*Prepared for*

**California Urban Water Agencies**
455 Capital Mall, Suite 705
Sacramento, CA 95814

# Urban Runoff Source Control Evaluation

## for Central Valley Drinking Water Policy

*Prepared by*


Geosyntec consultants

engineers | scientists | innovators

1111 Broadway, 6th Floor
Oakland, California 94607


Project No. WW1408

23 March 2011

*Final Report*

# TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF APPENDICES

## EXECUTIVE SUMMARY

The Central Valley Regional Water Board (Water Board) is in the process of developing a long term Drinking Water Policy for the Central Valley. The oversight committee for this work is the Central Valley Drinking Water Policy Workgroup that contains participants from the Water Board, USEPA, and representatives from the drinking water, agricultural, waste water, and urban runoff communities. The Workgroup is focusing its efforts on priority drinking water constituents of concern (COC) that include nutrients, dissolved solids, organic carbon, and pathogens.

As part of the process, the Water Board is funding, through the California Urban Water Agencies (CUWA), a comprehensive modeling effort that will integrate the effects of agricultural, urban, and wastewater discharges on drinking water COCs in the Sacramento-San Joaquin Delta and its tributaries. The Watershed Risk Management Framework (WARMF) model simulates the quantity and quality of runoff from urban areas in the Sacramento Valley and San Joaquin Valley. Results from WARMF ultimately will provide input boundary conditions for the Delta Simulation Model Version 2 (DSM2) to be applied within the Delta.

CUWA contracted with various consultants to provide input information and data to assist in providing input to the modeling effort, including Geosyntec Consultants, whose role was to provide data for calibrating the urban runoff portion of the WARMF model. Data includes existing and projected urban land uses in the Valley and existing urban runoff water quality.

With respect to projected urban land use, California Senate Bill 375 provides funding to Metropolitan Planning Organizations (MPOs), including counsels of governments, to develop sustainable community strategies. As part of this funding, various MPOs throughout the state are developing future urban land use plans that incorporate increased housing density and other smart growth principles. Projected land uses were obtained from the Sacramento Council of Governments (SACOG) and the San Joaquin Valley 8 County Consortium of Council of Governments (the latter through the UC Davis Environmental Information Center). These GIS data were compiled by NewFields who then provided the data to Systech Engineering who conducted the WARMF modeling. The California Department of Conservation Division of Land Resource Protection Farmland Mapping and Monitoring Program provided additional land use data.

Baseline dry and wet weather urban runoff quality data for various land uses from urban runoff discharge monitoring data was collected by the Sacramento Stormwater Quality Partnership and the National Stormwater Quality Database (NSQD). Data were also available from a recently completed wet detention basin effectiveness monitoring study conducted at Natomas Basin 4.

Summaries of the urban runoff quality data were provided, along with recommendations on which data should be used as calibration targets for existing conditions in the WARMF model.

Regulatory scenarios were developed based on current and anticipated trends in stormwater regulations. Information sources consisted of current NPDES permit conditions at various Regional Water Boards throughout the state, current USEPA guidance including recent guidance on the Stormwater Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, and recent policy announcements from USEPA on the incorporation of numeric effluent limits to support TMDLs and other programs. Projections for 2030 were made for planned, plausible and aggressive (“outer boundary”) regulatory scenarios that incorporated new development controls, retrofitting and numeric effluent limits.

For new development controls, BMP performance data were compiled and summarized from data collected by the Sacramento Stormwater Quality Partnership at North Natomas Basin 4 and data contained in the International Stormwater BMP Database. Special emphasis was given to those BMP types that are currently being encouraged as part of Low Impact Development and Green Infrastructure. Performance data were provided in the form of median effluent quality, which are considered to provide more robust estimates of performance than measures that had been traditionally used in the past. Recommendations on the BMP data to use in the model calibration varied depending on land use type, since different BMPs have been developed for different applications. Also the implementation of BMPs that primarily rely on infiltration was restricted, based on an evaluation of soil infiltration capacity in the Sacramento Valley and in the San Joaquin Valley.

The regulatory scenarios also included consideration of numeric effluent limits. Based on nutrient data compiled as part of the Conceptual Model for Nutrients in the Central Valley and Sacramento-San Joaquin Delta (Tetra Tech, 2006), numeric effluent limits were projected for 2030 in the San Joaquin Valley. Nominal effluent limits of TN of 2 mg/l and TP of 0.2 mg/L were postulated for the probable scenario, with TN of 1 mg/L and TP of 0.1 mg/L postulated for the more aggressive outer boundary regulatory scenario.

Retrofitting of existing industrial development was considered in the outer boundary scenario, since retrofitting is a regulatory tool that may be implemented in the future. This scenario assumes that retrofitting would be prioritized based on risk to receiving waters, which in turn is dependent on land use and specific activities on those land uses. For the purpose of the modeling, it was assumed that industrial land uses would be required to implement specific types of BMPs. In this case, the performance data for media filters were assumed to be representative of treatment that industries could potentially select to meet the retrofitting requirement.

BMP cost estimates were made through stormwater BMP costing templates provided by the Water Environment Research Foundation (WERF) that included land, capital, and maintenance costs. Additional information on construction and maintenance costs were provided by the City of Sacramento for the Natomas Basin 4, which were then used to guide the choice of unit costs in the WERF templates. Costs were converted to present value and normalized on a per acre of drainage area served. Total costs were estimated as the product of unit costs and projected increase in urban land uses. The total costs, which are intended to provide rough order of magnitude estimates only, ranged from 13 to 19 billion dollars depending on the scenario.

Although fecal indicator bacteria and pathogens such as *Cryptosporidium* and *Giardia* cannot be accurately modeled in WARMF, the study did review available literature on the presence of pathogens in stormwater. Such data is quite limited in the urban runoff literature. The Water Environment Research Foundation recently completed a study that sampled dry and wet weather runoff from various locations throughout the United States. Dry weather samples taken in Southern California were found to contain no detectible concentrations of *Cryptosporidium* or *Giardia*. Approximately 50% of wet weather samples collected at locations primarily in southeast U.S. did have detectible concentrations of *Cryptosporidium* and *Giardia*. Dry and wet weather data (3 dry weather station events and 5 wet weather station events) also have been collected and analyzed by the City of Stockton and County of San Joaquin for selected pathogenic viruses, and viruses (adenovirus) was detected in one of 30 wet weather urban discharge samples. A preliminary study conducted by the Sacramento Stormwater Quality Partnership collected five wet weather samples and 6 dry weather samples in various receiving waters and found no detections, but the study authors reported limits of detection that were higher than in another study that used the same detection methods.

# 1. INTRODUCTION

## 1.1 Background

California's Central Valley watershed is 40 percent of the land area in California, provides over 50 percent of the managed water supply, and contains 77 percent of the irrigated agriculture in California. Urban runoff, treated wastewater effluent, and agricultural practices discharge constituents that have the potential to affect downstream drinking water treatment facilities. Some of these drinking water constituents of concern include organic carbon that can contribute to carcinogenic compound formation during drinking water treatment, and pathogens. Additional drinking water constituents of concern include salinity and nutrients, which may cause taste and odor or downstream algal bloom issues. In response to these issues, the Central Valley Regional Water Quality Control Board (Water Board) is conducting a multi-year effort to develop a drinking water policy for surface waters. The goal of this effort is to help guide the Water Board in developing a policy to provide improved source water protection.

As part of this effort, the Water Board established a Central Valley Drinking Water Policy Workgroup (Workgroup) consisting of various stakeholders from the agricultural, urban runoff, waste water, and drinking water supply communities and State and federal agencies. The Workgroup developed a scope of work that contains a series of technical tasks that include reviewing and evaluating the effectiveness of a range of source control measures in controlling drinking water constituents of concern (COCs).

## 1.2 Project Objective

The objective of this project is to characterize urban runoff sources of drinking water COCs and summarize data on the effectiveness of various control measures in reducing the volume and improving the quality of dry and wet weather runoff from urban areas.

A key part of the project is to predict what the regulatory environment may be in 2030 for urban runoff management and stormwater Best Management Practice (BMP) implementation for existing and new development in the Central Valley. Three 2030 regulatory scenarios were developed. The 2030 Planned Changes Scenario describes a 2030 regulatory environment that implements present day 2011 regulations without any change. The Probable Scenario describes anticipated regulations based on current regulatory trends. The Outer Boundary Scenario represents a more stringent 2030 regulatory environment.

After summarizing the urban runoff data, Systech Engineering, Inc. will utilize this information in calibrating the urban runoff element in the Watershed and Risk Management Assessment Model (WARMF) to evaluate the benefits associated with each scenario. Geosyntec also conducted a planning level cost estimate for the scenarios, so that benefits could be evaluated in the context of estimated costs.

## 1.3 Organization of Report

Following this introductory section, Section 2 discusses sources and pathways of drinking water COCs and summarizes data from regional and national data sources. Section 3 discusses stormwater quantity and quality control technologies with an emphasis on applicability to new development. Stormwater regulatory requirements and trends are discussed in Section 4 along with projected regulatory requirements in 2030. Section 5 provides recommendations on how data summarized in Sections 2 and 3 can be utilized in the calibration of the WARMF model for existing conditions and for each regulatory scenario. Planning level costs for selected BMPs are provided in Section 6 as a means of estimating the cost of implementing BMPs associated with each regulatory scenario. Section 7 summarizes key assumptions and limitations.

## 1.4 Drinking Water Constituents of Concern (COCs)

One of the first tasks conducted by the Workgroup was to select high priority drinking water constituents of concern (COCs), which include the following: organic carbon, nutrients, pathogens, and salinity. The Workgroup also funded the development of conceptual models for each COC (Tetra Tech 2006a, Tetra Tech 2006b, CALFED 2007, and Tetra Tech 2007). The following describes each of these constituents and the species of interest.

### 1.4.1 Organic Carbon

Carbon is nature’s building block for cell growth and is therefore found in all plant and animal organisms. Organic carbon in water reacts with disinfectants used in water treatment plants to form carcinogenic compounds called disinfection byproducts (DBPs) including total trihalomethanes (TTHMs) and haloacetic acids (HAA5s). According to the U.S. Environmental Protection Agency, DBPs have been associated with an increased risk of cancer; liver, kidney, and central nervous system problems; and adverse reproductive effects (USEPA, 2001). DBPs are regulated by the Stage 1 and Stage 2 Disinfectants/Disinfection Byproducts Rules. The Stage 1 Rule established Maximum Contaminant Levels for TTHMs and HAA5 and established treatment requirements based on the concentrations of organic carbon and the levels of alkalinity in source waters. Additional removal of organic carbon is required when the source water TOC concentration exceeds 2 mg/L.

### 1.4.2 Nutrients

Plants in aquatic environments undergo photosynthesis whereby nutrients and carbon are metabolized in the presence of light. Nutrients are required for the proper functioning of aquatic ecosystems but when they are present in drinking water supplies at concentrations that exceed natural background levels, a number of adverse impacts occur. When nutrients are readily available and other environmental conditions are favorable, algal growth can reach levels that cause taste and odor in drinking water, add organic carbon, obstruct water conveyance facilities, clog filters, and increase the quantity and expense of handling solid waste from the treatment process. Excessive nutrients in the environment also may cause eutrophication, which can lead to changes in algae, benthic, and fish communities, and in the extreme, cause hypoxia or anoxia, resulting in fish kills.

The primary nutrients are nitrogen and phosphorus, both of which may limit algal growth depending on the relative amounts of each in the water body, and on limiting factors such as light and temperature. Inorganic nitrogen species are more bioavailable for phytoplankton growth and include ammonia, nitrite and nitrate. Total Kjeldahl nitrogen includes the dissolved and particulate forms of organic nitrogen and ammonia. Similarly, inorganic forms of phosphorus are more bioavailable. Dissolved orthophosphate is considered the only form of phosphorus that is bioavailable (Tetra Tech 2006b), although particulate phosphorus in sediments can be recycled under anaerobic conditions.

The setting of numeric effluent limits (NELs) for nutrients is an active area of research and regulatory focus and is complicated by the number and interactive nature of site-specific factors that affect photosynthesis in streams, rivers, and lakes.

### 1.4.3 Dissolved Solids

Dissolved solids are primarily ionic inorganic substances (salts) such as calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, bromide and nitrate. Bromide is of particular interest in that it can also act as a precursor to the formation of DBPs. Elevated dissolved solids can adversely affect taste and shorten the life of plumbing fixtures and appliances. High levels of TDS in drinking water restrict the ability of water and wastewater agencies to recycle the water and to recharge groundwater supplies. The Secondary Maximum Contaminant Level (MCL) for total dissolved solids (TDS) in drinking water is a recommended level of 500 mg/L, which is also the water quality objective for the municipal water supply (MUN) beneficial use (Starr, 2007). Other measures of dissolved solids include chloride that has a Secondary MCL with a recommended level of 250 mg/L and electrical conductivity that has a Secondary MCL with a recommended level of 900 mg/L.

### 1.4.4 Fecal Indicator Bacteria and Pathogens

Fecal Indicator Bacteria (FIB) are bacteria that are found in the intestines and feces of all warm blooded animals. For this reason FIB have historically been used as a surrogate for actual pathogens that may be present in the intestines of warm blooded animals (http://water.epa.gov/type/rsl/monitoring/vms511.cfm). FIB examples include fecal coliform, *E. coli* (as single species within the fecal coliform group), and *Enterococcus*. USEPA water quality criteria are available for FIB for both drinking water and recreational beneficial waterbody uses. Recreational criteria apply to waterbodies, such as the Sacramento and San Joaquin Rivers, which are designated for recreational uses. Such waterbodies may be impacted primarily by agricultural and urban runoff, whereas the recreational water quality criteria were originally developed based on epidemiological data from waterbodies that receive undisinfected municipal wastewater treatment plan effluent, thereby limiting their reliability for use as indicators of actual pathogens. Researchers and the EPA have recently acknowledged these weaknesses, and so the USEPA is now in the process of re-evaluating the current set of FIB-based recreational water quality criteria (USEPA 2007).

Pathogens include various forms of viruses, bacteria, and protozoa. Protozoa of concern in drinking water sources include *Giardia* and *Cryptosporidium*. The degree of treatment required for pathogens is based on source water levels of pathogens. The minimum treatment requirements are 2-log removal/inactivation of *Cryptosporidium*, 3-log removal/inactivation of *Giardia*, and 4-log removal/inactivation of viruses. The California Department of Public Health requires additional removal of *Giardia* if the source water average exceeds 0.01 cysts/L. Additional treatment or watershed protection is required if the average *Cryptosporidium* level exceeds 0.075 oocysts/L. The EPA has identified FIB and pathogens as the greatest cause (by pollutant category) of beneficial use impairment in rivers and streams in the United States (http://iaspub.epa.gov/tmdl_waters10/attains_nation_cy.control#causes).

## 1.5 <u>Role of WARMF Model</u>

Two WARMF models, one for the Sacramento Valley, and one for the San Joaquin Valley were developed by Systech Engineering to simulate the effects of agricultural, urban and waste water discharges on drinking water constituents of concern (exclusive of pathogens and pathogen indicators). The models are process based and address many of the physical, chemical and biological processes that can affect the drinking water quality. In the case of urban effects modeling, the WARMF model also includes treatment processes such as porous pavement, detention basins, and street sweeping. The purpose of this report was to provide data that could be used to support calibration and verification for the characterization and control of urban runoff sources in the WARMF model.

# 2. URBAN SOURCES OF DRINKING WATER COCS

## 2.1 Sources and Pathways of COCs

Sources of COCs refer to the activities that introduce the COCs into the environment, whereas pathways refer to the means by which COCs are mobilized and transported in the environment. For example, application of the nutrients to landscaping is a source activity, whereas excessive irrigation that causes these nutrients to be conveyed into the storm drain system may be viewed as a pathway. Section 2.2 below summarizes source activities for drinking water COCs, and Section 2.3 addresses pathways.

## 2.2 Sources of Drinking Water COCs

### 2.2.1 Organic Carbon

Urban sources that may contribute to elevated levels of organic carbon in stormwater runoff include: soil erosion; leaf and plant litter; fecal matter pollution that include pet wastes, leaks from failing septic systems, combined and separated sewer overflows; atmospheric deposition of combustion related emissions that may contain unburned hydrocarbon byproducts; and spills of oil and gasoline.

Widespread loss of organic carbon from soil erosion is a growing concern in the scientific community (Brown *et. al*., 2010). A study by Sickman demonstrated through the use of radiocarbon dating, that dissolved organic carbon in Central Valley waterways is the oldest carbon currently reported. The source of this old carbon in the waterways is considered to be soil organic matter that has been disturbed and eroded by human activity (Sickman, 2010). For example, construction practices associated with urban development can lead to excessive erosion of soils and associated carbon.

### 2.2.2 Nutrients

Urban sources of nutrients include landscaping fertilization, septic system leaks, CSO discharges, animal wastes, and atmospheric deposition associated with fuel combustion or industrial emissions. Other sources may include runoff that contains sediment and plant matter.

### 2.2.3 Dissolved Solids

Dissolved solids concentration and composition in natural waters is largely determined by the mineral assemblage of soils and rocks near the soil surface. Dissolved solids also include constituents of concern, such as bromide. While dissolved solids in surface and ground water can be caused by dissolution of salts that are naturally present in soils and rocks (CVRWQCB, 2008a), a study conducted by LWA for the Central Valley Salinity Coalition found that the primary sources of dissolved solids inputs to near surface groundwater (a portion of which eventually discharges to surface water) are the land application of irrigation and fertilizers.

Dissolved solids in fertilizer applications, imported water or irrigation water, may run off from urban landscaped areas. An additional concern for dissolved solids is the accumulation of salts. The LWA study demonstrated through mass balances that dissolved solids are increasing in near surface groundwater, indicating that there is accumulation over time from dissolved solids inputs (LWA 2010a).

Other specific sources of bromide and chloride in urban areas may include chlorine and bromine applications to pools, which may be improperly drained (USEPA, 2010a). Another source may be land-applied chemicals, including current and legacy pollutants such as chlorinated pesticides and methyl bromide, a fumigant which was phased out in 2005 due to air pollution concerns (USEPA, 2010b).

### 2.2.4 Bacteria, Viruses and Protozoa

Pathogens are disease-causing bacteria, protozoa, and viruses, including those derived from fecal materials. Pathogens may be introduced into source waters through the mobilization of domestic animal, wildlife, or human fecal wastes from the watershed by stormwater runoff. Even runoff from natural areas can contain pathogens (e.g., from wildlife). Other sources of bacteria, viruses, and protozoa in urban areas include pets, septic systems, combined sewer overflows, illicit sewer connections, creekside homeless encampments, illegal RV discharges, and leaky sanitary sewer systems. The presence of bacteria, viruses, and protozoa in runoff can impair receiving waters and contaminate drinking water sources. Elevated bacteria, virus and protozoa concentrations in receiving waters are typically caused by the transport of animal or human fecal wastes from the watershed.

#### *2.2.4.1 Fecal Indicator Bacteria (FIB)*

Sources of FIB include sanitary sewer overflows (SSOs), combined sewer overflows (CSOs), wet weather stormwater discharges from municipal separate storm sewer systems (MS4s), illicit connections to storm sewer systems that affect dry weather urban discharges, failing or improperly located onsite wastewater treatment systems (septic systems), and runoff from areas where fecal matter has been deposited by domestic pets and other animals.

Human sources have been found to be a significant source of bacteria in runoff. A 2005 Caltrans stormwater quality study analyzed 56 runoff samples from agricultural, urban and highway land uses. The researchers filtered 100 liters of water to concentrate bacteria, protozoa, and viruses. Microbial source tracking (MST) based on quantitative determination of human *Bacteriodales* marker found that 14 of 17 samples contained the human *Bacteriodales* marker (a DNA marker that is specific to human fecal material) (Caltrans, 2005).

