representative Central Valley and Delta drinking water intake locations. Both WARMF and DSM2 were linked to CALSIM II to provide a necessary connection to future assumptions regarding operation of the water projects (i.e. operation of dams, gates and pumps). Complications with initial runs of the upstream WARMF watershed model prevented the successful application of the DSM2 models during the spring of 2011. As a result, the Workgroup determined that the relative differences between the modeled scenarios would be the primary basis for conclusions, and that absolute concentration results would not be emphasized. If funding is available in the future, additional work could be done to improve the calibration of the WARMF model. With these improvements WARMF and DSM2 could be rerun with the revised boundary conditions to produce more refined and reliable concentration results for all scenarios.

A final study prepared for the Workgroup (by Malcolm Pirnie, Inc.) addressed the effects of potential changes in ambient levels of drinking water constituents of concern in the Delta and upper watersheds. Malcolm Pirnie also projected changes in the Safe Drinking Water Act regulatory environment for drinking water treatment plants as three regulatory scenarios: current, plausible future, and outer boundary future. These potential future regulatory scenarios were evaluated using an empirical drinking water treatment model that simulates disinfection byproduct (DBP) formation (total trihalomethanes, haloacetic acids, total organic halides, bromate, and chlorite) under different treatment conditions. Four Virtual Water Treatment Plants were developed to represent the four major source water areas identified by the Workgroup; Upper Watersheds, Central Delta, Coastal and East Branch of the California Aqueduct, and the West Branch of the California Aqueduct.

The Source Evaluation work showed that organic carbon concentrations at drinking water intakes will not likely increase in the future and may even slightly decrease under all three projected scenarios due to anticipated land use transitions and regulation of point and nonpoint sources. In the absence of final analytical modeling results, the drinking water treatment model was run based on existing water quality conditions to be conservative. Because future organic carbon concentrations are not expected to increase under all three future scenarios, the drinking water treatment model showed that no treatment targets are exceeded (or are predicted to be exceeded in the future) under the existing Safe Drinking Water Act regulatory environment. The future drinking water treatment regulatory scenarios contain more stringent maximum contaminant levels for disinfection by-products. The model predicts that VWTPs would exceed treatment targets if elements of the scenarios are implemented.

CONCLUSIONS

As a result of the technical work performed by and for the Workgroup, the following conclusions have been reached:

Methodology

- The methodology (source control studies, water quality modeling and water treatment modeling) used by the Work Group to address the need for increased regulation of sources of drinking water constituents of concern and to inform policy determinations was successful.

Modeling Tools

- The WARMF, CALSIM II and DSM2 models were successfully linked to develop a comprehensive set of flow and water quality modeling tools for the watershed upstream of representative Central Valley and Delta drinking water intake locations.
- The models are useful tools for both their original purpose and also in other water quality efforts including CV-SALTS, Nutrient Numeric Endpoint evaluations, TMDL development, and other management uses. The models should be highly useful in designing, coordinating, and managing regional monitoring activities.
- If funding becomes available in the future, the Sacramento and San Joaquin WARMF models should be recalibrated with the updated land use information that was developed for the Workgroup and with all available water quality data that the Workgroup has identified as appropriate for use in this model. The WARMF modeler has identified a calibration issue in agricultural areas that has not yet been resolved. The Workgroup has a scope of work and budget estimate available for implementation of those refinements.

Future Source Water Quality

- The source control analysis estimated that urban land in the Central Valley will increase by 450,000 acres by 2030. This is a 50 percent increase over 2010 conditions. The expansion of urban areas will result in a reduction of agricultural land in the Central Valley. POTW flows are projected to increase by 160 mgd. due to this urban growth. This is a 47 percent increase over 2010 conditions. Despite these projected changes to future land use and wastewater flows, the combined agricultural, urban runoff, and POTW loads of organic carbon and some otherdrinking water constituents of concern will likely decrease in the future.
- Although the WARMF and DSM2 modeling results provided to the Drinking Water Policy Workgroup cannot be used to quantitatively predict organic carbon concentrations at drinking water intakes, the source control scenarios that were evaluated indicate that organic carbon concentrations at drinking water intakes in the Sacramento River and the Delta will not likely increase in the future as a result of expected population growth in the Central Valley. This is due partly to decreased loads of these constituents from urban land compared to agricultural land and partly due to regulatory actions taken by the Central Valley Water Board that will result in decreased loading of these constituents in the future. The TDS load is expected to continue to increase in the future. Pathogens were not quantitatively modeled.

Future Water Treatment Requirements

- The Water Treatment Plant Model can be used to predict the impacts of changing ambient water quality conditions on treatment processes needed to comply with DBP (organic carbon) and pathogen drinking water standards. It cannot be used to evaluate the impacts of salts, nutrients or associated algal blooms on taste and odor and other operational problems.
- Projected future changes in source water organic carbon concentrations were considered too small to be evaluated in the Water Treatment Plant Model. The model was therefore run with existing water quality conditions and with both existing drinking water regulations and plausible future drinking water regulations to determine if water treatment plant upgrades would be needed. The virtual water treatment plants were based on existing water treatment plants that were designed to meet all drinking water standards with existing water quality conditions. The MPI report identifies the changes in water quality conditions that would result in the need to upgrade water treatment plants. Those results are not included in this Workgroup Synthesis Report because the source control scenarios indicate that water quality will likely stay the same or improve slightly in the future.
- The model predicts that upgrades will be needed for water treatment plants treating water from the upper watershed (Sacramento River), the Delta, and at some locations along the California Aqueduct to meet plausible future regulations, even if existing water quality is maintained.
- Drinking water agencies are required to provide varying levels of treatment based on the pathogen levels in their raw water supplies. Currently, water agencies treating water from the Sacramento River and the Delta fall into Bin 1 of the LT2ESWTR, meaning that *Cryptosporidium* levels are sufficiently low so additional treatment is not required. Although not anticipated, if pathogen levels were to increase and source water were to fall into Bins 2 to 4 in the future, water agencies would have to provide greater removal of pathogens in their water treatment plants to protect public health.

Linkage to Other Ongoing and Future Efforts

- The effectiveness of controlling nutrient levels in the watershed and the Delta as a means to manage taste and odor problems in water supplies and avoid other operational problems at water treatment plants will be studied in a separate regulatory venue (statewide nutrient policy for inland waters and the Delta NNE process).
- Salinity is being addressed through the CV-SALTS process.
- The influence on ambient water quality of changes proposed by BDCP or other programs (such as the conversion of agricultural lands to wetlands) should be evaluated by BDCP.
- Future monitoring may be needed to fill specific data gaps. The purpose for and use of new monitoring data should be articulated before regulated entities are required to contribute to such efforts. Monitoring may be needed to address

specific objectives and/or questions, such as model refinement to confirm linkage of sources to ambient conditions, ambient trend monitoring, and support for fate and transport modeling. Ambient water quality and source monitoring efforts described in the Drinking Water Policy should be coordinated with the Delta Regional Monitoring Program (RMP) currently under development.

Section 8. Recommendations

NEED FOR A DRINKING WATER POLICY

The Workgroup used objective, state-of-the-art tools to link source protection efforts conducted under the Clean Water Act and Porter Cologne Act to requirements in the Safe Drinking Water Act that base water treatment levels on source water quality.

A Drinking Water Policy is needed to protect the MUN beneficial use in the Delta and its tributaries. The source control studies conducted for this project indicate that organic carbon concentrations will likely remain the same or decrease slightly as a result of changing land use and regulatory actions already taken by the Central Valley Water Board. This conclusion is based on a number of assumptions that were made on future regulatory programs and the effectiveness of source control measures. Due to problems in calibrating the WARMF model, DSM2 modeling to determine if the reduced load of organic carbon will result in reduced concentrations at Delta drinking water intakes was not completed. There is also uncertainty over the future land use in the Delta since ecosystem restoration efforts underway call for increased tidal wetland acreage. These changes may result in increased loads of organic carbon discharged to Delta waterways.

Pathogens were not quantitatively assessed due to a lack of data and modeling tools; however, existing pathogen levels at drinking water intakes should be maintained to protect public health and prevent even more costly water treatment plant upgrades.

ADDITIONAL WORK

The Workgroup has determined that sufficient information has been developed to proceed with the development of the Drinking Water Policy. As with any long term technical study, data needs and study refinements were identified that could not be completed due to time or funding constraints. Previous sections of this report contain detailed descriptions of potential future studies that could be conducted if funding becomes available. The Workgroup recommendations are summarized below:

<u>Identify and address data gaps</u> – From both the source evaluation study and the analytical modeling efforts, numerous gaps were identified in the monitoring data compiled for this project. In particular, available data for pathogens and organic carbon were found to be insufficient. Data limitations prevented a full watershed-scale quantitative analysis of sources and transport. Further study of pathogen sources, as well as their fate and transport through the water shed, is needed to better evaluate their impact on water quality and to determine if they impact drinking water supplies. The conceptual model for organic carbon found that, like nutrients, organic carbon varies seasonally and also inter-annually. However, in-stream generation and consumption of organic carbon is not well understood and additional monitoring

locations for organic carbon are needed. The Workgroup recommends that all future monitoring be coordinated with the Regional Monitoring Program.

Refine future scenarios – The projected 2030 scenarios can be refined by improving the information developed in the source evaluation studies. The following items have been identified by the Workgroup as future improvements to the study:

- Evaluate Small Dischargers < 1mgd in Wastewater Effluent Source Evaluation: The wastewater source evaluation study did not consider small dischargers (< 1 mgd) because they are a negligible fraction of annual downstream river flow. Localized effects on downstream drinking water are already addressed by NPDES permitting. This Drinking Water Policy should not introduce further regulation on small discharges without further investigation.
- Evaluate Water Reuse / Water Recycling in Wastewater Source Evaluation: The wastewater source evaluation study also did not consider reuse of wastewater or a shift toward surface water from groundwater for drinking water supply.
- Evaluate Water Conservation and Improved Urban Irrigation Efficiency: The urban runoff source evaluation assumed significant reductions in dry weather runoff with aggressive water conservation and improved irrigation efficiency. This assumption should be verified through additional literature review and studies.
- Refine Organic Loading from Urban Sources: The urban runoff source evaluation study also recommended a more detailed evaluation of the sources and types of organic carbon in urban watersheds.
- Evaluate Agriculture BMPs and Costs: A thorough evaluation of best management practices that could be employed to control drinking water constituents of concern was deferred. As such, the three future scenarios included arbitrary constant load reductions from agricultural sources. An evaluation of potential controls of agricultural sources, along with their associated costs of implementation, would allow for a more realistic and meaningful modeling exercise.