Regardless of sources, FIB concentrations in urban stormwater are typically well above primary contact recreation standards, regardless of land use (Pitt, Mastre and Morquecho, 2008). Indicator bacteria also may grow under certain conditions where temperature and light are favorable, including storm drains, sediments, and vegetation.

#### *2.2.4.2 Protozoa*

Protozoa, including *Cryptosporidium* and *Giardia*, are single-celled, intestinal pathogenic parasites that infect both humans and animals. *Cryptosporidium* are widespread in ambient water and can persist for months in the environment. Urban sources of protozoa may include sources associated with combined or sanitary sewer overflows or other sources associated with animal and human waste independent of the sewer and wastewater treatment systems. Sewer system overflows can occur when their hydraulic capacity is exceeded, especially due to storm runoff inflow and infiltration or if blockages or pump or conveyance failures occur. The City of Sacramento combined sewer system in the older downtown “core” area conveys and treats both sewage and urban runoff and wildlife waste. Intermittent discharges to the Sacramento River occur when flows to the Sacramento Regional Wastewater Treatment Plant exceed 60 MGD and available storage is filled. In all but extreme conditions, this combined system flow is disinfected prior to river discharge.

Information on protozoa concentrations in urban stormwater runoff is limited. *Cryptosporidium* and *Giardia* are costly to measure. Additionally, wide variations in concentrations have been observed, making source identification challenging (USEPA, 2001a; Crokett and Haas, 1997, as referenced by Pitt, 2007).

Protozoa have been shown to be present in urban stormwater runoff. A monitoring study of 22 stormwater detention ponds in Florida demonstrated the presence of protozoa in runoff from developed areas. One of 29 samples (3.5%) of *Cryptosporidium* exceeded minimum detection limits (MDL is 10 oocysts/100 L), and was found in a detention pond adjacent to a heavily travelled highway. Three of 28 samples (10.7%) of *Giardia* exceeded the detection limit (MDL is 10 oocysts/100 L), which were associated with two urban roadway ponds and one pond located in a residential community known to use septic systems (Shaber, 2007).

The Water Environment Research Federation (WERF) is currently finalizing the draft final report of a research study led by Stefan Wuertz at University of California at Davis designed to help managers assess the risk of pathogens from a variety of sources (Bambic et al, 2010). As part of this project, the researchers collected and analyzed 8 dry and 29 wet weather samples from urban catchments. The 8 dry weather samples were obtained from one storm event at eight urbanized sites in southern California. The 29 wet weather samples were obtained from multiple events at residential and commercial/light industrial areas located in the Mid-Atlantic U.S., Southeastern U.S., and Texas. The data were analyzed for sources (including human *Bacteroidales*), and pathogens including protozoa, bacterial pathogens, and viruses. *Cryptosporidium* concentrations by microscopy indicated 100 percent non-detect in dry weather samples, 50 percent non-detect in runoff samples from residential catchments, and 77 percent non-detect from commercial/light industrial catchments. *Giardia* concentrations by microscopy were 85 percent non-detect in commercial/light industrial catchments, and 44 percent non-detect in residential catchments.

#### *2.2.4.3 Viruses*

Viruses, specifically enteroviruses, are pathogens which live in the intestines of infected humans and animals. Non-polio enteroviruses, which can often survive in water, are the second most common cause of viral infection in humans (CDC, http://www.cdc.gov/healthywater/drinking/private/wells/disease/enterovirus.html).

Viruses are difficult to sample without sophisticated measurement and analytical techniques, thus data regarding viruses in stormwater is limited. Viruses are known for host-specificity, in that there is little evidence of cross-species transmission, but research is still needed in this area (EPA, 2009). The 2005 Caltrans stormwater quality study tested for viruses in California stormwater. Human adenovirus and enterovirus, which were targets of the study, were found in 1 of 56 stormwater samples (Caltrans, 2005).

Results from the WERF study cited above found for example, that Enterovirus concentrations by quantitative Polymerase Chain Reaction (qPCR) was 38 percent non-detect in 13 runoff samples collected from commercial/light industrial catchments, and 44 percent non-detect in the 16 samples collected in runoff from residential catchments. Other viruses and associated percent non-detects for residential land uses were: Rotovaris (44% non-detect), Adenovirus (56%), and Norovirus (63 %).

The City of Stockton and County of San Joaquin are funding a UC/Davis study as part of a Pathogen Plan whose goal is to identify, monitor, and mitigate the controllable sources of bacteria in urban discharges to the San Joaquin River and tributaries (City of Stockton and County of San Joaquin, 2010). The study is a three phase project with a focus on viruses in urban stormwater discharges and local water bodies subject to the discharges. Samples were obtained for three dry weather events and five wet weather events at six urban drainage sites, one waterbody site, and an upstream site during the 2008/2009 and 2009/2010 monitoring periods. As of Phase II virus assays for four types of adenovirus and enterovirus were performed, and adenovirus were detected in one wet weather sample in an urban drainage site.

The Sacramento Stormwater Partnership also funded a UC/Davis study (McCaslin, 2008) to conduct a preliminary microbial source tracking and pathogen detection study that involved sampling in 2005/2006 two dry and two wet weather events at American River at Discovery Park and Strong Ranch Slough. Sampling for one dry and one wet event was also conducted at Arcade Creek at Watt Avenue and one dry weather sample was taken in the Sacramento River at Freeport Marina. Viruses were assayed in all samples, but none were detected. However, the authors note that limits of detection were higher than those in a previous published study using the same analytical methods.

## 2.3 Pathways for Drinking Water COCs

Pathways for urban runoff generally refer to the various means by which constituents are transported in the urban environment by a drainage system designed to convey runoff from various surfaces including roofs, parking lots, and roads into receiving waters. Stormwater monitoring also has tended to investigate runoff in terms of land use, which may also be considered a type of pathway.

COCs vary with land use based on specific activities associated with that land use. Land use specific data is summarized in this section from available data sources.

### 2.3.1 Stormwater Quality Data by Land Use

Available land-use specific stormwater quality data is summarized here. Data includes the Sacramento Stormwater Quality Partnership monitoring data, which has been collected at a number of locations since the 1990s, and the National Stormwater Quality Database (NSQD), a database supported by USEPA and managed by the University of Alabama, which includes land-use based stormwater data from 16 states (Pitt et. al., 2008).

The Sacramento Stormwater Quality Partnership has conducted monitoring of stormwater runoff quantity and quality at a number of different monitoring locations, including urban drainage areas and receiving waters.

#### *2.3.1.1 Strong Ranch Slough*

Strong Ranch Slough drains a 4,446 acre mixed use portion of the County of Sacramento. The catchment is primarily residential consisting of 72% light density residential, 13% medium density residential, and 1% high density residential. The remaining land use of 14% is commercial. Stormwater samples have been collected at this location since the 1994/95 storm season.

Table 2.1 summarizes drinking water COC data at Strong Ranch Slough for dry weather and Table 2-2 summarizes the wet weather data.

**Table 2-1: Dry Weather Summary of Drinking Water COCs at Strong Ranch Slough**

| Constituent Class | Constituent | Number of Dry Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 18 | 10.4 | 12.2 | mg/l |
| | Total Organic Carbon | 18 | 9.5 | 13.0 | mg/l |
| Nutrients | Ammonia as N | 6 | 0.20 | 0.20 | mg/L |
| | Nitrate as N | 6 | 0.10 | 0.28 | mg/L |
| | Nitrate as NO3 | 2 | 0.67 | 0.67 | mg/L |
| | Nitrite as N | 8 | 0.10 | 0.12 | mg/L |
| | Nitrate plus Nitrite as N | 10 | 0.10 | 0.12 | mg/L |
| | Total Kjeldahl Nitrogen | 14 | 1.05 | 1.09 | mg/L |
| | Phosphorus Total | 17 | 0.20 | 0.26 | mg/L |
| Dissolved Solids | Specific Conductance | 6 | 310 | 292 | µmhos/cm |
| | Specific Conductance[1] | 5 | 296[1] | 311[1] | µmhos/cm |
| | Solids Total Dissolved | 17 | 250 | 295 | mg/l |
| Bacteria | Escherichia Coli | 12 | 1,550 | 78,700 | MPN/100 mL |
| | Fecal Coliform | 15 | 3,000 | 65,300 | MPN/100 mL |
| | Total Coliform | 13 | 30,000 | 151,400 | MPN/100 mL |

**Notes:**
[1] Field measurement

**Table 2-2: Wet Weather Summary of Drinking Water COCs at Strong Ranch Slough**

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 33 | 8.9 | 13.1 | mg/L |
| | Total Organic Carbon | 35 | 11 | 16.7 | mg/L |
| Nutrients | Ammonia as N | 13 | 0.4 | 0.52 | mg/L |
| | Nitrate as N | 6 | 0.59 | 0.53 | mg/L |
| | Nitrate as NO3 | 12 | 2.1 | 2.2 | mg/L |
| | Nitrite as N | 18 | 0.15 | 0.13 | mg/L |
| | Nitrate plus Nitrite as N | 19 | 0.54 | 0.61 | mg/L |
| | Total Kjeldahl Nitrogen | 23 | 1.8 | 2.8 | mg/L |
| | Orthophosphate as P | 2 | 0.5 | 0.72 | mg/L |
| | Phosphorus Total | 35 | 0.26 | 0.26 | mg/L |
| Dissolved Solids | Specific Conductance | 11 | 69 | 86.9 | µmhos/cm |
| | Specific Conductance (field) | 9 | 62.7 | 84.6 | µmhos/cm |
| | Solids Total Dissolved | 34 | 56.5 | 66.1 | µmhos/cm |
| Bacteria | Escherichia Coli | 22 | 13,000 | 24,909 | MPN/100 mL |
| | Fecal Coliform | 32 | 22,000 | 47,938 | MPN/100 mL |
| | Fecal Streptococcus | 7 | 230,000 | 489,143 | MPN/100 mL |
| | Total Coliform | 26 | 170,000 | 658,115 | MPN/100 mL |

#### *2.3.1.2 Sump 104*

Sump 104 is a collection point for stormwater drained from an 867 acre mixed use portion of the City of Sacramento near to the sump location. The catchment is 85% light density residential, with the rest a mix of commercial, multi-family residential, industrial, park, and recreational. Sump 104 also receives runoff from other sump outflows for a total collection area of 2,220 acres of mixed commercial and residential land uses. Six storm pumps and one summer pump convey water to the Sacramento River. Stormwater monitoring began at this location during the 1990/91 storm season (LWA, 2010b). Table 2-3 provides the dry weather summary and Table 2-4 provides the wet weather summary of the drinking water COCs at Sump 104.

#### *2.3.1.3 Sump 111*

Sump 111 is a collection point for stormwater drained from an industrialized 439 acre portion of the City of Sacramento (98% industrial land use). Three storm pumps and one summer pump convey water to the American River. The Partnership has collected samples at this location since the 1989/90 storm season (LWA, 2010b). Table 2-5 summarizes the dry weather data and Table 2-6 summarizes the wet weather data for the drinking water COCs at Sump 111.

#### *2.3.1.4 Natomas Basin 4*

The Natomas Basin 4 drainage area consists of approximately 470 acres. The primary land use within the Basin 4 drainage area is low density single family residential with some multi-family residential, commercial, and schools. The drainage area also includes the 37 acre Natomas Community Park. The area drains into a wet detention basin, which settles and treats pollutants before discharging into the East Drainage Canal, which eventually drains to the Sacramento River (Geosyntec, 2010).

Table 2-7 gives the dry weather summary and Table 2-8 gives the wet weather summary of the drinking water COCs at the inflow to Natomas Basin 4.

**Table 2-3: Dry Weather Summary of Drinking Water COC Monitoring Data at Sump 104**

| Constituent Class | Constituent | Number of Dry Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 13 | 6.0 | 8.8 | mg/L |
| | Total Organic Carbon | 13 | 9.0 | 8.9 | mg/L |
| Nutrients | Ammonia as N | 9 | 0.40 | 0.60 | mg/L |
| | Nitrate as N | 8 | 2.25 | 2.41 | mg/L |
| | Nitrate as NO3 | 2 | 3.50 | 3.50 | mg/L |
| | Nitrite as N | 9 | 0.15 | 0.27 | mg/L |
| | Nitrate plus Nitrite as N | 8 | 1.80 | 2.00 | mg/L |
| | Total Kjeldahl Nitrogen | 13 | 1.00 | 1.17 | mg/L |
| | Dissolved Phosphorus | 1 | 0.50 | 0.50 | mg/L |
| | Total Phosphorus | 17 | 0.40 | 0.40 | mg/L |
| Dissolved Solids | Specific Conductance | 4 | 450 | 450 | µmhos/cm |
| | Specific Conductance (field) | 3 | 416 | 431 | µmhos/cm |
| | Solids Total Dissolved | 17 | 310 | 316 | mg/l |
| Bacteria | Escherichia Coli | 10 | 3,000 | 8,200 | MPN/100 mL |
| | Fecal Coliform | 14 | 6,000 | 23,000 | MPN/100 mL |
| | Fecal Streptococcus | 2 | 67 | 67 | MPN/100 mL |
| | Total Coliform | 14 | 65,000 | 167,200 | MPN/100 mL |

**Table 2-4: Wet Weather Summary of Drinking Water COC Monitoring Data at Sump 104**

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 26 | 9.4 | 14.2 | mg/L |
| | Total Organic Carbon | 29 | 11.0 | 18.5 | mg/L |
| Nutrients | Ammonia as N | 22 | 0.53 | 0.60 | mg/L |
| | Nitrate as N | 16 | 0.80 | 1.1 | mg/L |
| | Nitrate as NO3 | 11 | 3.2 | 3.0 | mg/L |
| | Nitrite as N | 28 | 0.11 | 0.12 | mg/L |
| | Nitrate plus Nitrite as N | 17 | 0.72 | 0.98 | mg/L |
| | Total Kjeldahl Nitrogen | 28 | 1.7 | 2.8 | mg/L |
| | Orthophosphate as P | 2 | 0.37 | 0.37 | mg/L |
| | Dissolved Phosphorus | 10 | 0.14 | 0.17 | mg/L |
| | Phosphorus Total | 41 | 0.40 | 0.54 | mg/L |
| Dissolved Solids | Specific Conductance | 5 | 92 | 408 | µmhos/cm |
| | Specific Conductance (field) | 4 | 58.1 | 105 | µmhos/cm |
| | Solids Total Dissolved | 46 | 71.5 | 90.8 | mg/l |
| Bacteria | Escherichia Coli | 15 | 22,000 | 103,133 | MPN/100 mL |
| | Fecal Coliform | 41 | 70,000 | 476,073 | MPN/100 mL |
| | Fecal Streptococcus | 20 | 225,000 | 709,165 | MPN/100 mL |
| | Total Coliform | 40 | 280,000 | 1,772,175 | MPN/100 mL |

**Table 2-5: Dry Weather Summary of Drinking Water COC Monitoring Data at Sump 111**

| Constituent Class | Constituent | Number of Dry Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 17 | 11.0 | 12.4 | mg/l |
| | Total Organic Carbon | 17 | 11.0 | 16.3 | mg/l |
| Nutrients | Ammonia as N | 9 | 0.20 | 0.46 | mg/l |
| | Nitrate as N | 9 | 0.12 | 0.30 | mg/l |
| | Nitrate as NO3 | 2 | 3.31 | 3.31 | mg/l |
| | Nitrite as N | 10 | 0.10 | 0.20 | mg/l |
| | Nitrate plus Nitrite as N | 10 | 0.35 | 0.51 | mg/l |
| | Total Kjeldahl Nitrogen | 15 | 1.00 | 1.00 | mg/l |
| | Dissolved Phosphorus | 1 | 0.49 | 0.49 | mg/l |
| | Total Phosphorus | 19 | 0.40 | 0.51 | mg/l |
| Dissolved Solids | Specific Conductance | 6 | 220 | 235 | µmhos/cm |
| | Specific Conductance (field) | 5 | 310 | 281 | µmhos/cm |
| | Solids Total Dissolved | 19 | 170 | 162 | mg/l |
| Bacteria | Escherichia Coli | 12 | 750 | 3,600 | MPN/100 mL |
| | Fecal Coliform | 16 | 4,000 | 110,300 | MPN/100 mL |
| | Fecal Streptococcus | 2 | 1,600 | 1,600 | MPN/100 mL |
| | Total Coliform | 14 | 150,000 | 272,500 | MPN/100 mL |

**Table 2-6: Wet Weather Summary of Drinking Water COC Monitoring Data at Sump 111**

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 31 | 7.9 | 10.9 | mg/l |
| | Total Organic Carbon | 33 | 9.5 | 13.3 | mg/l |
| Nutrients | Ammonia as N | 24 | 0.51 | 0.50 | mg/l |
| | Nitrate as N | 17 | 0.56 | 0.75 | mg/l |
| | Nitrate as NO3 | 11 | 2.7 | 2.7 | mg/l |
| | Nitrite as N | 28 | 0.1 | 0.10 | mg/l |
| | Nitrate plus Nitrite as N | 23 | 0.65 | 0.72 | mg/l |
| | Total Kjeldahl Nitrogen | 33 | 1.6 | 2.1 | mg/l |
| | Orthophosphate as P | 2 | 0.16 | 0.16 | mg/l |
| | Dissolved Phosphorus | 10 | 0.11 | 0.13 | mg/l |
| | Phosphorus Total | 49 | 0.25 | 0.34 | mg/l |
| Dissolved Solids | Specific Conductance | 11 | 49 | 57.2 | µmhos/cm |
| | Specific Conductance (field) | 9 | 67.5 | 84.5 | µmhos/cm |
| | Solids Total Dissolved | 50 | 43.5 | 56.2 | mg/l |
| Bacteria | Escherichia Coli | 21 | 3,000 | 5,180 | MPN/100 mL |
| | Fecal Coliform | 46 | 13,000 | 110,600 | MPN/100 mL |
| | Fecal Streptococcus | 21 | 30,000 | 147,800 | MPN/100 mL |
| | Total Coliform | 40 | 160,000 | 421,000 | MPN/100 mL |

**Table 2-7: Dry Weather Summary of Drinking Water COCs from Natomas Influent**

| Constituent Class | Constituent | Dry Weather Samples | Percent Detected | Median | Arithmetic Mean | Geometric Mean | Units |
|---|---|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 2 | 100% | 5.4 | 5.4 | | mg/L |
| | Total Organic Carbon | 4 | 100% | 6.2 | 6.3 | | mg/L |
| Nutrients | Ammonia (as N) | 4 | 100% | 0.28 | 0.27 | | mg/L |
| | Dissolved Orthophosphate as P | 2 | 100% | 0.22 | 0.22 | | mg/L |
| | Nitrate (as N) | 2 | 100% | 0.45 | 0.45 | | mg/L |
| | Nitrite (as N) | 2 | 100% | 0.02 | 0.02 | | mg/L |
| | Nitrogen, Nitrate-Nitrite | 2 | 100% | 0.51 | 0.51 | | mg/L |
| | Total Kjeldahl Nitrogen | 4 | 100% | 1.2 | 1.2 | | mg/L |
| | Total Dissolved Phosphorus | 3 | 100% | 0.25 | 0.27 | | mg/L |
| | Total Orthophosphate as P | 3 | 100% | 0.29 | 0.29 | | mg/L |
| | Total Phosphorus as P | 4 | 100% | 0.30 | 0.30 | | mg/L |
| Dissolved Solids | Conductivity | 2 | 100% | 240 | 240 | | umhos/cm |
| | Total Dissolved Solids | 4 | 100% | 178 | 170 | | mg/L |
| | Turbidity | 2 | 100% | 2.1 | 2.1 | | NTU |
| Bacteria[1] | E. coli | 4 | 100% | 1,200 | 1,580 | 1,410 | MPN/100 mL |
| | Fecal Coliform | 2 | 100% | 4,000 | 4,000 | 3,870 | MPN/100 mL |
| | Total Coliform | 2 | 100% | 100,500 | 100,500 | 92,400 | MPN/100 mL |

**Table 2-8: Wet Weather Summary of Drinking Water COCs from Natomas Influent**

| Constituent Class | Constituent | Wet Weather Samples | Percent Detected | Median | Arithmetic Mean | Geometric Mean | Units |
|---|---|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 6 | 100% | 6.1 | 5.8 | | mg/L |
| | Total Organic Carbon | 8 | 100% | 6.8 | 7.0 | | mg/L |
| Nutrients | Ammonia (as N) | 9 | 100% | 0.42 | 0.40 | | mg/L |
| | Dissolved Orthophosphate as P | 2 | 100% | 0.22 | 0.22 | | mg/L |
| | Nitrate (as N) | 2 | 100% | 0.45 | 0.45 | | mg/L |
| | Nitrite (as N) | 2 | 100% | 0.07 | 0.07 | | mg/L |
| | Nitrogen, Nitrate-Nitrite | 6 | 100% | 0.78 | 0.77 | | mg/L |
| | Total Dissolved Phosphorus | 5 | 100% | 0.24 | 0.28 | | mg/L |
| | Total Kjeldahl Nitrogen | 8 | 100% | 1.4 | 1.6 | | mg/L |
| | Total Orthophosphate as P | 5 | 100% | 0.19 | 0.22 | | mg/L |
| | Total Phosphorus as P | 8 | 100% | 0.35 | 0.34 | | umhos/cm |
| Dissolved Solids | Conductivity | 6 | 100% | 120 | 119 | | mg/L |
| | Total Dissolved Solids | 9 | 100% | 83 | 97 | | NTU |
| Bacteria[1] | E. coli | 9 | 100% | 23,000 | 54,100 | 22,400 | MPN/100 mL |
| | Fecal Coliform | 5 | 100% | 23,000 | 43,200 | 29,900 | MPN/100 mL |
| | Total Coliform | 4 | 100% | 146,000 | 141,300 | 108,400 | MPN/100 mL |

#### 2.3.1.5 National Stormwater Quality Database (NSQD)

The National Stormwater Quality Database (NSQD) summarizes concentrations of a number of pollutants of concern in stormwater runoff from around the country (Pitt et. al. 2008). All data in the database is wet weather data. Locations include monitoring sites in Alabama, Arizona, California, Colorado, Georgia, Kansas, Kentucky, Massachusetts, Maryland, Minnesota, North Carolina, Oregon, Pennsylvania, Tennessee, Texas, and Virginia. Data are categorized by tributary land use. Land uses include commercial, freeway, industrial, institutional, open space, residential, and unknown, as well as mixed land use categories. The drinking water COCs were extracted from this database and are summarized in Appendix A. Summaries include the number of samples, the 25$^{th}$ percentile value, median, and the 75$^{th}$ percentile for each constituent by land use. Note that for some constituents, the number of samples is quite limited. The medians for single land use categories only are also included in Table 2-9 and Table 2-10 below.