Improve analytical modeling tools – The successful linkage of CalSim II, WARMF and DSM2 created a valuable tool that allows water quality to be simulated from the upper watersheds of the Central Valley through the Delta. However, due to time constraints the models were not run with complete success.

The Workgroup will explore funding options to refine and rerun the WARMF and DSM2 models. The Workgroup will identify specific model outcomes that are important to support the Drinking Water Policy. The following issues should be considered in future modeling:

- In the locations identified by the WARMF modeler and Workgroup, the assumed model irrigation water application input values should be verified at certain limited and well defined locations against available irrigation application data.
- A sensitivity analysis for WARMF modeling of agricultural return flows in areas identified by the WARMF modeler should be performed. The sensitivity analysis

should be used to determine the overall effect of these input value assumptions on the larger conclusions made by the Workgroup.

- DSM2 should be calibrated and rerun with the updated WARMF outputs for baseline and all future scenario conditions. Additionally, the sensitivity of agriculture return flows will be assessed with at least one model run. The Workgroup will identify a minimum set of reporting outputs for the DSM2 modeler to provide.
- If the WARMF and DSM2 models are rerun in the future, the results should be evaluated to determine if the predicted changes in organic carbon concentrations at the drinking water intakes are substantial enough to warrant additional runs with the Water Treatment Plant Model.

Section 9. Lessons Learned

WHAT WORKED WELL

The following summarizes the aspects of the Workgroup efforts that were successful and have set the stage for a sustainable outcome:

- Stakeholders worked well together, despite different interests. All stakeholders were committed to developing sound scientific information as the basis for making decisions.
- Central Valley Water Board staff managed the Workgroup process well and to date has met the challenging time schedule established by the Central Valley Water Board in its July 2010 resolution.
- Completion of the tasks under the Technical Work Plan was a key to success. The results obtained were important in gaining agreement within the Workgroup on the direction of the policy.
- Work performed by expert consultants was essential in resolving differences of opinion within the Workgroup.
- The Workgroup reached consensus on a number of major technical and policy issues. This agreement sets the stage for a policy that will is more likely to be supported by stakeholders into implementation.
- The level of agreement reached on policy reduces likelihood of administrative and legal challenges to BPA by the stakeholders involved in the Workgroup.

WHAT COULD BE IMPROVED

The following summarizes areas where, in hindsight, improvements to the process could have been made:

- Duration of the effort – A stakeholder-driven process, for a complex project with a large watershed and potentially costly regulatory implications, requires coordination and collaboration with multiple groups and is both time and labor intensive. It is difficult to get the right stakeholders at the table, maintain consistency in individual participation, and reach consensus. The diverse stakeholders participating in this process often took many months to reach agreement. Establishment of ground rules at the beginning of the process may have improved efforts to complete the work in a timely manner. The schedule was also hindered by the State's stop work order. Almost one year was lost from the schedule when the funding was revoked.

- Performed work plan in step-wise fashion – may have been able to shorten time lines by more parallel activity on some tasks. However, the Water Treatment Plant Evaluation was initiated too early. The source control evaluations and analytical modeling should have been conducted first. The Workgroup could have allocated more funding to the source evaluations and modeling tasks and less funding to the Water Treatment Plant Evaluation if work had been conducted in a sequential manner.
- Considerable time was spent assembling and evaluating water quality and source data and developing a database because data were not readily available in online databases in 2004. This process could now be conducted more quickly. In future efforts, online databases should make data gathering more efficient.
- Conceptual modeling effort added significant time and took longer than anticipated.
- Clarity on the roles and responsibilities in the administration of the grant could have saved up to a year
- Technical work in 2010 and 2011 was performed on a compressed time schedule. This led to problems in getting information to the analytical modelers and did not allow for the iterations needed for Workgroup review, coordination between the modelers, and model refinement prior to the completion of the modeling effort and preparation of modeling reports. More time and budget should have been allocated to this effort.

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Appendices

Appendix 1: Timeline of Work Performed by Workgroup
Appendix 2: Evaluation of Water Quality Goals Summary Table (Starr Consulting, 2007e)
Appendix 3: WARMF Loading Summaries

APPENDIX 1: TIMELINE OF WORK PERFORMED BY WORKGROUP

Workgroup formed – 2002

Technical Studies Work Plan developed – January 2003

Agency Workshop on Regulatory Framework Associated with Drinking Water (State Water Board, Central Valley Water Board, DHS, EPA) – April 2003

Outreach Fact Sheet created – April 2004

Prioritization for first and second tier constituents began– April 2004

Drinking Water Panel at ACWA Spring Conference – May 2004

Coordination meeting with DWR Bay Delta and Tributaries Database Demonstration – December 2004

Data for nitrogen, phosphorus, salinity compiled – 2004-2005

Phase I Constituents of Concern selected: organic carbon, bromide, salt, nutrients, pathogens – 2004-2005

Final Drinking Water Policy Database complete. Link sent to Workgroup and database loaded to web site – April-May 2005

Stakeholder Interviews to inform them about policy and solicit input – 2005-2006

Draft Nutrient Conceptual Model completed – March 2006

Conceptual model for organic carbon prepared – April 2006

Conceptual model for pathogens prepared – August 2006

Conceptual model for nutrients prepared – September 2006

Central Valley Drinking Water Policy Public / Workshop Technical Study Presentation – October 2006

Spreadsheet model to assess water quality impacts of various source control measures – 2006-2008

Star Technical Memo 1: Review Procedures, Policies, and Guidance Used by Other California Agencies – February 2007

Conceptual model for salinity prepared – July 2007

Star Technical Memo 2: Review Procedures, Policies, and Guidance Used by the US EPA – August 2007

Star Technical Memo 3: Review Procedures, Identify Water Quality Goals or Policies Adopted by Other States and Countries – October 2007

Star Technical Memo 4: Review California Regional Water Board Basin Plans and Policies – October 2007

Summary Table for evaluation of drinking water quality goals – October 2007

Analytical model scope of work developed – October-December 2007

Public scoping meetings – August 2008

Malcolm Pirnie Technical Memorandum 1: Drinking Water Treatment Evaluation, Definition of Study Boundaries – September 2008

Prop 50 funding suspended due to State economic status – December 2008

Quality Assurance Project Plan (QAPP) for Monitoring for Drinking Water Constituents of Concern in Effluents from Publicly Owned Treatment Works and Fish Hatcheries in the Central Valley (UC Davis) – March 2009

Prop 50 funding reinstated – December 2009

Prop 50 Work halted due to decision not to seek an extension on Prop 50 funding – March 2010

Prop 50 Work restarted – August 2010

Re-scoping of Proposition 50 grant submitted/ approved – Fall 2010

Wastewater Control Measures Study (prepared by West Yost Associates) – March 2011

Urban Runoff Source Control Evaluation (prepared by Geosyntec) – March 2011

Technical Documentation and Limitations for Development of WARMF Model Input Parameters (prepared by Newfields) – March 2011

Drinking Water Treatment Evaluation Project Report (prepared by Malcolm Pirnie/ Arcadis) – April 2011

Analytical Modeling of the San Joaquin River (prepared by Systech Water Resources, Inc.) – April 2011

Analytical Modeling of the Sacramento River (prepared by Systech Water Resources, Inc.) – April 2011

Link to CALSIM to Run WARMF Simulations (prepared by Systech Water Resources, Inc.) – April 2011

Sensitivity Analysis of Water Quality Entering the Delta (prepared by Systech Water Resources, Inc.) – April 2011

Drinking Water Policy outline and work plan – November 2011

Workgroup Synthesis Report – January 2012

APPENDIX 2: EVALUATION OF WATER QUALITY GOALS SUMMARY TABLE (STARR CONSULTING, 2007E)

Constituent	Drinking Water Regulation	Central Valley Regional Board Source Water Regulation	Related Goals or Policies by Other Agencies
Total Organic Carbon (TOC)	Treatment technique with variable removal requirements when source or treated water TOC > 2 mg/L (Stage 1 Disinfectants/ Disinfection By Products Rule).	No water quality objective - may be impacted by objective for color.	British Columbia has a guideline of 4 mg/L for TOC in sources used for drinking water. No other Regional Boards (RBs) or other agencies currently have an objective. The Santa Ana RB is developing a TOC objective related to groundwater recharge with effluent dominated waters. DPH draft groundwater regulations.
Dissolved Organic Carbon (DOC)	Not directly regulated, indirectly through specific ultraviolet light absorbance (SUVA) calculation. TOC removal required if source or treated water SUVA > 2 L/mg-m (Stage 1 D/DBPR).	No direct water quality objective, may be impacted by objective for color.	No other RBs or agencies currently have a direct objective.
Bromide	No standard, is a precursor to disinfection by-products.	No direct water quality objective.	British Columbia has a working guide for bromide of 50 µg/L, based on the CALFED target. Florida developed criteria of 100 µg/L bromide based on fisheries impacts. New York has set a guidance value for bromide (2,000 µg/L) for surface water and groundwater. No other RBs have an objective.

Constituent	Drinking Water Regulation	Central Valley Regional Board Source Water Regulation	Related Goals or Policies by Other Agencies
Total Dissolved Solids (TDS)	Secondary Maximum Contaminant Level (MCL) with recommended level of 500 mg/L and an upper limit of 1,000 mg/L.	Water quality objective for municipal water supply (MUN) beneficial use set at recommended secondary MCL. More stringent site-specific objectives based on other beneficial uses.	Most RBs and other agencies have the same MUN objective as the Central Valley RB. Some RBs and states do not allow discharges to increase the salinity of the source water. This typically results in implementation of site-specific objectives.
Electrical Conductivity (EC)	Secondary MCL with recommended level of 900 mg/L and an upper limit of 1,600 mg/L.	Water quality objective for MUN beneficial use set at recommended secondary MCL. More stringent site-specific objectives based on other beneficial uses.	Most RBs and states have the same MUN objective as the Central Valley RB. Some RBs and states do not allow discharges to increase the salinity of the source water. This typically results in implementation of site-specific objectives.
Chloride	Secondary MCL with recommended level of 250 mg/L and an upper limit of 500 mg/L.	Water quality objective for MUN beneficial use set at recommended secondary MCL. More stringent site-specific objectives based on other beneficial uses. Delta Plan (State Water Board) includes water quality objective of 150 mg/L at the Contra Costa Canal.	USEPA and most RBs and states have the same MUN objective as the Central Valley RB. Some RBs and states do not allow discharges to increase the salinity of the source water. This typically results in implementation of site-specific objectives.
Total Nitrogen	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	Objective for the MUN designation is 10 mg/L as N. There is also a narrative objective for biostimulatory substances.	USEPA adopted draft nutrient criteria for total nitrogen for most ecoregions in the U.S. for states to consider. These criteria are site-specific and are being applied by some RBs and states. The San Diego RB uses a ratio of 10:1 for nitrogen to phosphorus to set source water objectives (see total phosphorus). Some states have a similar narrative objective. North Carolina and Oklahoma have set criteria for response parameters, such as chlorophyll a.