**Table 2-9: Drinking Water COC Medians from Data in the National Stormwater Quality Database- Nutrients**

| Land Use | Ammonia as N (mg/l) | Nitrate as N (mg/l) | Nitrite as N (mg/l) | (Nitrate + Nitrite) as N (mg/l) | Nitrogen Kjeldahl Total (mg/l) | Total Organic Nitrogen (mg/l) | Total Nitrogen (mg/l) | Orthophosphate as P (mg/l) | Phosphorous Dissolved (mg/l) | Total Phosphorous (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Commercial | 0.50 | | | 0.60 | 1.34 | 0.76 | 1.75 | 0.19 | 0.11 | 0.19 |
| Freeway | 1.04 | 0.84 | 0.18 | 1.18 | 1.73 | | 1.38 | 0.09 | 0.12 | 0.25 |
| Industrial | 0.45 | 0.67 | | 0.65 | 1.30 | 1.58 | 1.71 | 0.24 | 0.10 | 0.23 |
| Institutional | 0.32 | | | 0.60 | 1.20 | 0.80 | 1.40 | | 0.10 | 0.19 |
| Open Space | 0.20 | | | 0.49 | 0.45 | 0.47 | 1.66 | 0.16 | 0.14 | 0.06 |
| Residential | 0.47 | 0.70 | 0.15 | 0.54 | 1.27 | 2.02 | 1.41 | 0.20 | 0.15 | 0.20 |

**Table 2-10: Drinking Water COC Medians from Data in the National Stormwater Quality Database- Other Constituents**

| Constituent Class | Organic Carbon | Dissolved Solids | | | Bacteria | | | |
|---|---|---|---|---|---|---|---|---|
| Land Use | Total Organic Carbon (mg/L) | Chloride (mg/l) | Conductivity (uS/cm @25ºC) | TDS (mg/l) | Fecal Coliform (colonies/ 100 ml) | Fecal Streptococcus (colonies/ 100 ml) | Total Coliform (colonies/ 100 ml) | Total E. Coli (colonies/ 100 ml) |
| Commercial | | 9.5 | 114 | 78 | 3,000 | 12,000 | 800 | 1,660 |
| Freeway | 11 | | 99 | 89 | 2,000 | 17,000 | 50,000 | 1,900 |
| Industrial | | 7.6 | 131 | 84 | 2,400 | 11,000 | 30,000 | 310 |
| Institutional | | | | 61 | 3,400 | 2,400 | | |
| Open Space | 3.8 | 5.5 | 75 | 119 | 4,600 | 24,900 | 62,000 | 1,100 |
| Residential | 26 | 12 | 201 | 104 | 2,350 | 22,000 | 6,275 | 809 |

### 2.3.2 Summary of COC Concentrations from Urban Land Uses

#### *2.3.2.1 Organic Carbon*

Median total organic carbon (TOC) concentrations ranged from 6 mg/L to 11 mg/L for dry weather in samples from residential and industrial areas in Sacramento. Median wet weather TOC concentrations ranged from 7 mg/L to 11 mg/L. The dissolved portion of the samples is high, as median dissolved organic carbon (DOC) concentrations were typically 80 to 90% of the median TOC concentration. The National Stormwater Quality Database (NSQD) indicated TOC median concentrations of approximately 4 mg/L for open space, 11 mg/L for freeways, and 26 mg/L for residential land uses.

#### *2.3.2.2 Nutrients*

Median dry weather nitrate (as nitrogen) concentrations in the Sacramento residential and industrial runoff samples ranged from 0.10 mg/L to 2.25 mg/L, with the mixed residential/ commercial catchment producing the highest nitrate concentrations. Median wet weather samples ranged from 0.45 mg/L to 0.80 mg/L, with the highest concentrations from the mixed residential/ commercial catchment. Median nitrite concentrations ranged from 0.02 mg/L to 0.15 mg/L for dry weather and 0.07 mg/L to 0.15 mg/L for wet weather. Concentrations in the NSQD were comparable to the Sacramento data, with nitrate concentrations ranging from 0.7 mg/L to 0.8 mg/L and nitrite concentrations ranging from 0.15 mg/L to 0.18 mg/L.

Dry weather medians of Total Kjeldahl Nitrogen (TKN), which is the sum of ammonia, ammonium, and organic nitrogen, were about 1 mg/L for all Sacramento catchments. Wet weather TKN medians ranged from 1.4 mg/L to 1.8 mg/L for Sacramento catchments, slightly higher than the dry weather concentrations. TKN concentrations in the NSQD ranged from 0.45 mg/L (for open space) to 1.7 mg/L (for freeway land uses); slightly lower than the Sacramento wet weather data. Total Nitrogen concentrations in the NSQD ranged from 1.4 mg/L for residential/ institutional land uses to 1.7 mg/L for commercial and industrial land uses.

Median dry weather TP concentrations in the Sacramento data ranged from about 0.20 mg/L to 0.40 mg/L, with the highest median concentration from the industrialized catchment. Median wet weather concentrations ranged from 0.25 mg/L to 0.40 mg/L. Total phosphorus concentrations in the NSQD ranged from 0.06 mg/L for open space land uses to 0.25 mg/L for freeway land uses, again somewhat lower than median wet weather values from Sacramento locations.

#### 2.3.2.3 Dissolved Solids

Median dry weather total dissolved solids (TDS) concentrations in the Sacramento stormwater data ranged from 170 to 310 mg/L. The highest TDS concentrations were from the mixed-use catchment. Median wet weather TDS concentrations ranged from 43 mg/L to 83 mg/L, less than dry weather medians. The NSQD medians by land use were comparable to the Sacramento wet weather data, and ranged from 61 mg/L for institutional land uses to 119 mg/L for open space land uses. Chloride concentrations in the NSQD range from 5.5 mg/L for open space land uses to 12 mg/L for residential land uses. The chloride concentrations in the NSQD may not be representative of California chloride levels due to the presence of naturally-deposited chlorides within the Central Valley.

#### 2.3.2.4 Bacteria, Viruses, and Protozoa

The data sources indicated above did not contain land use data for protozoa and viruses; thus the discussion herein focuses on bacteria. Median dry weather FIB data from the Sacramento stormwater data ranged from 3,000 MPN/100 mL to 6,000 MPN/100mL for fecal coliform and 30,000 MPN/100mL to 150,000 MPN/ 100 mL for total coliform. Median wet weather FIB data from the Sacramento monitoring locations ranged from 13,000 MPN/100mL to 70,000 MPN/100 mL for fecal coliform and 146,000 MPN/100mL to 280,000 MPN/100 mL for total coliform. Wet weather medians were significantly higher than dry weather medians, which is a typical observation of FIB concentrations in stormwater.

Median fecal coliform data in the NSQD ranged from 2,000 MPN/100mL for freeway land uses and 4,600 MPN/100mL for open space land uses. Median total coliform data in the NSQD ranged from 800 MPN/100mL for commercial land uses to 62,000 MPN/100mL for open space land uses.

These data are indicative of the wide variability in the concentrations of FIB.

# 3. CONTROL STRATEGIES

## 3.1 Types of Control Strategies

The following are the elements of an integrated control strategy for stormwater management for new development that is currently found in many NPDES Permits.

- *Site Design Principles and Techniques* are part of a stormwater management strategy for new development and redevelopment that emphasizes conservation and use of existing site features to reduce the amount of runoff and pollutant loading that is generated from a project site.

- *Source Control Measures* limit the availability and exposure of materials and activities so that potential sources of pollutants are prevented from making contact with stormwater runoff.

- *Retention Best Management Practices (BMPs)* are stormwater BMPs that are designed to retain water onsite, and achieve a greater reduction in surface runoff volume from a project site than traditional stormwater treatment control measures. Retention BMPs are preferred and some NPDES permits require that retention BMPs shall be selected over biofiltration BMPs and treatment control measures, where technically feasible to do so.

- *Biofiltration BMPs* are vegetated stormwater BMPs that remove pollutants by filtering stormwater through vegetation and soils.

- *Treatment Control Measures* are engineered BMPs that provide a reduction of pollutant loads and concentrations in stormwater runoff.

These control measures can be applied at the parcel or project level (Distributed BMPs) or at a regional scale (Centralized BMPs). For the purposes of this report, the focus is on retention and biofiltration BMPs and on treatment control measures which have more quantitative performance data. However, all five categories of control strategies reduce stormwater quantity and improve stormwater quality.

Retention and biofiltration BMP requirements for new and redevelopment are being incorporated into a number of new municipal separate stormwater sewer system (MS4) permits in California and are likely to be adopted widely in the future. Permits which have incorporated a "retention standard", that is, a requirement to retain as much of the 'design' storm on site as feasible, with biofiltration as an option if retention is infeasible, include the San Francisco Bay Area Municipal

Regional Permit (Order No. R2-2009-0074), the San Diego MS4 permit (Order No. R9-2009-0002), the North and South Orange County MS4 permits (Order Nos. R8-2009-0030 and R9-2009-0002, respectively), and the Ventura MS4 permit (Order No. R4-2009-0057). Specificities of the retention standard and the 'design' storm vary between the permits. In general, treatment control measures are encouraged for regional or watershed master planning applications only.

Retention BMPs include infiltration basins, infiltration trenches, infiltrating bioretention facilities, drywells, permeable pavement, and other BMPs designed to infiltrate. Retention BMPs also include evapotranspiration BMPs, such as green roofs, and harvesting and reuse practices, involving storage of stormwater in cisterns, underground facilities, or blue roofs (roofs designed to temporarily detain water), and use of water for nonpotable applications.

Biofiltration BMPs include bioretention facilities with underdrains (i.e., not designed for infiltration), planter boxes, vegetated swales, vegetated filter strips, and manufactured biofilters. Treatment control measures include dry extended detention basins, wet detention basins, constructed wetlands, sand filters (unvegetated), cartridge media filters, and pretreatment measures such as hydrodynamic devices and catch basin inserts.

## 3.2 BMP Unit Processes

BMPs employ a number of different chemical and mechanical processes to retain stormwater and remove pollutants. These processes are optimized using specific materials and design criteria. Unit processes are described here.

- *Filtration* is a process that is employed by soil or BMP media and involves removal of pollutants and sediment. Particles are trapped in upper layers of media or soil as water moves through pores in the media.

- *Adsorption* supplements filtration as a pollutant removal mechanism. This process involves the mechanical or chemical attraction of particles or pollutants to soil such that they become attached to media and are removed from stormwater runoff.

- *Settling* is a process employed in standing water in which particles that are heavier than water descend through the water column. Particles are removed by collecting on the bottom of the water column, which prevents them from being mobilized to receiving waters. Settling is enhanced by flocculation, which occurs naturally as particles are attracted to each other and attach together, becoming heavier and settling quicker.

- *Infiltration* involves percolation of runoff into native soil. Infiltration BMPs utilize the filtration, adsorption, and biological decomposition processes of soil environments to remove pollutants and intentionally route runoff to the subsurface for groundwater recharge.

- *Evapotranspiration* is a sum process, which involves both plant transpiration of water, in which plants move water from their roots to plant surfaces, where it can be evaporated, along with evaporation of water molecules from soil surfaces and other surfaces.

- *Biofiltration* utilizes filtration through media as well as evapotranspiration and pollutant uptake through plant roots.

Retaining stormwater on-site eliminates a number of pollutant concerns, as pollutants are not discharged with runoff to receiving waters. Stormwater retention is achieved by infiltration and evapotranspiration. While infiltration is optimal for stormwater management, there are some cases where it is not feasible, which include (but are not limited to) high groundwater tables, contaminant plumes that could be mobilized, geotechnical concerns, and downstream beneficial uses which would be impacted by retention of stormwater upstream.

Pathogens, including bacteria, viruses, and protozoa, can also be inactivated by a number of biological chemical, and/or mechanical processes. These processes include solar irradiation, temperature fluctuations, predation by other microorganisms, lack of sufficient nutrients required for survival, and to a lesser degree, pH and salinity (Geosyntec, 2010 DRAFT).

### 3.3 Performance Measures

Research on characterizing BMP performance suggests that effluent quality rather than percent removal is more reliable in modeling stormwater treatment (Strecker et al. 2001). BMPs do not typically function with a uniform percent removal across a wide range of influent water quality concentrations. For example, a BMP that demonstrates a large percent removal under heavily polluted influent conditions may demonstrate poor percent removal where low influent concentrations exist (Geosyntec, 2009).

The decreased efficiency of BMPs with low concentration influent has been demonstrated and in some cases, there is a minimum achievable concentration through BMP implementation for many constituents (Schueler 2000; Minton 2005). This has been designated the "irreducible pollutant concentration”. Studies have demonstrated that a practical lower limit of pollutant removal exists for a given technology.

## 3.4 Treatment Performance for Drinking Water COCs

The development of the International Stormwater Best Management Practices (ISW BMP) Database was sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and the U.S. Environmental Protection Agency (USEPA) (collectively, the "Sponsors"). The Database was developed to provide a consistent and scientifically defensible set of data on BMP performance.

Effluent data from the BMP Database for drinking water COCs is summarized here. Appendix B includes complete statistical summaries, along with the number of studies and results. Note that the number of studies tends to be limited for certain constituents, such as fecal indicator bacteria.

### 3.4.1 Organic Carbon

The most effective BMPs in terms of effluent quality include filtration systems such as media filters where the median effluent concentration for TOC is 7.6 mg/L. Retention ponds, detention ponds, and biofilters (swales) provide a medium level of treatment with effluent TOC ranging from 10-12 mg/L. The least effective BMPs for TOC treatment is wetland basins where plant material can contribute to effluent TOC.

**Table 3-1: Drinking Water COC Median Effluent Concentrations from BMPs in the ISW BMP Database – Nutrients**

| BMP | Nitrate (NO3-N) (mg/L) | Nitrite (NO2-N) (mg/L) | Total Kjehdahl Nitrogen (TKN) (mg/L) | Dissolved Organic Nitrogen (mg/L) | Total Organic Nitrogen (mg/L) | Total Nitrogen (TN) (mg/L) | Suspended Ortho-phosphate (mg/L) | Dissolved Ortho-phosphate (mg/L) | Ortho-phosphate (mg/L) | Dissolved Organic Phosphorus (mg/L) | Suspended Phosphorus (mg/L) | Total Phosphorus (TP) (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bioretention | 0.170 | 0.012 | 0.84 | | | 0.83 | | | 0.111 | | | 0.180 |
| Detention Basin | 0.440 | 0.076 | 1.29 | 0.59 | 1.28 | 1.75 | 0.096 | 0.004 | 0.250 | 0.012 | 0.080 | 0.190 |
| Green Roof | 0.025 | | 0.99 | | | | | | 0.250 | | | 0.320 |
| Biofilter | 0.355 | 0.002 | 0.77 | 0.31 | 0.25 | 0.56 | 0.007 | 0.021 | 0.097 | 0.019 | | 0.194 |
| Manufactured Device[1] | 0.430 | 0.062 | 1.23 | 1.21 | 0.45 | 1.51 | | | 0.062 | 0.052 | | 0.128 |
| Media Filter | 0.370 | 0.006 | 0.60 | | 0.42 | 0.47 | | | 0.017 | | | 0.082 |
| Porous Pavement | 0.269 | | 0.90 | | | 1.48 | | | 0.059 | | | 0.074 |
| Retention Pond (Wet Pond) | 0.200 | 0.018 | 1.00 | 0.38 | 0.47 | 1.16 | | | 0.034 | 0.006 | 0.010 | 0.090 |
| Wetland Basin | 0.035 | 0.007 | 0.94 | | 0.73 | 1.06 | | | 0.015 | 0.050 | 0.026 | 0.065 |
| Wetland Channel | 0.081 | 0.060 | 1.10 | 0.38 | 0.20 | 0.90 | | | 0.042 | | 0.020 | 0.130 |

**Note:**

Blank spaces indicate there were less than 5 data points for that combination of BMP and constituent.

[1] Manufactured devices incorporate a broad range of types of facilities that rely on various unit processes including hydrodynamic separation and filtration.