Constituent	Drinking Water Regulation	Central Valley Regional Board Source Water Regulation	Related Goals or Policies by Other Agencies
Total Kjeldahl Nitrogen (TKN)	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	No direct water quality objective. There is a narrative objective for biostimulatory substances.	No other RBs or agencies currently have a direct objective.
Organic Nitrogen	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	No direct water quality objective. There is a narrative objective for biostimulatory substances.	No other RBs or agencies currently have a direct objective.
Nitrate	Primary MCL of 10 mg/L as N, Public Health Goal (PHG) of 10 mg/L as N.	Objective for the MUN designation is 10 mg/L as N. There is also a narrative objective for biostimulatory substances.	USEPA, RBs and other agencies have the same MUN objectives as the Central Valley RB.
Nitrite	Primary MCL of 1 mg/L as N, PHG of 1 mg/L as N .	Objective for the MUN designation is 1 mg/L as N. There is also a narrative objective for biostimulatory substances.	Some RBs and other agencies have the same MUN objectives as the Central Valley RB.
Ammonia	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	There is a site-specific objective for ammonia in Tulare Lake Basin at 0.025 mg/L. There is also a narrative objective for biostimulatory substances.	USEPA and many RBs and agencies have adopted the criteria for fisheries, which are variable depending on pH, temperature and life-stage development. Site-specific criteria are developed for one-hour and four-day periods.

Constituent	Drinking Water Regulation	Central Valley Regional Board Source Water Regulation	Related Goals or Policies by Other Agencies
Total Phosphorus	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	No direct water quality objective. There is a narrative objective for biostimulatory substances.	USEPA adopted draft nutrient criteria for total phosphorus for most ecoregions in the U.S. for states to consider. These criteria are site-specific and are being applied by some RBs and states. Michigan has an effluent standard for point sources of 1 mg/L and Utah has a source water criterion of 0.05 mg/L. British Columbia limits total phosphorus in drinking water supplies to <10 µg/L. The San Diego RB has limits of 100 µg/L in streams, 50 µg/L in streams that enter a lake/ reservoir, and 25 µg/L in lakes/ reservoirs. Some states have similar narrative objectives. North Carolina and Oklahoma have set criteria for response parameters, such as chlorophyll a.
Dissolved Phosphorus	No direct standard, nutrients cause algae growth leading to taste & odor/operational issues.	No direct water quality objective. There is a narrative objective for biostimulatory substances.	USEPA has a water quality criterion for phosphate phosphorus, based on potential impacts to water treatment. This includes a limit of 100 µg/L in streams, 50 µg/L in streams that enter a lake/ reservoir, and 25 µg/L in lakes/ reservoirs.
Giardia	Treatment technique requires minimum of 3-log (99.9%) reduction (Surface Water Treatment Rule). Additional treatment based on source water quality, levels > 1 cyst/100 L or high surrogate levels.	No direct water quality objective. There is a numeric objective for indicator organism (fecal coliform) for the body contact recreation (REC1) beneficial use which may be indirectly protective of the MUN use.	No other RBs or agencies currently have a direct objective.

Constituent	Drinking Water Regulation	Central Valley Regional Board Source Water Regulation	Related Goals or Policies by Other Agencies
Cryptosporidium	Treatment technique requires minimum of 2-log (99%) reduction, additional treatment based on direct measurement of source water for oocysts, levels > 0.075 oocysts/L (Interim Enhanced Surface Water Treatment Rule and Long Term 2 Enhanced Surface Water Treatment Rule [LT2ESWTR]).	No direct water quality objective. There is a numeric objective for indicator organism (fecal coliform) for the body contact recreation (REC1) beneficial use which may be indirectly protective of the MUN use.	No other RBs or agencies currently have a direct objective.
Total Coliform	Historically used as indicator organism for microbial risk. DHS had assigned a trigger threshold of 1,000 most probable number per 100 mL (MPN/100 mL) for advanced treatment. Unfiltered surface water supplies must have levels < 100 MPN/100 mL.	There is a water quality objective for groundwater sources, < 2.2 MPN/100 mL, for the MUN designation.	San Francisco Bay and Santa Ana RBs have objectives of 100 MPN/100 mL for MUN designated surface water sources. These objectives have no practical application at this time. Oklahoma limits MUN sources to 5,000 MPN/100 mL. Massachusetts limits unfiltered drinking waters supplies to 100 MPN/100 mL. Most RBs also have an objective for MUN designated groundwaters to have non-detectable total coliform. Some states and other countries have set objectives/ criteria for MUN supplies which vary, based on the amount of treatment provided for the drinking water.

APPENDIX 3: WARMF LOADING SUMMARIES

Additional data are needed to fully calibrate the WARMF model at this time. Therefore the load reductions between scenarios reported in this appendix should be viewed as general indicators of the effectiveness of the source controls in the projected 2030 scenarios. The WARMF output at I Street reflects the quality of water at drinking water intakes in the lower Sacramento River. Due to the WARMF calibration issue, specific projections of the magnitude of future water quality constituent concentrations cannot be made. The WARMF results do provide reasonably reliable indications of the direction of changes in source loads between the evaluated scenarios.

The quality and quantity of flows from WARMF were the boundary conditions for the DSM2 modeling of the Delta. In-Delta sources (some portion of the Sacramento urban area and the Sacramento Regional County Sanitation District discharge) are considered in WARMF, but are downstream from the DSM2 boundary. The WARMF results for the downstream location on the Sacramento River at Morrison Creek include these urban inputs, and are included in this appendix for comparative purposes.

The WARMF modeler developed outputs to match the location, data period and time step duration to develop usable DSM2 model inputs using CALSIM II (Systech Water Resources, 2011d). CALSIM II performs simulations of the State Water Project and Central Valley Project operations using the Water Resource Integrated Modeling System model engine.

Table A3-1: WARMF Loading of Organic Carbon to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table 4-25)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at I Street)	**102.30**	**99.79**	**97.50**	**95.11**
Boundary Inflows	46.75	46.97	46.86	46.75
Agriculture	24.03	20.20	19.53	18.68
Urban	2.55	2.94	2.94	2.73
Natural Land Cover	27.10	26.77	26.79	26.80
Point Sources	1.87	2.92	1.38	0.15
Yolo Bypass (at Lisbon)	**38.50**	**37.82**	**37.40**	**36.78**
Boundary Inflows	33.85	33.19	32.96	32.63
Agriculture	0.71	0.68	0.65	0.63
Urban	0.09	0.09	0.09	0.09
Natural Land Cover	3.39	3.40	3.39	3.39
Point Sources	0.46	0.46	0.29	0.03
Cosumnes River (at Mokelumne R)	**9.30**	**9.09**	**9.05**	**8.91**
Boundary Inflows	0.00	0.00	0.00	0.00
Agriculture	0.95	0.82	0.78	0.71
Urban	0.32	0.62	0.62	0.60
Natural Land Cover	8.03	7.65	7.65	7.60
Point Sources	0.00	0.00	0.00	0.00
Mokelumne River (at Cosumnes R)	**2.47**	**2.44**	**2.43**	**2.43**
Boundary Inflows	2.29	2.29	2.29	2.29
Agriculture	0.14	0.10	0.10	0.09
Urban	0.01	0.02	0.01	0.01
Natural Land Cover	0.03	0.03	0.03	0.03
Point Sources	0.00	0.00	0.00	0.00
Calaveras River (at Stockton)	**2.42**	**2.39**	**2.38**	**2.37**
Boundary Inflows	1.70	1.70	1.70	1.70
Agriculture	0.32	0.27	0.26	0.25
Urban	0.03	0.05	0.05	0.05
Natural Land Cover	0.37	0.37	0.37	0.37
Point Sources	0.00	0.00	0.00	0.00
San Joaquin River (at Vernalis)	**52.20**	**51.42**	**50.89**	**50.33**
Boundary Inflows	40.55	40.74	40.74	40.87
Agriculture	7.95	7.16	6.87	6.57
Urban	0.21	0.26	0.24	0.22
Natural Land Cover	2.69	2.65	2.65	2.64
Point Sources	0.79	0.61	0.38	0.04
TOTAL	**207.18**	**202.95**	**199.64**	**195.91**

Table A3-2: WARMF Loading of Organic Carbon to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table A-4)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at Morrison Ck)	**116.11**	**104.95**	**100.55**	**94.63**
Boundary Inflows	46.31	46.53	46.42	46.31
Agriculture	23.84	20.02	19.37	18.54
Urban	2.62	3.01	3.01	2.78
Natural Land Cover	26.92	26.58	26.61	26.63
Point Sources	16.43	8.82	5.15	0.37

Note: The WARMF model simulation results at Morrison Creek were not used by DSM2 as the model handoff occurred further upstream at the I Street Bridge (the Legal Delta Boundary). DSM2 modeling considered sources downstream of I Street. The table is provided as additional information on this reach of the Sacramento River.

Table A3-3: WARMF Loading of Total Dissolved Solids to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table 24)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at I Street)	**4179**	**4057**	**4100**	**3992**
Boundary Inflows	2150	2139	2161	2161
Agriculture	1035	885	901	896
Urban	87	100	101	87
Natural Land Cover	833	822	831	831
Point Sources	75	111	105	18
Yolo Bypass (at Lisbon)	**1143**	**1101**	**1101**	**0**
Boundary Inflows	934	923	923	0
Agriculture	44	40	40	0
Urban	4	4	4	0
Natural Land Cover	106	116	116	0
Point Sources	54	18	17	0
Cosumnes River (at Mokelumne R)	**155**	**152**	**154**	**152**
Boundary Inflows	0	0	0	0
Agriculture	33	28	29	28
Urban	8	16	17	16
Natural Land Cover	114	109	109	109
Point Sources	0	0	0	0
Mokelumne River (at Cosumnes R)	**59**	**58**	**59**	**58**
Boundary Inflows	53	53	53	53
Agriculture	6	5	5	5
Urban	0	0	1	0
Natural Land Cover	1	1	1	1
Point Sources	0	0	0	0
Calaveras River (at Stockton)	**119**	**116**	**116**	**116**
Boundary Inflows	72	72	72	72
Agriculture	32	28	28	28
Urban	1	3	3	3
Natural Land Cover	13	13	13	13
Point Sources	0	0	0	0
San Joaquin River (at Vernalis)	**4444**	**4432**	**4425**	**4361**
Boundary Inflows	2144	2161	2162	2163
Agriculture	1929	1844	1842	1838
Urban	44	88	81	74
Natural Land Cover	252	247	247	246
Point Sources	74	92	92	40
TOTAL	**10099**	**9917**	**9956**	**8680**