**Table 3-2: Drinking Water COCs Median Effluent Concentrations from BMPs in the ISW BMP Database – Other Constituents**

| Constituent Class | Organic Carbon | | Dissolved Solids | | | | Bacteria | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| BMP | Dissolved Organic Carbon | Total Organic Carbon | Dissolved Chloride | Total Chloride | Total Dissolved Solids (TDS) | Specific Conductance | E. Coli | Entero-coccus | Fecal Coliform | Total Coliform |
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (umhos/cm) | (MPN/ 100 mL) | (MPN/ 100 mL) | (MPN/ 100 mL) | (MPN/ 100 mL) |
| Bioretention | | | | 2.75 | 52.1 | 53.2 | 3 | 1,700 | 50 | |
| Detention Basin | 8.8 | 11.0 | | | 76.0 | 104 | 118 | 400 | 465 | |
| Green Roof | | | | | 2.0 | 57.5 | 3 | | 3 | |
| Biofilter | 11.0 | 12.0 | | 1.18 | 74.0 | 91.0 | 2,200 | | 2,300 | |
| Manufactured Device[1] | 19.0 | 19.0 | 49.5 | 25.5 | 72.0 | 52.0 | | 1,700 | 800 | |
| Media Filter | 5.35 | 7.65 | | 2.55 | 46.0 | 80.0 | 5 | 200 | 150 | 220 |
| Porous Pavement | | 7.0 | | 10.0 | | | | | | |
| Retention Pond (Wet Pond) | 10.0 | 10.0 | | 11.0 | 79.8 | 326 | 50 | | 19 | 238 |
| Wetland Basin | | 16.0 | | 2.50 | 20.0 | 0.05 | 8 | | 5 | |
| Wetland Channel | | 8.0 | | 2.44 | 97.7 | 114 | | | | |

**Note:**
Blank spaces indicate there were less than 5 data points for that combination of BMP and constituent.
[1] Manufactured devices incorporate a broad range of types of facilities that rely on various unit processes including hydrodynamic separation and filtration.

### 3.4.2 Nutrients

The most effective BMPs in terms of effluent quality for total nitrogen are those BMPs that incorporate filtration including media filters, bioretention, and biofilters. The median effluent quality for TN for these BMPs range from about 0.5 to 0.8 mg/L. Detention basins and retention ponds (wet ponds) are less effective and have median effluent TN that range from about 1.2 to 1.7 mg/L. The data also indicate that BMPs that incorporate filtration perform better for TKN which is primarily organic nitrogen. BMPs in general perform less well in treating dissolved constituents such as NO3 and the effluent data for many of the BMPs range from about 0.2 to 0.4 mg/L. Enhanced nitrate removals have also been shown for bioretention facilities which allow for an anaerobic zone below the media (created with an upturned underdrain or similar) (Brown, 2009; Passeport, 2009; FAWB, 2008).

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. This same trend applies to total orthophosphate where the lower effluent concentrations are associated with media filters (0.017 mg/L), retention ponds ( 0.034 mg/L) and wetland basins (0.015 mg/L). Dissolved orthophosphate is the more biologically available form of phosphorus but there is limited data on this constituent.

### 3.4.3 Dissolved Solids

Dissolved solids are generally relatively low in stormwater runoff and are not a constituent of concern in terms of adversely affecting beneficial uses. For example, median effluent TDS from stormwater controls is less than 100 mg/L. Dissolved solids also are conservative and not treated in traditional stormwater management controls.

### 3.4.4 Bacteria, Viruses, and Protozoa

The ISW BMP Database did not include BMP effluent information on protozoa or viruses, but does include considerable data for FIB. A quantitative discussion of treatment of FIB is included below, as well as a qualitative section on protozoa and viruses.

#### *3.4.4.1 Bacteria*

BMPs that provide better performance for removal of fecal indicator bacteria are those that utilize filtration/infiltration unit processes, such as retention ponds, media filters, and bioretention BMPs. For example, data for media filters indicate a median concentration of 220

MPN/100 mL for total coliform, 150 MPN/100mL for fecal coliform, and 200 MPN/100 mL for *Enterococcus.* Detention appears to be moderately effective with a median effluent concentration of 465 MPN/100 mL for fecal coliform. In contrast biofilters (swales) are least effective with a median fecal coliform concentration of 2300 MPN/100mL..

### 3.4.5 Advanced Treatment

Stormwater management has typically involved passive treatment which generally depended on natural processes to effect treatment. This is in contrast with active treatment such as is more typically associated with waste water treatment. However, there are instances where active or advanced treatment concepts are now being considered. For example, there is a provision in the recently issued Construction General Permit whereby high risk construction site may be required to implement active treatment in the form of adding coagulants to reduce suspended sediment concentrations. The following discusses some limited active treatment technologies being applied for stormwater runoff where the issue is pathogen management.

The City of Santa Monica has installed a 0.5 MGD dry weather runoff treatment and recycling facility referred to as the City of Santa Monica Urban Runoff Recycling Facility (SMURRF) (http://www.smgov.net/Departments/PublicWorks/ContentCivEng.aspx?id=7796). The facility treats and recycles dry weather flows with a treatment train that includes coarse sediment screening, dissolved air flotation, degritting, microfiltration, and ultra-violet (UV) radiation. The treated water is recycled and used for landscape irrigation and toilet flushing. Data from several years of sampling indicate that total coliform, fecal coliform and *Enterococci* are treated to non-detect levels.

Hydrophix, Inc. has developed a proprietary antimicrobial filter media that includes an antimicrobial agent which is chemically bound to the polymer surface of the media (referred to as Smart Sponge® Plus). Testing of the media has been conducted by researchers at California State University, Fullerton (CSUF) in a pilot-plant system in two phases. Testing was conducted in a laboratory using drinking water that was seeded with FIB. Phase I consisted of 22 experimental runs and Phase II consisted of an additional 16 runs in a longer reactor column. The tests indicated inactivation efficiencies for *Enterococci* of 95% or greater, and for *E. coli* a range from 66% to 82% (Hydrophix, 2008). Testing was not conducted for viruses or protozoa.

# 4. PROJECTED REGULATORY SCENARIOS

The management of urban runoff is largely dictated by California's multifaceted regulatory framework. The State Water Resources Control Board and nine Regional Water Quality Control Boards are the entities that establish the rules and regulations on how to manage stormwater, implement the appropriate level of BMPs, and ensure enforcement.

Currently, each Regional Water Board has separate regional permits to regulate municipal separate storm sewer systems (MS4s) through the National Pollutant Discharge Elimination System (NPDES) program. The goal of the various municipal stormwater permits is to reduce pollutant loadings to the maximum extent practicable (MEP) in order to protect the beneficial uses of the receiving water bodies.

## 4.1 Current Regulatory Approaches

In determining the future of regulations in California, the current trends in permitting throughout the State, as well as federal requirements under Section 438 of the Energy Independence and Security Act, were analyzed.

In the majority of stormwater permits throughout California, there are requirements for new and redevelopment projects that add or replace 5,000 square feet or 10,000 square feet of impervious area. Generally, the requirements can be categorized as either runoff reduction or treatment requirements.

The goal of runoff reduction requirements is to retain rainfall onsite, reduce peak flows, increase the duration of release, and minimize impacts on receiving waters bodies and their beneficial uses. This is done by setting requirements that manage the volume of runoff that occurs from a design storm event (e.g. the 2-year, 24 hour storm event). Permittees are provided some flexibility in deciding which runoff reduction or low impact development (LID) BMPs to implement to meet the regulations.

The goal of treatment requirements is to ensure that any runoff that is released from a site is treated, such that pollutants of concerns (i.e., nutrients, sediment, metals, etc.) in urban runoff are removed to the MEP. For regulated projects, the permittees must treat the runoff design flow or volume, typically with LID treatment measures or at a joint stormwater treatment facility. Depending on the size of the project, a permittee may be required to treat the runoff from up to 100% of the developed area.

All treatment control BMPs must be collectively sized to comply with either volume-based or flow-based sizing criteria. For example, the Sacramento Stormwater Quality Design Manual

(Sacramento Stormwater Partnership, 2007) contains design criteria for treatment type BMPs that are primarily flow-based or volume based. The design criteria for flow based type controls is a design rainfall intensity of 0.18 to 0.2 in/hr depending on location within Sacramento County. The Sacramento County Volume Based Design Methods utilizes the method contained in the Urban Runoff Quality Management (WEF Manual of Practice 23/ASCE Manual of Practice No. 87, 1998).

Table 4-1 describes current requirements in a variety of recently-issued stormwater permits throughout California, as well as federal regulations under Section 438 of the Energy Independence and Security Act (EISA). A variety of regulatory requirements were compared including the applicable land use type, design storm event, runoff reduction and treatment requirements, whether retrofitting is required, and if the permit contained numeric action levels (NALs) or numeric effluent limits (NELs).

Currently, MS4 permits that require some form of retrofitting include the South Orange County MS4 permit (Order No. R9-2009-0002) and the Riverside County MS4 permit (Order No. R8-2010-0033). The permits require that permittees develop and implement a retrofitting program that may include identification of sources of pollution, identification of potential retrofit candidates, evaluation criteria, incorporation of retrofits into annual work plans, tracking and inspection, and proposal of regional mitigation projects if retrofitting is infeasible.

**Table 4-1: Comparison of Existing Stormwater Permit Requirements**

| Regu-latory Require-ments | Sacramento MS4 (R5-2008-0142) | San Francisco Bay MRP (R2-2009-0074) | City of Stockton MS4 (R5-2007-0173) | South Orange County MS4 (R9-2009-0002) | Riverside County MS4 (R8-2010-0033) | Federal - Section 438 of EISA |
|---|---|---|---|---|---|---|
| Land Use Type | New and re-development | New and re-development | New and re-development | New and re-development | New and re-development | New and re-development |
| BMP Design Storm Event | $85^{th}$ percentile storm event | $85^{th}$ percentile storm event | $85^{th}$ percentile storm event | $85^{th}$ percentile storm event | $85^{th}$ percentile storm event | $95^{th}$ percentile storm event |
| Treatment | Treat 100% of water quality design volume or flow rate with source control, LID BMPs, and other treatment BMPs | Treat 100% of water quality design volume or flow rate with source control, LID BMPs, and other treatment BMPs | Maximum extent practicable | Treat 100% of water quality design volume or flow rate with source control, LID BMPs, and other treatment BMPs | Treat 100% of water quality design volume or flow rate with source control, LID BMPs, and other treatment BMPs | Treat 100% of water quality design volume or flow rate with source control, LID BMPs, and other treatment BMPs |
| Retrofitting | None | None | None | Requires Retrofit Plan development | Requires retrofit of existing MS4 facilities | None |
| NALs/ NELs | None | None | None | NALs for non-stormwater dry weather flows | None | None |

Additionally, the USEPA issued a proposed rulemaking on stormwater discharges for new and redevelopment projects in the December 2009 Federal Register. In the notice, USEPA solicited public comments on whether it should consider requirements for the retrofit of existing development through the use of green infrastructure and LID BMPs. In particular, USEPA requested comments on requiring MS4s to develop a long-term retrofit implementation plan targeted at addressing stormwater problems in urban waters. USEPA also solicited input on where retrofit practices have been installed, what the drivers were for the projects, and information on the specific retrofit practices that were installed. This USEPA rulemaking may be an indicator that retrofitting may become a requirement in future municipal stormwater permits.

Currently, the South Orange County MS4 Permit (Order No. R9-2009-0002) has NALs for non-stormwater dry weather flows for pathogens (i.e. fecal coliform and *enterococci*), conventional pollutants (i.e. pH, turbidity, dissolved oxygen, total nitrogen, and total phosphorus), and some priority pollutants (i.e. cadmium, copper, chromium, lead, nickel, silver, and zinc). A new total maximum daily load (TMDL) policy from the USEPA, described in a November 2010 memorandum, recommends the use of NELs, rather than the iterative implementation of BMPs, to ensure compliance with water quality standards. The new USEPA policy goes beyond total maximum daily loads (TMDLs) and represents a fundamental shift toward NELs in permits for municipal stormwater and small construction discharges (CASQA, 2010).

The State Water Board recently adopted the General Permit for Discharges of Storm Water Associated with Construction Activity (Construction General Permit (CGP)), Order No. 2009-0009-DWQ on September 2, 2009. Unlike the previous permit, the revised CGP incorporates several concepts new to construction stormwater permitting including a risk-based analysis, incorporation of NALs and NELs, and post-construction monitoring requirements. In particular, the CGP requires effluent monitoring of pH and turbidity to determine compliance with newly-assigned NALs and NELs for projects depending on site risk levels.

Additionally, the State Water Board recently issued the administrative draft of the General Permit for Discharges of Storm Water Associated with Industrial Activities (Industrial General Permit (IGP)), on January 28, 2011. Like the new CGP, the draft IGP incorporates NALs and NELs, where NAL exceedances may trigger structural or nonstructural BMP actions and potentially NELs. In particular, the draft IGP requires effluent monitoring for pH, total suspended solids, specific conductance, and oil and grease; and for SIC-specific NALs, total organic carbon, chemical and biological oxygen demand, nitrate + nitrite nitrogen, total phosphorus, ammonia, and some metals.

## 4.2 Projected Regulatory Approaches for 2030

Geosyntec developed three 2030 regulatory scenarios consisting of: 1. Planned Changes Scenario, 2. Probable Scenario, and 3. Outer Boundary Scenario, which are detailed in Appendix C. The 2030 Planned Changes Scenario describes a 2030 regulatory environment in the Central Valley that is comparable to the most stringent 2010 regulations currently in effect in California. The 2030 Probable Scenario describes a 2030 regulatory environment that incorporates a feasible change in requirements for new development and redevelopment, and NELs. The 2030 Outer Boundary Scenario describes a 2030 regulatory environment that incorporates an aggressive change in requirements for new development and redevelopment, retrofitting, and NELs.

For each scenario, there are three main regulatory program categories: 1. New Development and Redevelopment, 2. Retrofitting, and 3. Numeric Effluent Limits (NELs). New Development and Redevelopment applies to single family and multi-unit residential housing developments, commercial and industrial buildings, and roads. In this study, retrofitting is assumed to apply primarily to industrial land uses, assumed to occur in response to requirements of future revisions to the IGP. NELs apply to new and existing development including single family and multi-unit residential housing, commercial buildings, and industrial land uses.

Various regulatory requirements that were considered include dry weather flow reduction (through improved landscaping practices including irrigation control), BMP design storm standards, runoff reduction standards, treatment standards, retrofitting in industrial areas, and NELs for nutrients.

**Table 4-2. Comparison of the 2030 Regulatory Scenarios**

| 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 | $85^{th}$ percentile storm event | $85^{th}$ percentile storm event | $95^{th}$ 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<br>TP = 0.2 mg/L<br>(SJV only) | TN = 1 mg/L<br>TP = 0.1 mg/L<br>( SJV only) |

### 4.2.1 2030 Planned Changes Scenario

The 2030 Planned Changes Scenario describes a 2030 regulatory environment that implements the most stringent present day 2011 regulations in California. This scenario encompasses both population growth and land use changes.

Under this scenario for new development, it is assumed that by 2030 under current regulatory requirements 20% of dry weather flows will be eliminated which is generally consistent with planned water conservation targets in California. Consistent with current municipal stormwater permits throughout California, the BMP design storm event will be set to the $85^{th}$ percentile storm event. On-site retention of runoff from a design rainfall event will be suitable on and applied to 5% of a newly developed urban area in the Sacramento Valley and in 10 % of newly developed area in the San Joaquin Valley[1]. The treatment standard will be to the maximum

[1] The assumed levels of areas subject to urban development where onsite retention may be feasible are based on a GIS analysis of projected urban land use and soils which indicted that approximately 20% of the soils in the

extent practicable (MEP). In this future regulatory environment, there will be no NELs or retrofitting requirements. These assumptions are consistent with present day regulations.

### 4.2.2 2030 Probable Scenario

The 2030 Probable Scenario describes a 2030 regulatory environment that incorporates feasible changes in requirements for new development and redevelopment and NELs. This scenario was developed by comparing and identifying runoff reduction and treatment requirements in recently revised California permits and federal regulations, which include LID BMPs and retrofit plan requirements. This scenario also considers the economics of BMP implementation and operation and maintenance in determining feasibility of implementing the control strategies.

Based on trends from the various California municipal stormwater permits, USEPA Green Infrastructure Guidance Documents, the incorporation of NALs and NELs in the Construction General Permit, and strict federal stormwater requirements, it is assumed that for the 2030 Probable Scenario, there will be continued emphasis on source control, site design, onsite retention, and maximized treatment of runoff from sites. Further, retrofitting of existing sites will be required to some extent.

Under this scenario for new development, it is assumed that by 2030 40% of dry weather flows will be reduced or harvested (capture, treatment, reuse) through a combination of conservation efforts including progressive water pricing, irrigation control, and harvesting. The basis for this target is emphasis in reducing/capturing dry weather flows in regulatory programs as a measure to benefit water quality, and water conservation[2]. Regarding technical feasibility, one of the primary sources of dry weather flows is excessive irrigation for which there are proven management methods. For example, a study conducted in Orange County by the Irvine Ranch Water District (IRWD, 2004) found that the implementation of ET controllers in a residential neighborhood resulted in a 50 percent reduction in dry weather flows.

---

projected urban growth areas in the Sacramento Valley will be located on soils that are classified in Hydrologic Groups A or B which are generally considers suitable for infiltration. The analysis was also conducted for the San Joaquin Valley where it was indicated that 50% of the soils are in the A or B Groups. There are constraints beyond soil infiltration capacity that may make it infeasible to infiltrate, so the assumed extent of area suitable for infiltration only corresponds to these percentages for the outer boundary scenario.

[2] The staff draft of the Delta Plan identifies stormwater capture, including dry weather flows, as among the vital options for improving reliability of California's water supply. http://www.deltacouncil.ca.gov/docs/draft_delta_plan/Preliminary_Staff_Delta_Plan_2011_02_14.pdf

Like the 2030 Planned Changes Scenario, the BMP design storm event will be set to the 85th percentile storm event. On-site retention of runoff from a design event will be suitable and applied to 10% of a newly developed urban area in the Sacramento Valley and 25% in the San Joaquin Valley. Additionally, the treatment standard will be to the MEP through the use of LID BMPs where feasible.

NELs will be required for nutrients in the San Joaquin Valley based on elevated nutrients data presented in the 2006 Final Report entitled, *Conceptual Model for Nutrients in the Central Valley and Sacramento – San Joaquin Delta*, prepared by Tetra Tech for USEPA Region IX, Central Valley Drinking Water Policy Group (Tetra Tech, 2006b). The 2006 report contains nutrient data collected at various monitoring stations throughout the Delta.

This scenario calls for numeric effluent limits (NELs) for nutrients in the San Joaquin Valley based primarily on the elevated levels of nutrients found in the San Joaquin Valley compared to data in the Sacramento Valley. Some of the longest records of nutrient concentrations exist at the Sacramento River at Hood/Greene's Landing and the San Joaquin River at Vernalis with data collected between 1980 and 2004. The two river locations are important because they constitute the majority of flow into the Delta. Table 4-3 lists average nutrient concentrations at key Delta monitoring locations.

For the Sacramento River, TP concentrations increase with flow downstream due to the influences of agriculture, urban runoff, and wastewater sources. The average concentration of TP in the Sacramento River at Hood/Green Landing is 0.12 mg/L. The average concentration of TP in the San Joaquin River at Vernalis is 0.25 mg/L. Additionally, TP concentration values show minimal trends by month for either river, with little discernible influence due to wet weather flows or irrigation return flows.

For TN, there are elevated concentrations in the San Joaquin River compared to the Sacramento River. Where nutrient species data are available, much of the nitrogen is present as nitrate. The data also shows inter-seasonal variation for TN for both rivers. The high TN concentrations are observed during the wet months in the Sacramento River and in the dry months in the San Joaquin River. The average concentration of TN in the Sacramento River at Hood/Greene's Landing is 0.64 mg/L and in the San Joaquin River at Vernalis is 2.5 mg/L.