Table A3-4: WARMF Loading of Total Dissolved Solids to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table A-3)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at Morrison Ck)	**25.16**	**11.72**	**10.24**	**9.59**
Boundary Inflows	1.93	1.95	1.84	1.83
Agriculture	8.30	6.32	6.17	5.91
Urban	0.82	1.17	1.18	1.03
Natural Land Cover	0.77	0.72	0.73	0.73
Point Sources	13.34	1.55	0.32	0.09

Note: The WARMF model simulation results at Morrison Creek were not used by DSM2 as the model handoff occurred further upstream at the I Street Bridge (the Legal Delta Boundary). DSM2 modeling considered sources downstream of I Street. The table is provided as additional information on this reach of the Sacramento River.

Table A3-5: WARMF Loading of Ammonia to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table 26)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at I Street)	**12.52**	**11.19**	**9.86**	**9.37**
Boundary Inflows	1.85	1.87	1.76	1.75
Agriculture	8.31	6.34	6.18	5.91
Urban	0.77	1.13	1.13	0.98
Natural Land Cover	0.75	0.70	0.71	0.71
Point Sources	0.84	1.15	0.08	0.02
Yolo Bypass (at Lisbon)	**2.89**	**2.86**	**2.71**	**2.61**
Boundary Inflows	2.38	2.37	2.25	2.17
Agriculture	0.35	0.34	0.33	0.31
Urban	0.00	0.00	0.00	0.00
Natural Land Cover	0.07	0.07	0.07	0.07
Point Sources	0.08	0.07	0.06	0.05
Cosumnes River (at Mokelumne R)	**3.24**	**3.22**	**3.17**	**3.06**
Boundary Inflows	0.00	0.00	0.00	0.00
Agriculture	1.39	1.22	1.17	1.09
Urban	0.23	0.54	0.54	0.52
Natural Land Cover	1.61	1.46	1.46	1.45
Point Sources	0.00	0.00	0.00	0.00
Mokelumne River (at Cosumnes R)	**0.55**	**0.56**	**0.55**	**0.54**
Boundary Inflows	0.31	0.31	0.31	0.31
Agriculture	0.21	0.20	0.19	0.18
Urban	0.02	0.03	0.03	0.03
Natural Land Cover	0.02	0.03	0.02	0.02
Point Sources	0.00	0.00	0.00	0.00
Calaveras River (at Stockton)	**2.75**	**2.61**	**2.59**	**2.56**
Boundary Inflows	1.80	1.80	1.80	1.80
Agriculture	0.82	0.66	0.63	0.61
Urban	0.03	0.06	0.06	0.06
Natural Land Cover	0.10	0.10	0.10	0.10
Point Sources	0.00	0.00	0.00	0.00
San Joaquin River (at Vernalis)	**4.90**	**4.62**	**4.43**	**4.24**
Boundary Inflows	0.48	0.52	0.53	0.53
Agriculture	4.02	3.94	3.76	3.59
Urban	0.03	0.03	0.03	0.03
Natural Land Cover	0.06	0.06	0.06	0.06
Point Sources	0.31	0.07	0.05	0.03
TOTAL	**26.85**	**25.07**	**23.31**	**22.38**

Table A3-6: WARMF Loading of Ammonia to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table A-3)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at Morrison Ck)	**25.16**	**11.72**	**10.24**	**9.59**
Boundary Inflows	1.93	1.95	1.84	1.83
Agriculture	8.30	6.32	6.17	5.91
Urban	0.82	1.17	1.18	1.03
Natural Land Cover	0.77	0.72	0.73	0.73
Point Sources	13.34	1.55	0.32	0.09

Note: The WARMF model simulation results at Morrison Creek were not used by DSM2 as the model handoff occurred further upstream at the I Street Bridge (the Legal Delta Boundary). DSM2 modeling considered sources downstream of I Street. The table is provided as additional information on this reach of the Sacramento River.