**Table 4-3**. **Average Nutrient Concentrations at Key Delta Locations**

| Constituent (mg/L) | Sacramento at Hood/Greene's Landing | San Joaquin at Vernalis | Banks Pumping Plant |
|---|---|---|---|
| Total Nitrogen | 0.64 | 2.5 | 1.1 |
| NO3+NO2-N | 0.14 | 1.5 | 0.61 |
| Ammonia-N | 0.23 | 0.1 | 0.064 |
| TKN | 0.50 | 0.85 | 0.44 |
| Total Phosphorus | 0.12 | 0.25 | 0.12 |
| Orthophosphate | 0.07 | 0.12 | 0.071 |

Setting a limit on nutrients to meet beneficial uses is complex as nutrients are a key element in the natural aquatic ecology, and the utilization of nutrients by algae depends on a number of factors such as light, temperature, and food chain dynamics including the effects of other organisms that harvest plant nutrients or prey on species that utilize algae. The establishment of NELs for nutrients is therefore very site specific and in this case, the proposed limits are based solely on setting discharge levels that are comparable or less than currently observed concentrations in receiving waters. For the 2030 Probable Scenario, NELs are set to a TN of 2 mg/L and TP of 0.2 mg/L, which is slightly lower than the average TN and TP concentrations at the San Joaquin at Vernalis station. This scenario further assumes that the implementation of NELs will be implemented over an extended time period such that at 2030 25% of the urban portion of the San Joaquin Valley watershed will be meeting this NEL.

### 4.2.3 2030 Outer Boundary Scenario

The 2030 Outer Boundary Scenario describes a 2030 regulatory environment that incorporates an aggressive change in requirements for new development and redevelopment, retrofitting, and NELs. This scenario was developed by considering the most stringent interpretation of water quality control requirements with no consideration of the economics of BMP implementation and operation and maintenance. This scenario represents the most protective of water quality and beneficial uses in the Sacramento and San Joaquin watersheds.

For new development in the Central Valley, following the federal regulations under Section 438 of the Energy Independence and Security Act, the BMP design storm event will be the $95^{th}$ percentile storm event. On-site retention of runoff from a design event is assumed to be suitable and applied to 20% of a newly developed urban area in the Sacramento Valley and to 50% of the area in the San Joaquin Valley. Additionally, the treatment standard will be to the MEP through the implementation of LID BMPs where feasible.

For new and existing development in the Central Valley, the 2030 Outer Boundary Scenario assumes that there will be a regulatory requirement to reduce or harvest 60% of dry weather flows. This is considered a highly aggressive water conservation goal that would require comprehensive and large scale implementation (including retrofitting) utilizing a array of measures including irrigation control and water harvesting (storage, treatment and reuse).

For new and existing development in the San Joaquin Valley, it is assumed that NELs will be required for existing and new development and are more stringent than in the 2030 Probable Scenario. NELs are set to a TN of 1 mg/L and TP of 0.1 mg/L, which is closer to the average concentrations in the Sacramento River at Hood/Green Landing, as shown in Table 4-3.

For new and existing development in the Central Valley, it is assumed that there will be retrofitting requirements for existing industrial development implemented through the General Industrial Stormwater Permit to meet Best Available Technology Best Current Technology (BAT/BCT) criteria. This scenario further assumes that 20% of industrial areas will be subject to retrofitting and source control of drinking water COCs.

# 5. WARMF MODEL INPUTS AND RECOMMENDED CALIBRATION TARGETS

The inputs to the WARMF model included projected changes in land use and recommendations for targets for calibration of simulated urban runoff quantity and quality for each scenario. The recommendations for calibration targets, including supporting data tables, are contained in Appendix C, and summarized below in Sub-section 5.2.

## 5.1 Land Use

A key input to the WARMF model are projections of urban land uses and the changes in other land uses such as agriculture in the Central Valley by 2030. The sources of information for these projections were based on projections conducted by planning agencies in the Central Valley, as part of a statewide planning effort (Senate Bill 375 -Sustainable Communities Strategy).

Urban land use projections for the San Joaquin Valley for 2050 were obtained in the form of GIS maps from the Information Center for the Environment, Department of Environmental Science & Policy, University of California at Davis. The maps were developed as part of the San Joaquin Valley Blueprint Planning Process (Harnish, 2010), a statewide planning process being conducted by Metropolitan Planning Organizations designed to plan for the population growth that is anticipated in California over the next 40 plus years. The planning process envisions a significant shift in the pattern of future development to more dense development and development that is more efficient with respect to energy utilization and the environment.

The projected area is within the jurisdiction of the eight Valley Council of Governments (COGs), which include 62 cities and eight counties in the San Joaquin Valley. The projections were scaled back from 2050 to 2030 with the aid of projections based on extrapolating the Farmland Mapping and Monitoring Program data published by the California Department of Conservation (2009). The Farmland Mapping and Monitoring Program provide data on urban land uses by county for every two years since approximately 1988.

A similar planning process is being conducted by the Sacramento Council of Governments (SACOG), which is referred to as the Blueprint for Smarter Growth Project (SACOG, 2010). SACOG provided urban land use projections for the six county areas (Sacramento, El Dorado, Placer, Sutter, Yuba and Yolo) in the form of parcel based GIS maps. The projections were made to 2035, which was considered suitable for the 2030 projection called for in this report. The projections also included land use types that were then consolidated into the more general land use categories of residential, commercial, industrial, and open space used in this study.

Table 5-1 summarizes the projected increase in urban land uses by 2030 in the Sacramento Valley and the San Joaquin Valley. The land uses in the original data have been aggregated, as shown in Table 5-1, into residential, commercial, industrial, paved areas, and open space. The methodologies used to make the projections and the land use categories differed between the Sacramento and SJV data sets, so comparisons are difficult. The data however are consistent in showing that most growth will be in residential and commercial land uses, and in general more growth is projected for the Sacramento Valley than the San Joaquin Valley. The total projected increase in urban land use is approximately 50%.

It is of interest to compare these projections with observed historic growth, which is provided by the Farmland Mapping and Monitoring Program (FMMP)[3] where data are organized by county and therefore not wholly comparable to data summarized in Table 5-1. The FMMP indicates a range in the rate of historical increase in urbanization of counties within SACOG from about 30% (Yuba County) to 150% (Placer County), with most other counties within 35-60%. The projected increase in urban land for Sacramento County from 1998-2008 is about 35%. The land use projection can be compared to population projections. The SACOG projection for population is 3.08M in 2035, which compared to a 2.19M population in 2008, is about a 40% increase.

**Table 5-1 Projected 2030 Increase in Urban Land Uses in Central Valley**

| 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.

[3] http://redirect.conservation.ca.gov/DLRP/fmmp/county_info_results.asp

## 5.2 Existing Conditions Scenario

The first scenario to be modeled is existing conditions in order to establish baseline loading conditions. Appendix C, Table 1 provides measured dry weather design flows that vary by land use, drainage basin size, soil types and other factors. These data reflect annual averages; however previous loading models performed by the Sacramento Stormwater Quality Partnership (Ruby 2005, LWA 1996) indicate that dry weather flows differ between the dry season (April 1 to September 30) and the dry periods between storm events during the wet season (October 1 to March 31). The mean dry weather flows used in these reports were 4E-4 cfs per acre for the dry season (approximately May through September), and 5E-4 cfs per acre for those dry periods between runoff events during the wet season (October through April).

For dry weather urban runoff water quality, the recommended calibration target is data from Sacramento taken at Strong Ranch Slough and Sump 104. These stations drain catchments that contain mostly residential and commercial land uses, and have a more extensive data base than, for example, Natomas Basin 4.

For wet weather urban runoff water quality, the calibration targets should take into account the effects of regulations requiring implementation of stormwater controls for new development starting around 1996. Therefore, the recommended runoff concentration for the period 1996-2010 is a weighted average based on the percent of urban development pre- and post-1996. This weighted average is based on an analysis of land use data from 1988 to 2008 from the Sacramento County Farmlands Mapping Project. From this analysis, approximately 80% of current development occurred before 1996 prior to control requirements and the remaining 20% occurred after 1996.

For the pre-1996 development area, the recommended calibration target is from uncontrolled catchments. For residential and commercial land uses, the recommendation is to use wet weather median concentrations data from Strong Ranch Slough and Sump 104. For industrial land uses, use wet weather median concentrations from Sump 111.

For the post-1996 development area the recommended calibration target is for a controlled catchment. The recommendation is to use Natomas wet weather median effluent concentration data as this is more representative of a catchment that is primarily residential, which is the largest projected land use type. The recommendation is to use the Natomas data for all land uses, as there is a lack of newer development and future development regional BMP data for other urban land use types in the Central Valley. Appendix C, Table 3 provides the wet weather influent and effluent median values for the Natomas Basin. In Section 2 of this Report, Table 2-2 provides the wet weather median concentrations for Strong Ranch Slough and Table 2-6 provides the median concentrations for Sump 111.

## 5.3 2030 Planned Changes Scenario

The 2030 Planned Changes Scenario assumes a 2030 regulatory environment identical to present day 2010 regulations, but applicable to 2030 population growth and land use changes.

Under this scenario, it is assumed that the regulatory requirement for dry weather flows would result in a 20% elimination of dry weather flows for new and existing development. Therefore, the calibration target for urban runoff dry weather flows for new and redevelopment should be about 80 percent of the wet season (5E-4 cfs/acre) or dry season (4E-4 cfs/acre) dry weather flows. Achieving this goal could incorporate a combination of water conservation measures conducted at the parcel or neighborhood scales including homeowner education, conservation pricing, landscape management, irrigation control, restrictions on outdoor washing, and dry weather flow harvesting (capture, treatment and reuse). Depending on local conditions, this level of control could likely be achieved by focusing on the home owner education, landscape management and irrigation control.

For wet weather flows for new and redevelopment, a calibration target for runoff reduction through on site retention is 5% in Sacramento Valley Model and 10% in the San Joaquin Model. This recommendation is based on a GIS analysis conducted by NewFields of the union of soils and projected urban area that indicates that suitable soils (soils in Hydrologic Soil Group A&B) for infiltration are in 20% of the Sacramento Valley and 50% of the San Joaquin Valley. The assumption is that, under this scenario, only a portion of these areas would be found to be suitable for on-site retention.

For wet weather water quality, an analysis was done of both dissolved and total organic carbon median effluent concentrations for a variety of BMPs, which is shown in Table 5-2. For total organic carbon there is a range of median values from 7 to 19 mg/L and for dissolved organic carbon from 5.4 to 19 mg/L for a variety of BMPs. For calibration of the WARMF model, the recommended target is the median effluent concentration of 7.6 mg/L for media filter BMPs, as a media filter is the most similar of the BMPs to bioretention.

Under this scenario, there will be no NELs or retrofitting requirements. There will also be no change in dissolved solids. This is consistent with present day regulations.

**Table 5-2. BMPs Median Effluent Concentration**

| **Constituent Class** | **Organic Carbon** | |
|---|---|---|
| **BMP Category** | **Dissolved Organic Carbon (mg/L)** | **Total Organic Carbon (mg/L)** |
| Detention Basin | 8.8 | 11.0 |
| Biofilter | 11.0 | 12.0 |
| Manufactured Device | 19.0 | 19.0 |
| Media Filter | 5.35 | 7.65 |
| Porous Pavement | --- | 7.0 |
| Retention Pond (Wet Pond) | 10.0 | 10.0 |
| Wetland Basin | --- | 16.0 |
| Wetland Channel | --- | 8.0 |

**References**:
International Stormwater Best Management Practices (BMP) Database. 2010.

## 5.4 2030 Probable Scenario

The 2030 Probable Scenario describes a 2030 regulatory environment that incorporates feasible changes in requirements for new development and redevelopment, and numeric effluent limits.

For new and existing development, it is assumed that there will be a regulatory requirement of 40% reduction of dry weather flows for existing and new development. For dry weather flows during the dry season (May through September) the reduced dry weather flow would be 60% of 4E-4 cfs/acre or about 2.4 E-4 cfs/acre. For those dry weather periods during the wet weather season (October – April) the reduced dry weather flows would be 60% of 5E-4 cfs/acre or about 3.0E-4 cfs/acre (Appendix C, Table 1). Achieving this 40% goal could incorporate a combination of water conservation measures including homeowner education, conservation pricing, landscape management, irrigation control, and dry weather flow harvesting (capture, treatment and reuse). In this scenario, literature indicates that the goal of 40% reduction is technically feasible through the utilization of ET controllers that manage irrigation water application[4]. If such measures are not adequate to meet the 40% goal, other options include

[4] The Residential Runoff Reduction Study conducted by the Municipal Water District of Orange County and the Irvine Ranch Water District (2004) retrofitted 138 advanced ET controllers on a total of 20.5 acres of a 168 acre catchment. The controllers were sited on 112 single family residential parcels, a condominium, and on 15 medium-size (0.14-1.92 acres) landscape sites adjacent to City streets. Monitoring recorded a 50% reduction in dry weather flows from about 0.17 GPM/permeable acre (pre-intervention period) to 0.08 GPM/permeable acre (post-intervention period).

centralized collection, treatment and reuse facilities operating at the neighborhood or larger scale.

For new development, it is assumed that in the Sacramento Valley 10 percent of newly developed areas will be located on soils suitable for on-site retention of the 85$^{th}$ percentile storm event. In the San Joaquin Valley the assumption is that 25% of the soils in newly developed urban areas would be suitable for on-site retention (Appendix C, Table 11).

For new development, it is assumed that wet weather controls will achieve a median TOC effluent concentration of 7.6 mg/L corresponding to the performance for media filters from the ISW BMP Database (Table 5-2 above).

Under this scenario, NELs will be required and would be applicable to existing and new development in the San Joaquin Valley. The selection of NELs is based on a literature review of the 2006 Final Report entitled, *Conceptual Model for Nutrients in the Central Valley and Sacramento – San Joaquin Delta*, prepared by Tetra Tech for USEPA Region IX, Central Valley Drinking Water Policy Group. The report contains nutrient data collected at monitoring stations throughout the Delta. In Section 4 of this Report, Table 4-3 shows monitored average nutrient concentrations for key locations in the Delta. The average concentration of TN for the San Joaquin River at Vernalis is 2.5 mg/L, and the average concentration of TP at Vernalis is 0.25 mg/L. For the purpose of calibration of the WARMF model, the recommended target concentrations in the San Joaquin WARMF model are set equal to the NELs which are assumed to equal 2 mg/L for TN and 0.2 mg/L for TP. This would ensure that urban discharges from new and existing development would not cause any increase in the current ambient nutrient concentrations at Vernalis.

For new development, it is assumed that controls do not have any effect on dissolved solids. Under this scenario, there will be no retrofitting requirements.

## 5.5 2030 Outer Boundary Scenario

The 2030 Outer Boundary Scenario describes a 2030 regulatory environment that incorporates an aggressive change in requirements for new development and redevelopment, retrofitting, and NELs.

For new and existing development, it is assumed that there will be a regulatory requirement of 60% reduction of dry weather flows. The assumption herein is that reduction of dry weather flows from new development will be managed per projected new development stormwater management requirements which emphasize on on-site retention where conditions permit, and continued efforts to improve water conservation in California. To meet this goal would also involve retrofitting existing development with a combination of advanced landscape management measures including landscaping irrigation and conversion to drought resistant or native plants; and, if necessary, dry weather runoff capture, storage, treatment and reuse[5].

For new development, it is assumed that on site retention of the 95$^{th}$ percentile storm would be feasible on 20 percent of the newly developed area in the Sacramento Valley and on 50% of the area in the San Joaquin Valley.

For new development, it is assumed that urban areas with BMPs would achieve a wet weather median effluent concentration of 7.6 mg/L corresponding to the media filters from the ISW BMP database. Media filter performance was selected as representative as media filters incorporate many of the same unit processes as bioremediation for which there is no data in the ISW BMP database.

For new and existing development, it is assumed that NELs will be required for nutrients in the San Joaquin Valley. The NELs are assumed to be more stringent than the 2030 Plausible Future Scenario NELs and are set at 1 mg/L for TN and 0.1 mg/L for TP. This would result in the nutrients in urban runoff being approximately 50% of the mean nutrient concentrations measured at Vernalis.

For new development it is assumed that controls have no effect on dissolved solids.

For existing development it is assumed that industrial land uses will be subject to retrofitting through the use of media filters, as the representative BMP type. For calibration of the WARMF model, the median effluent quality equals the median effluent concentration for media filter BMPs from the ISW BMP Database. It is further assumed that the implementation of the requirements will be such that the above requirement applies to only 20% of the industrial areas existing as of 2010.

---

[5] An example of dry weather runoff harvesting technology is the City of Santa Monica's Urban Runoff Recycling Facility (SMURRF) which is designed to capture, treat, and recycle approximately 0.5 MGD of dry weather runoff from two storm drains which have a total catchment area of 5100 acres and contribute about 90% of the city's total dry weather flows. The SMURRF utilizes a treatment train that includes screening, settling, microfiltration, and uv disinfection prior to pumping the water back for use in indoor plumbing and for irrigation. The facility is located close to the Santa Monica Pier in a highly visited location and was designed to also provide an educational and artistic experience. The capital cost of the facility was $12M.

# 6. COSTS

Costs for selected BMPs were estimated with the aid of cost spreadsheets and a user guide developed by the Water Environment Research Foundation (2009). The user guide provides cost spreadsheets for the following practices: extended detention basin, retention pond, swale, permeable pavement, green roof, large commercial cistern, residential rain garden, curb-contained bioretention, and in-curb planter vault. The extended detention basin, retention pond, swale and permeable pavement spreadsheets were first included in a WERF report by Lampe et al. (2005). The spreadsheets can be used for making planning level or site specific estimates (commonly referred to as an engineer's estimate). All cost estimates are in 2011 dollars.

For this study the planning level analysis was appropriate. The models take into account design considerations including catchment information and design storm criteria, land costs, capital costs, maintenance costs, and whole life cycle and present value analysis. Default unit rates are provided based on generalized information which the user may override to the extent that local data is available.

For this study costs were estimated for the following three BMPs that were considered representative of the types of BMPs that could likely be employed, namely:

- Curb-contained bioretention (often suitable for commercial areas)
- Rain gardens (more suitable for residential lots), and
- Retention ponds (more suitable for centralized project scale or regional approaches)

Bioretention and rain gardens are considered low impact development (LID) BMPs suitable to new development and are being strongly encouraged by USEPA as part of their Green Infrastructure Program. Such BMPs also are considered in California as BMPs that should be considered first (prior to considering more traditional BMPs such as biotreatment) as they can provide for on-site retention. Retention ponds are considered more of a centralized BMP that can provide treatment at the project or regional scale, otherwise provide supplemental treatment to that achieved with more distributed measures.

Sizing of each BMP requires estimates of basic parameters including catchment size and imperviousness, and the design water quality volume or flow rate. Design criteria were obtained from the Sacramento Stormwater Quality Design Manual for the Sacramento and South Placer Regions (Sacramento Stormwater Quality Partnership, 2007). Catchment characteristics varied depending on the type of BMP as distributed BMPs like rain gardens and bioretention are designed to serve smaller areas and are more suitable for certain types of development.

## 6.1 Cost Input Assumptions

Table 6-1 shows the inputs to the WERF spreadsheet for the curb-contained bioretention BMP. In this case it is assumed that the catchment is commercial and is highly impervious (90%). Design and other inputs are listed in the table including the source for the value of the input parameter. Land costs are estimated at $250,000 acre or approximately $6/ft2 which is consistent with costs in the CASQA BMP Handbook for New Development (CASQA, 2003). Labor for maintenance is estimated at $75/hr (including benefits) based in part on information provided by the City of Sacramento for the maintenance of the North Natomas Sump 14 for FY 2009/2010.

**Table 6-1**. **Cost Input Assumptions for Curb-Contained Bioretention**

| WERF Input Table | Item | Value | Source |
|---|---|---|---|
| ***Watershed Characteristics*** | Drainage Area | 1 acres | |
| | Land Use | Commercial | |
| | Percent Imperviousness | 80% | |
| ***Design and Maintenance Options*** | Water Quality Volume (WQV) | 0.6 inches | Figure E-4 of Sacramento Stormwater Quality Design Manual (2007) Assuming 24 hour Drawdown |
| | Design Average Surcharge Depth ($d_s$) | 12 inches | (Table SP-1, Design Manual) |
| | Bioretention Area | ~ 2500 $ft^2$ | =WQV/ds<br>~ 6% of drainage area |
| | Construction Cost | $20/$ft^2$ | |
| ***Capital Costs (WERF Template Method A)*** | Engineering & Planning Costs as Percent of Construction Costs | 10% | |
| | Land Costs | $14,250 | ~ $250,000/acre or about $6/$ft^2$ |
| ***Maintenance Costs*** | Labor Rate (with Benefits) | $75/hr | |

**Table 6-2. Cost Input Assumptions for Rain Gardens**

| WERF Input Table | Item | Value | Source |
|---|---|---|---|
| ***Watershed Characteristics*** | Land Use | Single Family Residential | |
| | Drainage Area (Roof Area and Paved Area) | 1000 $ft^2$* | |
| | Garden Area | 20% of DA | WERF Default |
| ***Capital Costs (WERF Template Method A)*** | Cost per $ft^2$ | $16/ft^2$ | |
| | Landscape Design Costs | $5000 | |
| ***Maintenance Costs*** | Labor Rate (with benefits) | $30/hr | |

**Note:**
*Assumes residential density of 4 units/acre and for each unit 1000 $ft^2$ is roof or paved, including driveway and patio.

Table 6-2 shows cost input assumptions for rain gardens. Assumptions assume rain gardens are placed on each residential parcel and are integrated into overall landscaping plan such that there are no separate land costs assigned to the use of the rain garden as a water quality practice. The assumption is that the rain gardens are placed in a single family residential area with housing density of 4 units per acre and an assumed 1000 $ft^2$ of impervious surfaces (roof and paved surfaces) for each unit. It is further assumed that the construction of the rain garden is done by professionals for an estimated cost of $16/ft^2$ and that maintenance is conducted by trained landscaping professionals charging $30/hr.

Table 6-3 shows cost input assumptions for a retention pond, where the design criteria are taken from the Sacramento Stormwater Quality Design Manual (2007), which has detailed guidance on retention pond design. Catchment and other characteristics were selected to replicate the catchment that drains to the City of Sacramento North Natomas Basin 4. Cost input assumptions similarly utilized information provided by the City of Sacramento for the cost of construction and operation of the North Natomas Basin 4 (Sump 14).

**Table 6-3. Cost Inputs for Retention Pond**

| WERF Input Table | Item | Value | Source |
|---|---|---|---|
| ***Watershed Characteristics*** | Catchment Area | 500 acres | |
| | Land Use | Residential | |
| | Percent Imperviousness | 40% | |
| ***Facility Storage Volume*** | Drawdown Time | 48 hrs | |
| | Water Quality Design Volume | 0.3 inches | Figure E-4 of Stormwater Quality Design Manual, 2007 |
| | Water Quality Volume (acre-ft) | 12.5 | 0.3/12*500 |
| | Water Quality Volume ($ft^3$) | 544,500 | |
| | Permanent Pool/WQV Ratio | 1.125 | Table DB-1 Stormwater Quality Design Manual, 2007 |
| | Area of Pond with Buffer | 6.1 acres | |
| ***Design and Maintenance Options*** | Forebay Volume | 1500 $yd^3$ | 5% of total design volume (Table DB-1, Design Manual) |
| | Percent Full when Sediment Removed from Forebay | 10% | |
| ***Whole Life Cost Options*** | Discount Rate | 5.5% | |
| ***Capital Costs (WERF Template Method A)*** | Construction Cost/ Catchment Acre | $3000 | WERF Users Guide 2009 |
| | Engineering Costs as Percent of Construction Costs | 10% | |
| | Land Costs | $250,000/acre | |
| ***Maintenance Costs*** | Labor Rate (with benefits) | $75/hr | |
| | Sediment Cost per $yd^3$ to Remove and Dispose of Sediment | $50/$yd^3$ | |
| | Sediment Volume Removed from Forebay | 900$yd^3$ | 30% of Forebay Volume |

## 6.2 Estimated Costs

Costs are summarized in Table 6-4 for the three types of BMPs being considered. Table 6-4 shows the estimated capital and maintenance costs and the total cost in present value form (assumes 2011 dollars, a 50 year design life and discount rate of 3%). In order to make projections of estimated cost to implement a mix of BMPs, the costs for each BMP is normalized on area to yield a cost per acre.

**Table 6-4. Summary of Estimated Unit Costs for Selected New Development and Redevelopment BMPs**

| 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.

The next step in the cost analysis was to develop an estimate for the total cost of BMP implementation for the planned, probable and outer boundary scenarios. For wet weather this was done by applying the unit costs in Table 6-4 to the total areas projected to be developed (Table 5-1). The area metric for wet weather is the impervious area as it is this area that drives wet weather BMP sizing and therefore cost. For dry weather costs were estimated based on unit costs for ET controllers[6] and harvesting[7] and the total existing areas as the dry weather requirement must be met for both wet and dry weather. In contrast to the wet weather estimate, the important land use metric for dry weather is the pervious acreage.

Table 6-5 shows the total estimated costs for the planned regulatory scenario for wet weather. The cost analysis assumes a mix of BMPs depending on the type of land use. A weighted unit price is then computed based on the assumed mix of BMPs and multiplied by the impervious area which drives BMP sizing. The analysis is conducted for each valley separately. Table 6-6 shows the estimated costs for the planned regulatory scenario for dry weather control, where it is assumed that ET controllers would be the only control measure required to meet the 20% reduction regulatory requirement.

---

[6] ET controller unit costs are based on an $2500/parcel for ET controllers from vendor information (HydroPoint Data Systems, Inc.) and assumed density of 4 dwelling parcels per acre resulting in a per acre cost of $10,000.

[7] Harvesting unit costs based on Santa Monica Urban Runoff Recycling Facility (SMURRF) which had capital cost of $12M serving approximately 5000 acre catchment in which it was assumed that percent pervious was 20% or 1000 acres. Unit cost then equaled $12M divided by 1000 acres or $12000/acre.

**Table 6-5. Total Estimated Costs for 2030 Planned Changes Scenario (Wet Weather)**

| Land Use | Drainage Area (acres) | Impervious Fraction | Impervious Area (acres) | Detention (cost/ac) | Bioretention (cost/ac) | Rain Gardens (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|
| ***Unit cost*** | | | | $7,000 | $115,000 | $72,000 | |
| ***Sacramento*** | | | | | | | |
| Residential | 173,460 | 0.4 | 69,400 | 0.50 | 0.25 | 0.25 | $3,490,000,000 |
| Commercial | 70,860 | 0.8 | 56,700 | 0.50 | 0.50 | 0.00 | $3,450,000,000 |
| Industrial | 31,621 | 0.8 | 25,300 | 0.25 | 0.75 | 0.00 | $2,230,000,000 |
| Paved | 495 | 0.9 | 446 | 0.00 | 1.00 | 0.00 | $51,200,000 |
| ***Sub-Total*** | 276,436 | | 152,000 | | | | $9,220,000,000 |
| ***San Joaquin*** | | | | | | | |
| Residential | 82,141 | 0.4 | 32,800 | 0.50 | 0.25 | 0.25 | $1,650,000,000 |
| Commercial | 14,232 | 0.8 | 11,400 | 0.50 | 0.50 | 0.00 | $694,000,000 |
| Industrial | 6029 | 0.8 | 4,820 | 0.25 | 0.75 | 0.00 | $424,000,000 |
| ***Sub-Total*** | 102,402 | | 49,100 | | | | $2,700,0,000 |
| ***Combined*** | | | | | | | |
| **Total** | **378,838** | | **200,880** | | | | **$12,000,000,000** |

**Table 6-6. Total Estimated Costs for 2030 Planned Changes Scenario (Dry Weather)**

| Land Use | Drainage Area (acres) | Pervious Fraction | Pervious Area (acres) | Dry Weather Reduction Goal | Dry Weather Pervious Area (acres) | ET Controller (cost/ac) | Rainwater Harvesting (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|---|
| ***Unit cost*** | | | | | | $10,000 | $12,000 | |
| ***Sacramento*** | | | | | | | | |
| Residential | 302,041 | 0.6 | 181,225 | 0.20 | 36,245 | 1.00 | 0.00 | $362,000,000 |
| Commercial | 57,217 | 0.2 | 11,443 | 0.20 | 2,289 | 1.00 | 0.00 | $22,900,000 |
| Industrial | 42,507 | 0.2 | 8,501 | 0.20 | 1,700 | 1.00 | 0.00 | $17,000,000 |
| Paved | 21,379 | 0.1 | 2,138 | 0.20 | 428 | 1.00 | 0.00 | $4,270,000 |
| ***Sub-Total*** | 423,144 | | 203,307 | | 40,661 | | | $407,000,000 |
| ***San Joaquin*** | | | | | | | | |
| Residential | 102,272 | 0.6 | 61,363 | 0.20 | 12,273 | 1.00 | 0.00 | $123,000,000 |
| Commercial | 27,470 | 0.2 | 5,494 | 0.20 | 1,099 | 1.00 | 0.00 | $11,000,000 |
| Industrial | 15,803 | 0.2 | 3,161 | 0.20 | 632 | 1.00 | 0.00 | $6,320,000 |
| Paved | 3,533 | 0.1 | 353 | 0.20 | 71 | 1.00 | 0.00 | $707,000 |
| ***Sub-Total*** | 149,078 | | 70,371 | | 14074 | | | $141,000,000 |
| ***Combined*** | | | | | | | | |
| **Total** | **572,222** | | **273,678** | | **54,736** | | | **$547,000,000** |

**Table 6-7. Total Estimated Costs for 2030 Probable Scenario (Wet Weather)**

| Land Use | Drainage Area (acres) | Impervious Fraction | Impervious Area (acres) | Detention (cost/ac) | Bioretention (cost/ac) | Rain Gardens (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|
| ***Unit cost*** | | | | $7,000 | $115,000 | $72,000 | |
| ***Sacramento*** | | | | | | | |
| Residential | 173,460 | 0.4 | 69,384 | 0.25 | 0.25 | 0.50 | $4,610,000,000 |
| Commercial | 70,860 | 0.8 | 56,688 | 0.50 | 0.50 | 0.00 | $3,460,000,000 |
| Industrial | 31,621 | 0.8 | 25,297 | 0.25 | 0.75 | 0.00 | $2,230,000,000 |
| Paved | 495 | 0.9 | 446 | 0.00 | 1.00 | 0.00 | $51,200,000 |
| ***Sub-Total*** | 276,436 | | 151,814 | | | | $10,400,000,000 |
| ***San Joaquin*** | | | | | | | |
| Residential | 82,141 | 0.4 | 32,856 | 0.25 | 0.25 | 0.50 | $2,180,000,000 |
| Commercial | 14,232 | 0.8 | 11,386 | 0.50 | 0.50 | 0.00 | $694,000,000 |
| Industrial | 6029 | 0.8 | 4,823 | 0.25 | 0.75 | 0.00 | $424,000,000 |
| ***Sub-Total*** | 102,402 | | 49,065 | | | | $3,300,000,000 |
| ***Combined*** | | | | | | | |
| **Total** | **378,838** | | **200,880** | | | | **$13,700,000,000** |

**Table 6-8. Total Estimated Costs for 2030 Probable Scenario (Dry Weather)**

| Land Use | Drainage Area (acres) | Pervious Fraction | Pervious Area (acres) | Dry Weather Reduction Goal | Dry Weather Area (acres) | ET Control-ler (cost/ac) | Rain-Harvest-ing (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|---|
| ***Unit cost*** | | | | | | $10,000 | $12,000 | |
| ***Sacramento*** | | | | | | | | |
| Residential | 302,041 | 0.6 | 181,225 | 0.4 | 72,490 | 0.5 | 0.5 | $797,000,000 |
| Commercial | 57,217 | 0.2 | 11,443 | 0.4 | 4,577 | 0.5 | 0.5 | $50,300,000 |
| Industrial | 42,507 | 0.2 | 8,501 | 0.4 | 3,401 | 0.5 | 0.5 | $37,400,000 |
| Paved | 21,379 | 0.1 | 2,138 | 0.4 | 855 | 0.5 | 0.5 | $9,400,000 |
| ***Sub-Total*** | 423,144 | | 203,307 | | 81,323 | | | $894,000,000 |
| ***San Joaquin*** | | | | | | | | |
| Residential | 102,272 | 0.6 | 61,363 | 0.4 | 24,545 | 0.5 | 0.5 | $270,000,000 |
| Commercial | 27,470 | 0.2 | 5,494 | 0.4 | 2,198 | 0.5 | 0.5 | $24,200,000 |
| Industrial | 15,803 | 0.2 | 3,161 | 0.4 | 1,264 | 0.5 | 0.5 | $13,900,000 |
| Paved | 3,533 | | | | | | | |
| ***Sub-Total*** | 149,078 | | 70,018 | | 28,007 | | | $308,000,000 |
| ***Combined*** | | | | | | | | |
| **Total** | **572,222** | | **273,325** | | **109,330** | | | **$1,200,000,000** |

Table 6-7 shows the total estimated costs for the probable regulatory scenario. This scenario also incorporates NELs for nutrients in the San Joaquin Valley, however the assumed median effluent concentrations for the selected BMPs are comparable to the NELs so this consideration does not add cost to this scenario. Table 6-8 shows the estimated costs for the planned regulatory scenario for dry weather control, where it is assumed that ET controllers and harvesting would be applied equally to meet the 20% reduction regulatory requirement.

**Table 6-9. Total Estimated Costs for 2030 Outer Boundary Scenario (Wet Weather)**

| Land Use | Drainage Area (acres) | Imper-vious Fraction | Imper-vious Area (acres) | Deten-tion (cost/ac) | Bioreten-tion (cost/ac) | Rain Gardens (cost/ac) | Weighted (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|---|
| **New Development** | | | | | | | | |
| ***Sacramento*** | | | | | | | | |
| ***Unit Cost*** | | | | $7,000 | $115,000 | $72,000 | | |
| Residential | 173,460 | 0.4 | 69,384 | 0.25 | 0.25 | 0.50 | $66,500 | $4,610,000,000 |
| Commercial | 70,860 | 0.8 | 56,688 | 0.50 | 0.50 | 0.00 | $61,000 | $3,460,000,000 |
| Industrial | 21,621 | 0.8 | 17,297 | 0.25 | 0.75 | 0.00 | $88,000 | $1,520,000,000 |
| Paved | 495 | 0.9 | 446 | 0.00 | 1.00 | 0.00 | $115,000 | $51,200,000 |
| ***Sub-Total*** | **266,436** | | **143,814** | | | | | **$9,640,000,000** |
| ***San Joaquin*** | | | | | | | | |
| ***Unit Cost*** [1] | | | | $8,400 | $138,000 | $86,400 | | |
| Residential | 82,141 | 0.4 | 32,856 | 0.25 | 0.25 | 0.50 | $79,800 | $2,620,000,000 |
| Commercial | 14,232 | 0.8 | 11,386 | 0.50 | 0.50 | 0.00 | $73,200 | $833,000,000 |
| Industrial | 6029 | 0.8 | 4,823 | 0.25 | 0.75 | 0.00 | $105,600 | $509,000,000 |
| ***Sub-Total*** | **102,402** | | **49,065** | | | | | **$3,960,000,000** |
| **Retrofitting Existing Development** [2] | | | | | | | | |
| ***Sacramento*** | | | | | | | | |
| Industrial | 20,000 | 0.8 | 16,000 | | 1.00 | | $179,400 | $2,870,000,000 |
| ***San Joaquin*** | | | | | | | | |
| Industrial | 4000 | 0.8 | 3,200 | | 1.00 | | $179,400 | $574,000,000 |
| ***Sub-Total*** | | | **1,9200** | | | | | **$3,440,000,000** |
| **Combined – New and Retrofitting** | | | | | | | | |
| **Total** | | | | | | | | **$17,000,000,000** |

**Notes:**

[1] Unit prices for BMPs in SJV increased by 20% to incorporate denitrification to meet nutrient NEL

[2] Assumes retrofitting applied to 20% of existing industrial areas or 4000 acres of industrial area in SJV and 20,000 acres in Sacramento Valley and adds 30% to unit cost

Table 6-9 shows the total estimated costs for the outer boundary scenario. The costs are similar to the probable scenario except for two considerations, the NELs in the San Joaquin Valley and the retrofitting for industrial land uses. In order to meet the nutrient NELs it is assumed that the BMP designs would need to incorporate an anaerobic zone to foster de-nitrification. It is assumed that this design requirement would increase the unit costs of the BMPs in the San Joaquin Valley by 20%. These unit costs are shown in Table 6-9 below the unit costs used for the Sacramento Valley.

**Table 6-10. Total Estimated Costs for 2030 Outer Boundary Scenario (Dry Weather)**

| Land Use | Drainage Area (acres) | Pervious Fraction | Pervious Area (acres) | Dry Weather Reduction Goal | Dry Weather Pervious Area (acres) | ET Controller (cost/ac) | Rain-water Harvesting (cost/ac) | Cost |
|---|---|---|---|---|---|---|---|---|
| ***Unit cost*** | | | | | | $10,000 | $12,000 | |
| | | | | ***Sacramento*** | | | | |
| Residential | 302,041 | 0.6 | 181,225 | 0.6 | 108,735 | 0.26 | 0.75 | $1,260,000,000 |
| Commercial | 57,217 | 0.2 | 11,443 | 0.6 | 6,866 | 0.26 | 0.75 | $79,600,000 |
| Industrial | 42,507 | 0.2 | 8,501 | 0.6 | 5,101 | 0.26 | 0.75 | $59,200,000 |
| Paved | 21,379 | 0.1 | 2,138 | 0.6 | 1,283 | 0.26 | 0.75 | $14,900,000 |
| ***Sub-Total*** | 423,144 | | 203,307 | | 121,984 | | | 1,420,000,000 |
| | | | | ***San Joaquin*** | | | | |
| Residential | 102,272 | 0.6 | 61,363 | 0.6 | 36,818 | 0.26 | 0.75 | $427,000,000 |
| Commercial | 27,470 | 0.2 | 5,494 | 0.6 | 3,296 | 0.26 | 0.75 | $38,200,000 |
| Industrial | 15,803 | 0.2 | 3,161 | 0.6 | 1,896 | 0.26 | 0.75 | $22,000,000 |
| Paved | 3,533 | | | | | | | |
| ***Sub-Total*** | 149,078 | | 70,018 | | 42,011 | | | $487,000,000 |
| | | | | ***Combined*** | | | | |
| **Total** | **572,222** | | **273,325** | | **163,995** | | | **$1,900,000,000** |

Costs in this case also must be adjusted for the assumed retrofitting of 20% of the existing industrial land uses. Based on available land use information it was estimated that 20% of the existing industrial land use in the SJV was approximately 4000 acres, and was approximately 20,000 acres in the Sacramento Valley. Moreover retrofitting was assumed to increase the unit costs by 30% compared to new development. These cost estimates indicate that retrofitting would cost an additional 3.5 billion dollars. Table 6-10 shows the estimated costs for the planned regulatory scenario for dry weather control, where it is assumed that harvesting would be applied to 75% of the acreage to meet the 60% reduction regulatory requirement.

Table 6-11 is a summary of the costs to meet planned and projected wet and dry weather regulatory requirements. Note that both wet and dry weather requirements for the probable and outer boundary scenarios include retrofitting existing land uses. For wet weather, retrofitting is assumed required to meet nutrient numeric effluent limits assumed to apply in the San Joaquin Valley, and retrofitting is assumed to apply to industrial land uses in both valleys to meet NELS. For dry weather, the costs in Table 6-8 are wholly for retrofitting assumed required to meet dry weather flow reductions.

**Table 6-11. Cost Summary**

| 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 |

It should be emphasized that these costs are based on a number of assumptions and therefore are subject to large uncertainty and should be regarded as rough order of magnitude cost estimates only.