Table A3-7: WARMF Loading of Nitrate to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table 27)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at I Street)	**9.73**	**9.44**	**8.50**	**8.25**
Boundary Inflows	2.65	2.59	2.66	2.66
Agriculture	4.69	4.01	3.99	3.81
Urban	0.44	0.59	0.60	0.55
Natural Land Cover	0.87	0.83	0.84	0.84
Point Sources	1.08	1.42	0.41	0.39
Yolo Bypass (at Lisbon)	**2.96**	**3.16**	**2.69**	**2.63**
Boundary Inflows	1.97	1.93	1.90	1.85
Agriculture	0.48	0.45	0.43	0.42
Urban	0.01	0.01	0.01	0.01
Natural Land Cover	0.21	0.22	0.22	0.22
Point Sources	0.28	0.55	0.13	0.13
Cosumnes River (at Mokelumne R)	**0.53**	**0.50**	**0.49**	**0.46**
Boundary Inflows	0.00	0.00	0.00	0.00
Agriculture	0.39	0.33	0.32	0.29
Urban	0.03	0.06	0.06	0.06
Natural Land Cover	0.12	0.11	0.11	0.11
Point Sources	0.00	0.00	0.00	0.00
Mokelumne River (at Cosumnes R)	**0.18**	**0.15**	**0.15**	**0.15**
Boundary Inflows	0.04	0.04	0.04	0.04
Agriculture	0.14	0.12	0.11	0.11
Urban	0.00	0.00	0.00	0.00
Natural Land Cover	0.00	0.00	0.00	0.00
Point Sources	0.00	0.00	0.00	0.00
Calaveras River (at Stockton)	**0.43**	**0.38**	**0.38**	**0.37**
Boundary Inflows	0.18	0.18	0.18	0.18
Agriculture	0.24	0.19	0.18	0.18
Urban	0.01	0.01	0.01	0.01
Natural Land Cover	0.00	0.00	0.00	0.00
Point Sources	0.00	0.00	0.00	0.00
San Joaquin River (at Vernalis)	**10.44**	**10.37**	**9.66**	**9.42**
Boundary Inflows	4.09	4.10	4.08	4.07
Agriculture	5.18	4.79	4.57	4.36
Urban	0.09	0.07	0.05	0.04
Natural Land Cover	0.62	0.60	0.59	0.59
Point Sources	0.47	0.81	0.36	0.36
TOTAL	**24.27**	**24.01**	**21.86**	**21.27**

Table A3-8: WARMF Loading of Nitrate to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table A-4)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at Morrison Ck)	**7.20**	**14.70**	**9.61**	**9.30**
Boundary Inflows	0.00	2.56	2.62	2.62
Agriculture	4.68	3.99	3.96	3.79
Urban	0.45	0.60	0.61	0.56
Natural Land Cover	0.87	0.83	0.84	0.84
Point Sources	1.19	6.73	1.58	1.48

Note: The WARMF model simulation results at Morrison Creek were not used by DSM2 as the model handoff occurred further upstream at the I Street Bridge (the Legal Delta Boundary). DSM2 modeling considered sources downstream of I Street. The table is provided as additional information on this reach of the Sacramento River.

Table A3-9: WARMF Loading of Phosphorus to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table 28)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at I Street)	**1.487**	**1.492**	**1.076**	**1.034**
Boundary Inflows	0.418	0.445	0.391	0.387
Agriculture	0.658	0.529	0.507	0.485
Urban	0.045	0.071	0.070	0.063
Natural Land Cover	0.097	0.097	0.097	0.097
Point Sources	0.270	0.349	0.010	0.001
Yolo Bypass (at Lisbon)	**0.454**	**0.412**	**0.412**	**0.000**
Boundary Inflows	0.313	0.310	0.309	0.000
Agriculture	0.023	0.022	0.022	0.000
Urban	0.001	0.001	0.001	0.000
Natural Land Cover	0.022	0.022	0.022	0.000
Point Sources	0.095	0.057	0.057	0.000
Cosumnes River (at Mokelumne R)	**0.063**	**0.060**	**0.065**	**0.061**
Boundary Inflows	0.000	0.000	0.000	0.000
Agriculture	0.027	0.020	0.024	0.021
Urban	0.006	0.012	0.013	0.012
Natural Land Cover	0.030	0.028	0.028	0.028
Point Sources	0.000	0.000	0.000	0.000
Mokelumne River (at Cosumnes R)	**0.007**	**0.007**	**0.006**	**0.006**
Boundary Inflows	0.000	0.000	0.000	0.000
Agriculture	0.006	0.005	0.005	0.005
Urban	0.001	0.001	0.001	0.001
Natural Land Cover	0.000	0.000	0.000	0.000
Point Sources	0.000	0.000	0.000	0.000
Calaveras River (at Stockton)	**0.006**	**0.006**	**0.006**	**0.006**
Boundary Inflows	0.000	0.000	0.000	0.000
Agriculture	0.004	0.003	0.003	0.003
Urban	0.001	0.002	0.002	0.002
Natural Land Cover	0.001	0.001	0.001	0.001
Point Sources	0.000	0.000	0.000	0.000
San Joaquin River (at Vernalis)	**1.389**	**1.352**	**1.270**	**1.259**
Boundary Inflows	0.490	0.495	0.505	0.506
Agriculture	0.241	0.214	0.204	0.195
Urban	0.007	0.009	0.008	0.008
Natural Land Cover	0.514	0.514	0.510	0.510
Point Sources	0.137	0.119	0.043	0.039
TOTAL	**3.405**	**3.329**	**2.835**	**2.366**

Table A3-10: WARMF Loading of Phosphorus to the Delta 1976-1991, tons/day (taken from Systech 2011c, Table A-5)

Watershed	Current	Future Planned	Future Plausible	Future Outer Boundary
Sacramento River (at Morrison Ck)	**2.942**	**2.243**	**1.116**	**1.040**
Boundary Inflows	0.427	0.465	0.396	0.391
Agriculture	0.652	0.526	0.503	0.482
Urban	0.048	0.073	0.073	0.066
Natural Land Cover	0.096	0.097	0.097	0.097
Point Sources	1.720	1.082	0.048	0.003

Note: The WARMF model simulation results at Morrison Creek were not used by DSM2 as the model handoff occurred further upstream at the I Street Bridge (the Legal Delta Boundary). DSM2 modeling considered sources downstream of I Street. The table is provided as additional information on this reach of the Sacramento River.