# 7. SUMMARY AND LIMITATIONS

The goal of this report was to provide information and data for the characterization and control of urban sources in the Central Valley for current and projected future regulatory conditions and to provide cost estimates for the identified control measures. The focus was on the quantity and quality of dry and wet weather flows with an emphasis on drinking water constituents of concern. A major element in the work was to provide recommendations for calibration targets to the WARMF modelers for their Sacramento and San Joaquin modeled areas which also took into account the effects of agricultural and waste water discharges.

## 7.1 Summary

Key assumptions regarding future regulatory conditions and inputs to the WARMF model follow:

- The Central Valley is anticipated to undergo continued rapid urban growth; however there are specific state funded urban planning efforts underway that are supportive of smart growth measures that have been taken into account in the land use projections used herein. Analysis of the data provided by the Sacramento Council of Governments and the Council of Governments in the eight county San Joaquin Valley indicate an increase in urban land uses of approximately 450,000 acres which is roughly a 50% increase over the current 2011 urban areas.

- The focus of the report is on priority drinking water COCs consisting of nutrients, dissolved solids, organic carbon, and pathogens, with an emphasis on *Cryptosporidium* and *Giardia*, although pathogens were not modeled in WARMF.

- Current and future stormwater regulations and water conservation requirements will continue to emphasize measures to better manage our urban water resources through such activities as improved landscaping practices, onsite retention and groundwater recharge, and recycling and reuse.

- Data sources for runoff characterization were based on regional Central Valley data and the 2010 Nationwide Stormwater Quality Database (NSQD).

- Data sources for runoff controls were based on data collected during Water Years 2007, 2008, and 2009 in North Natomas Detention Pond and the 2010 International Stormwater BMP Data Base. The latter database provided performance statistics in the form of volume reduction and effluent quality for a variety of measures including bioretention, bioswales, media filters, retention ponds, and where available, porous pavement.

- The performance statistics apply to a design rainfall event estimated as the 85th percentile storm event which is relatively small compared to flood design criteria. For example, in the Sacramento area, the design event is approximately 0.75 inches.

- Current and future stormwater regulations for new development and redevelopment will emphasize low impact development (LID) and green infrastructure measures that encourage on-site retention and maintenance of the pre-development hydrologic water balance to the extent feasible. This trend was incorporated in this report by including a mix of LID and traditional BMPs in the analysis.

- Future regulatory requirements may include numeric effluent limits (NELs) for some drinking water constituents of concern such as nutrients which also can have adverse environmental consequences. In this report, it was assumed that NELs for nutrients is a reasonable regulatory scenario for the San Joaquin Valley where data from the Central Valley Nutrient Conceptual Model indicates elevated levels of nutrients compared to rivers in the Sacramento Valley.

- Future regulatory requirements may include retrofitting of areas currently developed. In this report it was assumed that retrofitting was a regulatory requirement for industrial facilities in the more aggressive regulatory scenario. The retrofitting would involve the installation of treatment facilities for stormwater runoff. The assumption in the cost analysis was that bioretention using an underground vault was representative of the type of controls could meet the constraints commonly encountered in industrial sites.

- A detailed list of recommended calibration targets for the WARMF model was included in Appendix C which provided guidance on how the quality and quantity of urban runoff might vary in 2030 for each regulatory scenario.

- An analysis of costs was conducted using a cost template developed by the Water Environment Research Federation that was applied to estimate the cost per acre for selected BMPs. Rough order of magnitude costs were then estimated based on the projected increase in land use and land use types. The cost of the scenarios ranged from approximately 13 to 19 billion dollars depending on the scenario.

## 7.2 Limitations

The following summarizes limitations in this study and potential areas of enhancement for future work.

- The WARMF modeling domain extends to Lander Avenue in Turlock and thus includes Modesto, where approximately 70% of the Modesto MS4 runoff is captured by rock wells that infiltrate stormwater into the shallow aquifer rather than discharging directly to surface water. Moreover water quality data for runoff from the Central Valley was based primarily on data collected by the Sacramento Stormwater Partnership, with supplemental data provided by nationwide databases. Future work could include improved characterization of the runoff and water quality characteristics in Modesto and Stockton and other MS4s contained within the WARMF domain.

- A key input to the urban source control projections is the projected land use, which was based on projections conducted by the Sacramento Council of Governments and a consortium of councils of governments in the Central Valley. The projected increase in urban land use by 2030 in Sacramento called for an increase of about 50%, whereas the historical urban growth rates in most of the counties within the SACOG jurisdiction range from about 20% to 150%. Further work on confirming the projected land use in both the Sacramento and San Joaquin Valleys with a variety of sources, including projected population growth, could improve the confidence of this key input.

- The scenarios call for a decrease in dry weather flows ranging from 20% for the planned scenario to 60% for the outer boundary scenario. Achievement of this decrease would include implementing measures to reduce overwatering of landscaped areas, and a movement towards more drought tolerant plant species. Reduced irrigation could lead to lower groundwater levels and reduced return flows to streams and other water bodies. This study did not address the potential changes in return flow water quality that might occur because of the requirement to reduce dry weather flows.

# 8. REFERENCES

Bambic, D. G. McBride, W. Miller, R. Stott, S. Wuertz, 2010. Quantification of Pathogens and Sources of Microbial Indicators for QMRA in Recreational Waters, Draft Final Report 1-4-11, PATH2R08.

Brown, D.J., E.R. Hunt Jr., R.C. Izaurralde, K.H Paustian, C.W. Rice, B. L. Schumaker, and T.O. West, 2010. Soil Organic Carbon Change Monitored Over Large Areas. Eos, Transactions, American Geophysical Union, Vol. 91, No. 47, P. 441, 2010.

Brown, R.A., Hunt, W.F., and Kennedy, S.G., 2009. Designing Bioretention with an Internal Water Storage (IWS) Layer.
(http://www.bae.ncsu.edu/stormwater/PublicationFiles/IWS.BRC.2009.pdf)

CALFED Bay-Delta Program. 2007. Conceptual Model for Salinity in the Central Valley and Sacramento-San Joaquin Delta, prepared for Drinking Water Policy Workgroup.

California Department of Conservation 2009. Farmland Mapping and Monitoring Program, (http://redirect.conservation.ca.gov/DLRP/fmmp/county_info_results.asp)

California Stormwater Quality Association 2003. Stormwater Best Management Practice Handbook, New Development and Redevelopment, January.

Caltrans, 2005. Methodology for Quantitative Molecular Determination of Viruses, Bacteria and Protozoa. July 2005.

CASQA Water Quality Newsflash. 2010. New EPA Policy for Stormwater – Memorandum Proposes Expanded Use of Numeric Limitations for Stormwater.

City of Stockton and County of San Joaquin, 2010. Stormwater Management Program: Supplement to the 2009-2010 Annual Report, December.

Central Valley Regional Water Quality Control Board. 2008. Waste Discharge Requirements, Cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova, Sacramento, and County of Sacramento, Stormwater Discharges from Municipal Separate Storm Sewer System, Sacramento County. Order No. R5-2008-0142. NPDES No. CAS082597. September 11, 2008.

Central Valley Regional Water Quality Control Board. 2008a. Overview of Salinity Issues in the Central Valley.
(http://www.swrcb.ca.gov/rwqcb5/water_issues/basin_plans/cvwb_jt_pub_wkshp/salt_staff_rpt.pdf)

Central Valley Regional Water Quality Control Board. 2010, Management Agency Agreement between the Central Valley Regional Water Quality Control Board and the United States Bureau of Reclamation. (Updated from 2008)

Facility for Advancing Water Biofiltration (FAWB), 2008. Advancing the Design of Stormwater Biofiltration. June 2008.

Florida Department of Environmental Protection, 2003. Monitoring for Protozoan Pathogens in Reclaimed Water: Florida's Requirements and Experience.

Geosyntec and Wright Water Engineers, Inc., 2009. Urban Stormwater BMP Performance Monitoring. October 2009.

Geosyntec, 2010. Wet Detention Basin Effectiveness Study, Phase II. Prepared for the City of Sacramento Department of Utilities. August 31, 2010.

Hanlon, J. 2010. Memorandum – Revisions to the November 22, 2002 Memorandum "Establishing Total maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Stormwater Sources and NPDES Permit requirements Based on Those WLAs". United States Environmental Protection Agency. November 12, 2010.

Harnish, Minter, 2010. San Joaquin Valley Blueprint Planning Process, Summary Report, September, prepared by Minter Harnish in association with Carol Whiteside Consulting, Mogavero Notestine Associates, and The Rios Company.
(http://www.fresnocog.org/files/Blueprint/SJVBR_Summary_Final_2010-09-22.pdf)

Heidel, K., Roy, S., Creager, C., Chung, C., and Grieb, T. 2006. Conceptual Model for Nutrients in the Central Valley and Sacramento – San Joaquin Delta, Final Report. Tetra Tech, Inc. September 20, 2006.

Hydrophix, 2008. A Series of Independent Studies Featuring Smart Sponge® Plus, the Anitimicrobial Storm Water Treatment Media.

Lampe, L., Andrews, H.O., Hollon, M., Jefferies, C., Kellagher, R., Matin, P. 2005. Performance and Whole-Life Costs of Best Management Practices and Sustainable Urban Drainage Systems. Final Report for Phases 1 and 2 of the Project 01-CTS-21T. Water Environment Research Foundation, Alexandria, Virginia.

LWA, 1996. Sacramento NPDES Stormwater Discharge Characterization Program 1996 DCP Update Report. Prepared for County of Sacramento, City of Sacramento, City of Folsom, and City of Galt. Larry Walker Associates. September 1996.

LWA, 2010a. Salt and Nitrate Sources Pilot Implementation Study Report. Part of the CV-SALT Initiative. February 2010.

LWA, 2010b. Sacramento Stormwater Quality Partnership data and location descriptions. E-mail communication with Brian Laurenson, December 21, 2010.

McCaslin, Hope, 2008. Microbial Source Tracking and Pathogen Detection in Receiving Waters and Urban Runoff for the Sacramento Stormwater Quality Partnership, Memorandum addressed to Delia McGrath and Ken Ballard dated August 29, 2008.

Minton, G.R. 2005. Stormwater Treatment. Resources Planning Associates, Seattle, WA.

Municipal Water District of Orange County and Irvine Ranch Water District, 2004. The Residential Runoff Reduction Study, July 2004.

Passeport et. al, 2009. Field Study of the Ability of Two Grassed Bioretention Cells to Reduce Storm-Water Runoff. Journal of Irrigation and Drainage Engineering, ASCE, Volume 135, No. 4, pp 505-510, July/August 2009.

Pitt, R. 2004. Control of Microorganisms in Urban Waters. (http://unix.eng.ua.edu/~rpitt/Class/ExperimentalDesignFieldSampling/MainEDFS.html).

Pitt, R., 2007. Module 7: Microorganisms in Urban Surface Waters. August 23, 2007.

Pitt, R. Maestre, A. and R. Morquecho, 2008. National Stormwater Quality Database, Version 3. (unix.eng.ua.edu/~rpitt/Research/ms4/Table%20NSQD%20v3%20Feb%2003%202008.xls)

Ruby, A. 2005. Sacramento Urban Runoff Discharge Characterization 2005, Armand Ruby Consulting in association with Larry Walker Associates. Prepared for the Sacramento Stormwater Quality Partnership. pp. 11 August 2005.

Sacramento Council of Governments, 2010. Blueprint for Smarter Growth, (http://www.sacog.org/mtp/2035/workshop2010/materials/map-regional.pdfhttp://www.sacog.org/mtp/2035/workshop2010/materials/map-regional.pdf)

Sacramento Country. 2010. Farmland Mapping and Monitoring Program, California Department of Conservation, 1988-2008 Land Use Summary.

Sacramento Stormwater Quality Partnership, 2007. Stormwater Quality Design Manual for the Sacramento and South Placer Regions, May 2007.

San Diego Regional Water Quality Control Board. 2009. Waste Discharge Requirements for Discharges of Runoff from the Municipal Separate Storm Sewer Systems (MS4s) Draining the watershed of the County of Orange, the Incorporated Cities of Orange County, and The Orange County Flood Control District Within the San Diego Region. Order No. R9-2009-0002. NPDES No. CAS0108740. December 16, 2009.

San Francisco Bay Regional Water Quality Control Board. 2009. Municipal Regional Stormwater NPDES Permit (MRP), Order No. R2-2009-0074. NPDES No. CAS612008. October 14, 2009.

Santa Ana Regional Water Board. 2010. Waste Discharge Requirements for the Riverside County Flood Control and Water Conservation District, the County of Riverside, and the Incorporated Cities of Riverside County Within the Santa Ana Region. Order No. R8-2010-0033. NPDES No. CAS618033. January 29, 2010.

Schroeder, E.D., W.M. Stallard, D.E. Thompson, F.J. Loge, M.A. Deshusses, Huub H.J. Cox, 2002. Management of Pathogens Associated with Storm Drain Discharge, Results of Investigations of the Presence of Human Pathogens in Urban Storm Drains, prepared by Center for Environmental and Water Resources Engineering, Department of Civil and Environmental Engineering, University of California, Davis for California Department of Transportation, Report CTSW-RT-02-025.

Schueler, T.R. 2000. Irreducible Pollutant Concentrations Discharged from Stormwater Practices. Article 65 in The Practice of Watershed Protection, Schueler, T.R. and H.K. Holland (eds.). Center for Watershed Protection, Ellicott City, MD.

Sickman, J.O., C. L. DiGiorgio, M.L. Davisson, D. M. Lucero, B. Bergamaschi, 2010. Identifying sources of dissolved organic carbon in agriculturally dominated rivers using radiocarbon age dating: Sacramento–San Joaquin River Basin, California. Biogeochemistry, Volume 99, pp 79-96, 2010.

Shaber, N. and Slifko, T., 2007. Microbiological Assessment of Stormwater Ponds for Alternative Water Supplies. Proceedings of the 9th Biennial Conference on Stormwater Research and Watershed Management, UCF Stormwater Management Academy. May 2-3 2007. http://www.stormwater.ucf.edu/conferences/9thstormwaterCD/index.htmlhttp://www.stormwater.ucf.edu/conferences/9thstormwaterCD/index.html.

Starr Consulting. 2007. Summary Table for Evaluation of Drinking Water Quality Goals, prepared for Drinking Water Policy Workgroup, October 10.

State Water Resources Control Board, 2009. General Permit for Discharges of Storm Water Associated with Construction Activity (CGP). Order No. 2009-0009-DWQ. General NPDES Permit No. CAS000001. September 2009.

State Water Resources Control Board, 1997. Waste Discharge Requirements for Discharged of Stormwater Associated with Industrial Activities Excluding Construction Activities, Order No. 97-03-DWQ. General NPDES Permit No. CAS000001. April 1997.

Strecker, E., Quigley, M., Urbonas, B., Jones, J., and Clary, J., 2001. "Determining Urban Stormwater BMP Effectiveness," Journal of Water Resources Planning and Management May/June 2001.

Tetra Tech. 2006a. Conceptual Model for Organic Carbon in the Central Valley and Sacramento-San Joaquin Delta, prepared for US Environmental Protection Agency, Region IX and Central Valley Drinking Water Policy Workgroup.

Tetra Tech. 2006b. Conceptual Model for Nutrients in the Central Valley and Sacramento-San Joaquin Delta, prepared for US Environmental Protection Agency, Region IX and Central Valley Drinking Water Policy Workgroup.

Tetra Tech. 2007. Conceptual Model for Pathogens and Pathogen Indicators in the Central Valley and Sacramento-San Joaquin Delta, prepared for US Environmental Protection Agency, Region IX and Central Valley Drinking Water Policy Workgroup.

United States Environmental Protection Agency. 2000. Giardia: Drinking Water Fact Sheet. Office of Water. 4304. September 2000.

USEPA. 2001a. Stage 1 Disinfectants and Disinfection Byproduct Rule: A Quick Reference Guide.

United States Environmental Protection Agency. 2001b. Cryptosporidium: Drinking Water Health Advisory. Office of Science and Technology, Office of Water. EPA-822-R-01-009. March 2001.

United States Environmental Protection Agency. 2007. Report of the Experts Scientific Workshop on Critical Research Needs for the Development of New of Revised Recreational Water Quality Criteria, EPA 823-R-07-006.

(http://water.epa.gov/scitech/swguidance/waterquality/standards/criteria/health/recreation/upload/2007_06_26_criteria_recreation_experts_front-matter.pdf)

United States Environmental Protection Agency. 2009a. Review of Zoonotic Pathogens in Ambient Waters. Office of Water, Health and Ecological Criteria Division, February 2009. EPA 822-R-09-002.

United States Environmental Protection Agency. 2009b. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. Office of Water. EPA 841-B-09-001. December 2009.

United States Environmental Protection Agency. 2009c. Stakeholder Input; Stormwater Management Including Discharges From New and Redevelopment. Federal Register, Volume 74, No. 247. Notice. December 28, 2009.

United States Environmental Protection Agency. 2010a. EPA Chlorinated Water Discharge Options. (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=103. Last updated November 10, 2010. Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm; http://cfpub.epa.gov/ npdes/stormwater/menuofbmps/index.cfm)

United States Environmental Protection Agency. 2010b Phase Out of Methyl Bromide http://www.epa.gov/ozone/mbr/ Last updated on Thursday, August 19, 2010.

Water Environment Research Foundation, 2009. User’s Guide to BMP and LID Whole Life Cycle Cost Models, Version 2. Report SW2R08.

Wright Water Engineers and Geosyntec, 2010. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Bacteria. DRAFT.

Wright Water Engineers and Geosyntec, 2010. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Nutrients. DRAFT.

## APPENDIX A. SUMMARY OF DATA FROM THE NATIONAL STORMWATER QUALITY DATABASE (NSQD)

### A.1 Constituent and Land Use Summary

The drinking water constituents of concern available in the NSQD are listed in Table A-1 below along with their units. The total number of samples is also included. Constituents are categorized by land use in Table A-3 through A-12 below.

**Table A-1: Drinking Water Constituents of Concern**

| Constituent Class | Contituent | Number of Samples |
|---|---|---|
| Organic Carbon | Total Organic Carbon (mg/L) | 85 |
| Nutrients | Ammonia as N (mg/l) | 1313 |
| | Nitrate as N (mg/l) | 175 |
| | Nitrite as N (mg/l) | 70 |
| | (Nitrate + Nitrite) as N (mg/l) | 4307 |
| | Nitrogen Kjeldahl Total (mg/l) | 4612 |
| | Total Organic Nitrogen (mg/l) | 34 |
| | Total Nitrogen (mg/l) | 570 |
| | Orthophosphate as P (mg/l) | 34 |
| | Phosphorous Dissolved (mg/l) | 1901 |
| | Phosphorous Total (mg/l) | 5686 |
| Dissolved Solids | Chloride (mg/l) | 164 |
| | Conductivity (uS/cm @25ºC) | 769 |
| | TDS (mg/l) | 2753 |
| Fecal Indicator Bacteria | Fecal Coliform (colonies/100 ml) | 1628 |
| | Fecal Streptococcus (colonies/100 ml) | 919 |
| | Total Coliform (colonies/100 ml) | 133 |
| | Total E. Coli (colonies/100 ml) | 133 |

Land uses available in the database include commercial, freeway, industrial, institutional (i.e. educational, etc), open space, residential, and unknown, along with mixes of these land uses. Land use names, average percent imperviousness, and percent of each land use in the mixed land use, if applicable, are shown in Table A-2 below.

## Table A-2: Land Use Type Summary

| Land Use | Number of Samples | Number of Sample Locations | Average Imperviousness (%) | Percent of Land Use Type (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Residential | Institutional | Commercial | Industrial | Open Space | Freeway | Unknown |
| Commercial | 1080 | 62 | 73 | | | 100 | | | | |
| Commercial/ Industrial | 7 | 3 | 0 | | | 50 | 50 | | | |
| Commercial/ Mixed Use | 446 | 30 | 66 | 20 | 2 | 61 | 5 | 4 | 3 | |
| Commercial/ Open Space | 9 | 1 | 47 | 20 | | 39 | 5 | 37 | | |
| Freeway | 734 | 28 | 68 | | | | | | 100 | |
| Freeway/ Mixed Use | 18 | 2 | 29 | 2 | | 1 | 14 | 20 | 64 | |
| Industrial | 883 | 70 | 71 | | | 1 | 98 | 1 | | |
| Industrial/ Mixed Use | 223 | 19 | 51 | 13 | 4 | 7 | 51 | 17 | | |
| Institutional | 55 | 3 | 45 | | 100 | | | | | |
| Institutional/ Mixed Use | 15 | 1 | 37 | 48 | 52 | | | | | |
| Open Space | 125 | 16 | 2 | 1 | | 1 | 1 | 98 | | |
| Open Space/ Mixed Use | 233 | 13 | 20 | 9 | 4 | 10 | 8 | 67 | 3 | |
| Residential | 2949 | 129 | 33 | 97 | 1 | | | 2 | | |
| Residential/ Commercial | 67 | 3 | 57 | 46 | | 46 | | 8 | | |
| Residential/ Mixed Use | 1335 | 64 | 39 | 66 | 3 | 11 | 3 | 6 | 1 | 4 |
| Unknown | 329 | 10 | 54 | | | | | | | 100 |
| Unknown/ Mixed Use | 94 | 3 | 55 | 15 | | | | 24 | | 61 |

## A.2 Constituent Concentrations by Land Use

The total number of data points, 25th percentile, Median, and 75th percentile concentration of each concentration are summarized by land use in Tables A-3 through A-12 below.

### Table A-3: Total Organic Carbon (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Freeway | 61 | 8 | 11.4 | 17 |
| Industrial/ Mixed Use | 12 | 12.2 | 18.5 | 29.75 |
| Open Space | 1 | 3.8 | 3.8 | 3.8 |
| Residential | 3 | 19 | 26 | 29 |
| Residential/ Mixed Use | 8 | 30.25 | 48.5 | 83.75 |

### Table A-4: Ammonia as N (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 352 | 0.26 | 0.5 | 0.92 |
| Commercial/ Mixed Use | 95 | 0.33 | 0.6 | 1.13 |
| Freeway | 82 | 0.61 | 1.04 | 1.68 |
| Freeway/ Mixed Use | 3 | 0.85 | 0.92 | 1.44 |
| Industrial | 297 | 0.23 | 0.45 | 0.77 |
| Industrial/ Mixed Use | 42 | 0.33 | 0.49 | 0.80 |
| Institutional | 17 | 0.20 | 0.32 | 0.53 |
| Open Space | 12 | 0.11 | 0.20 | 0.43 |
| Open Space/ Mixed Use | 14 | 0.36 | 0.51 | 0.92 |
| Residential | 139 | 0.30 | 0.47 | 0.74 |
| Residential/ Mixed Use | 184 | 0.22 | 0.41 | 0.85 |
| Unknown | 76 | 0.20 | 0.49 | 0.88 |

### Table A-5: Nitrate as N (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial/ Mixed Use | 13 | 0.32 | 0.49 | 1.14 |
| Freeway | 98 | 0.49 | 0.84 | 1.45 |
| Industrial | 6 | 0.62 | 0.67 | 1.07 |
| Industrial/ Mixed Use | 22 | 0.49 | 0.66 | 0.96 |
| Residential | 12 | 0.62 | 0.70 | 1.23 |
| Residential/ Mixed Use | 24 | 0.49 | 0.72 | 1.06 |

**Table A-6: Nitrite as N (mg/L)**

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial/ Mixed Use | 1 | 0.164 | 0.164 | 0.164 |
| Freeway | 42 | 0.125 | 0.175 | 0.400 |
| Industrial/ Mixed Use | 11 | 0.055 | 0.100 | 0.130 |
| Residential | 5 | 0.110 | 0.150 | 0.710 |
| Residential/ Mixed Use | 11 | 0.070 | 0.140 | 0.218 |

**Table A-7: (Nitrate + Nitrite) as N (mg/L)**

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 823 | 0.33 | 0.60 | 0.96 |
| Commercial/ Industrial | 5 | 0.40 | 0.76 | 0.90 |
| Commercial/ Mixed Use | 274 | 0.39 | 0.56 | 0.91 |
| Commercial/ Open Space | 9 | 0.30 | 0.40 | 0.41 |
| Freeway | 110 | 0.42 | 1.18 | 2.07 |
| Freeway/ Mixed Use | 14 | 0.49 | 0.65 | 0.78 |
| Industrial | 591 | 0.40 | 0.65 | 1.01 |
| Industrial/ Mixed Use | 159 | 0.40 | 0.61 | 0.91 |
| Institutional | 52 | 0.29 | 0.60 | 0.84 |
| Institutional/ Mixed Use | 14 | 0.26 | 0.30 | 0.51 |
| Open Space | 112 | 0.20 | 0.49 | 1.09 |
| Open Space/ Mixed Use | 213 | 0.28 | 0.49 | 0.80 |
| Residential | 682 | 0.18 | 0.54 | 1.08 |
| Residential/ Commercial | 33 | 0.05 | 0.15 | 0.23 |
| Residential/ Mixed Use | 938 | 0.41 | 0.63 | 0.96 |
| Unknown | 278 | 0.27 | 0.53 | 0.90 |

## Table A-8: Total Kjeldahl Nitrogen (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 775 | 0.84 | 1.34 | 2.22 |
| Commercial/ Industrial | 3 | 0.35 | 0.60 | 1.15 |
| Commercial/ Mixed Use | 314 | 0.80 | 1.40 | 2.31 |
| Commercial/ Open Space | 9 | 0.50 | 1.12 | 1.40 |
| Freeway | 435 | 1.12 | 1.73 | 2.75 |
| Freeway/ Mixed Use | 14 | 0.73 | 1.75 | 2.66 |
| Industrial | 642 | 0.80 | 1.30 | 2.19 |
| Industrial/ Mixed Use | 147 | 0.60 | 1.10 | 2.30 |
| Institutional | 51 | 0.77 | 1.20 | 1.88 |
| Institutional/ Mixed Use | 15 | 0.93 | 1.04 | 1.71 |
| Open Space | 79 | 0.28 | 0.45 | 0.82 |
| Open Space/ Mixed Use | 167 | 0.64 | 1.00 | 1.70 |
| Residential | 783 | 0.79 | 1.27 | 2.04 |
| Residential/ Mixed Use | 1053 | 0.88 | 1.40 | 2.37 |
| Unknown | 112 | 1.00 | 1.53 | 2.32 |
| Unknown/ Mixed Use | 13 | 0.61 | 0.73 | 0.85 |

## Table A-9: Total Organic Nitrogen (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75$^{th}$ Percentile |
|---|---|---|---|---|
| Residential/ Mixed Use | 10 | 0.84 | 0.97 | 1.61 |

## Table A-10: Total Nitrogen (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 81 | 1.17 | 1.75 | 3.00 |
| Commercial/ Mixed Use | 72 | 0.90 | 1.60 | 2.60 |
| Freeway | 14 | 1.16 | 1.38 | 1.59 |
| Industrial | 85 | 1.09 | 1.71 | 2.52 |
| Industrial/ Mixed Use | 71 | 0.80 | 1.70 | 3.23 |
| Institutional | 7 | 1.11 | 1.40 | 2.05 |
| Open Space | 18 | 0.76 | 1.65 | 3.07 |
| Open Space/ Mixed Use | 48 | 1.00 | 1.70 | 2.37 |
| Residential | 64 | 0.66 | 1.41 | 2.41 |
| Residential/ Mixed Use | 110 | 1.20 | 1.60 | 2.70 |

## Table A-11: Orthophosphate as P (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 44 | 0.0925 | 0.19 | 0.3225 |
| Commercial/ Mixed Use | 20 | 0.07 | 0.1215 | 0.165 |
| Freeway | 103 | 0.05 | 0.09 | 0.15 |
| Freeway/ Mixed Use | 1 | 0.25 | 0.25 | 0.25 |
| Industrial | 59 | 0.14 | 0.24 | 0.375 |
| Industrial/ Mixed Use | 8 | 0.081 | 0.16 | 0.4675 |
| Open Space | 4 | 0.155 | 0.16 | 0.1775 |
| Residential | 41 | 0.13 | 0.196 | 0.24 |
| Residential/ Mixed Use | 30 | 0.09 | 0.14 | 0.2895 |
| Unknown | 11 | 0.12 | 0.16 | 0.22 |

## Table A-12: Dissolved Phosphorus as P (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 345 | 0.060 | 0.110 | 0.210 |
| Commercial/ Mixed Use | 194 | 0.050 | 0.090 | 0.230 |
| Freeway | 44 | 0.055 | 0.118 | 0.230 |
| Freeway/ Mixed Use | 11 | 0.016 | 0.030 | 0.053 |
| Industrial | 404 | 0.060 | 0.100 | 0.180 |
| Industrial/ Mixed Use | 139 | 0.050 | 0.090 | 0.170 |
| Institutional | 19 | 0.060 | 0.100 | 0.150 |
| Open Space | 36 | 0.060 | 0.135 | 0.282 |
| Open Space/ Mixed Use | 126 | 0.051 | 0.090 | 0.204 |
| Residential | 139 | 0.084 | 0.150 | 0.242 |
| Residential/ Mixed Use | 394 | 0.070 | 0.122 | 0.200 |
| Unknown | 50 | 0.112 | 0.155 | 0.285 |

**Table A-13: Total Phosphorus as P (mg/L)**

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 942 | 0.11 | 0.19 | 0.35 |
| Commercial/ Industrial | 6 | 0.18 | 0.27 | 0.43 |
| Commercial/ Mixed Use | 386 | 0.15 | 0.27 | 0.46 |
| Commercial/ Open Space | 9 | 2.88 | 3.34 | 4.38 |
| Freeway | 588 | 0.15 | 0.25 | 0.44 |
| Freeway/ Mixed Use | 14 | 0.07 | 0.25 | 0.39 |
| Industrial | 678 | 0.13 | 0.23 | 0.41 |
| Industrial/ Mixed Use | 178 | 0.12 | 0.24 | 0.39 |
| Institutional | 52 | 0.12 | 0.19 | 0.27 |
| Institutional/ Mixed Use | 15 | 0.11 | 0.22 | 0.25 |
| Open Space | 115 | 0.02 | 0.06 | 0.23 |
| Open Space/ Mixed Use | 211 | 0.13 | 0.22 | 0.42 |
| Residential | 879 | 0.11 | 0.20 | 0.41 |
| Residential/ Commercial | 40 | 0.15 | 0.27 | 0.39 |
| Residential/ Mixed Use | 1183 | 0.18 | 0.31 | 0.50 |
| Unknown | 299 | 0.08 | 0.17 | 0.31 |
| Unknown/ Mixed Use | 91 | 0.10 | 0.19 | 0.38 |

Dissolved Solids

## Table A-14: Chloride (mg/L)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 38 | 7 | 9.5 | 31.75 |
| Industrial | 40 | 3.75 | 7.55 | 42.75 |
| Industrial/ Mixed Use | 4 | 4.875 | 7.55 | 25.2 |
| Open Space | 6 | 2.68 | 5.5 | 10.75 |
| Residential | 48 | 5.825 | 12.2 | 33.75 |
| Residential/ Mixed Use | 28 | 2.7525 | 6 | 10.55 |

## Table A-15: Conductivity (μS/ cm at 25° C)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 88 | 66.7 | 114.1 | 171 |
| Commercial/ Mixed Use | 46 | 69.2 | 106 | 161 |
| Freeway | 86 | 60.0 | 99.0 | 121 |
| Freeway/ Mixed Use | 13 | 303 | 418 | 830 |
| Industrial | 131 | 81.6 | 131 | 206 |
| Industrial/ Mixed Use | 48 | 91.5 | 130 | 233 |
| Open Space | 7 | 47.5 | 75.0 | 88.5 |
| Open Space/ Mixed Use | 65 | 137 | 215 | 417 |
| Residential | 63 | 96.0 | 201 | 420 |
| Residential/ Mixed Use | 148 | 74.9 | 109 | 240 |
| Unknown | 74 | 80.0 | 158 | 293 |

## Table A-16: Total Dissolved Solids

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 542 | 49.0 | 77.6 | 138 |
| Commercial/ Mixed Use | 240 | 50.7 | 75.5 | 128 |
| Freeway | 114 | 47.7 | 89.0 | 177 |
| Freeway/ Mixed Use | 15 | 145 | 177 | 230 |
| Industrial | 574 | 53.0 | 83.5 | 143 |
| Industrial/ Mixed Use | 175 | 63.0 | 98.0 | 140 |
| Institutional | 24 | 48.0 | 61.0 | 100 |
| Open Space | 47 | 67.0 | 119 | 217 |
| Open Space/ Mixed Use | 144 | 76.0 | 109 | 147 |
| Residential | 262 | 64.5 | 103 | 164 |
| Residential/ Mixed Use | 518 | 53.8 | 80.0 | 126 |
| Unknown | 98 | 51.0 | 70.0 | 101 |

Bacteria and Protozoa

## Table A-17: Fecal Coliform (colonies/ 100 mL)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 279 | 900 | 3000 | 16000 |
| Commercial/ Industrial | 5 | 220 | 2400 | 3707 |
| Commercial/ Mixed Use | 105 | 1040 | 6000 | 23000 |
| Freeway | 67 | 705 | 2000 | 4945.16129 |
| Freeway/ Mixed Use | 13 | 400 | 730 | 4000 |
| Industrial | 371 | 410 | 2400 | 11450 |
| Industrial/ Mixed Use | 67 | 500 | 1733 | 15000 |
| Institutional | 3 | 2500 | 3400 | 3850 |
| Open Space | 29 | 1964 | 4600 | 22000 |
| Open Space/ Mixed Use | 83 | 640 | 3400 | 17000 |
| Residential | 202 | 800 | 2350 | 14917.7 |
| Residential/ Mixed Use | 363 | 2700 | 15000 | 57050.67 |
| Unknown | 41 | 950 | 3600 | 8000 |

## Table A-18: Fecal Streptococcus (colonies/ 100 mL)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 182 | 3,350 | 12,000 | 30,750 |
| Commercial/ Mixed Use | 96 | 3,075 | 11,400 | 28,250 |
| Freeway | 25 | 3,000 | 17,000 | 43,900 |
| Freeway/ Mixed Use | 15 | 3,925 | 19,000 | 26,500 |
| Industrial | 234 | 3,000 | 11,000 | 28,000 |
| Industrial/ Mixed Use | 44 | 7,525 | 15,000 | 28,500 |
| Institutional | 3 | 2,000 | 2,400 | 33,700 |
| Open Space | 20 | 6,675 | 24,900 | 58,750 |
| Open Space/ Mixed Use | 75 | 6,950 | 21,000 | 61,500 |
| Residential | 57 | 6,000 | 22,000 | 46,500 |
| Residential/ Mixed Use | 159 | 12,000 | 35,000 | 79,500 |
| Unknown | 9 | 9,900 | 30,500 | 40,000 |

## Table A-19: Total Coliform (colonies/ 100 mL)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 9 | 500 | 8,00 | 1,100 |
| Commercial/ Mixed Use | 1 | 9,000 | 9,000 | 9,000 |
| Freeway | 16 | 20,500 | 50,000 | 90,000 |
| Industrial | 25 | 8,000 | 30,000 | 80,000 |
| Industrial/ Mixed Use | 10 | 1,075 | 2,466 | 5,650 |
| Open Space | 1 | 62,000 | 62,000 | 62,000 |
| Residential | 14 | 5,250 | 6,275 | 19,500 |
| Residential/ Mixed Use | 22 | 2,250 | 5,667 | 11,000 |
| Unknown | 35 | 3,900 | 10,000 | 20,000 |

## Table A-20: Total *E. Coli* (colonies/ 100 mL)

| Land Use | Count of Data | 25th Percentile | Median | 75th Percentile |
|---|---|---|---|---|
| Commercial | 36 | 472 | 1,660 | 3,800 |
| Commercial/ Mixed Use | 9 | 130 | 1,200 | 2,100 |
| Freeway | 13 | 900 | 1,900 | 3,800 |
| Industrial | 19 | 67 | 310 | 3,950 |
| Industrial/ Mixed Use | 1 | 15 | 15 | 15 |
| Open Space | 5 | 780 | 1,100 | 1,100 |
| Residential | 34 | 162 | 809 | 6,225 |
| Residential/ Mixed Use | 16 | 355 | 1,155 | 7,375 |
| Unknown | 6 | 3,942 | 4,150 | 4,800 |

## APPENDIX B. SUMMARY OF DATA FROM THE INTERNATIONAL STORMWATER BEST MANAGEMENT PRACTICES (BMP) DATABASE

### B.1 International Stormwater BMP Database Drinking Water COCs Summary

The International Stormwater BMP Database was developed to provide a consistent and scientifically defensible set of data on BMP designs and related performance. The work is sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (USEPA). More information can be found at http://www.bmpdatabase.org/ or in the disc attached to this report.

The BMP database was sorted for drinking water COCs described in the report body. BMP influent and effluent values were obtained from the database and analyzed to determine the 25$^{th}$ percentile, median (along with the 95$^{th}$ confidence interval around the median), and 75$^{th}$ percentile. The tables below show these values as well as the number of studies and number of data points for each BMP type by constituent.

**Table B-1: Dissolved Organic Carbon Effluent Only**

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 38 | 5 | 8.7 | 8.8 | 12.0 | 14.5 | 18.8 |
| Biofilter | 174 | 17 | 8.3 | 11.0 | 12.0 | 14.5 | 20.0 |
| Manufactured Device | 151 | 14 | 9.7 | 19.0 | 23.4 | 25.5 | 29.4 |
| Media Filter | 114 | 11 | 3.3 | 5.3 | 8.1 | 10.5 | 14.0 |
| Retention Pond (Wet Pond) | 38 | 2 | 10.0 | 10.0 | 11.0 | 12.5 | 13.0 |

**Table B-2: Total Organic Carbon Effluent Only**

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 52 | 7 | 9.95 | 11.0 | 12.8 | 16.0 | 19.3 |
| Biofilter | 200 | 19 | 9.5 | 12.0 | 13.0 | 15.0 | 21.3 |
| Manufactured Device | 176 | 17 | 10.0 | 19.0 | 23.0 | 26.1 | 30.6 |
| Media Filter | 146 | 13 | 3.9 | 7.6 | 11.0 | 12.0 | 17.0 |
| Porous Pavement | 43 | 2 | 7.0 | 7.0 | 10.0 | 11.0 | 14.9 |
| Retention Pond (Wet Pond) | 172 | 11 | 8.3 | 10.0 | 10.8 | 11.0 | 13.1 |
| Wetland Basin | 68 | 2 | 15.2 | 16.0 | 16.1 | 16.3 | 17.6 |
| Wetland Channel | 17 | 2 | 9.0 | 8.0 | 12.0 | 14.6 | 21.3 |

**Table B-3: Nitrate Effluent Only**

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 11 | 1 | 0.22 | 0.17 | 0.34 | 0.48 | 0.48 |
| Detention Basin | 113 | 9 | 0.25 | 0.44 | 0.60 | 0.63 | 0.89 |
| Green Roof | 16 | 4 | 0.02 | 0.02 | 0.02 | 0.15 | 0.15 |
| Biofilter | 248 | 24 | 0.20 | 0.35 | 0.43 | 0.50 | 0.83 |
| Manufactured Device | 159 | 12 | 0.25 | 0.43 | 0.58 | 0.65 | 1.03 |
| Media Filter | 233 | 14 | 0.20 | 0.37 | 0.46 | 0.52 | 0.87 |
| Porous Pavement | 6 | 2 | 0.38 | 0.27 | 0.74 | 1.26 | 1.11 |
| Retention Pond (Wet Pond) | 185 | 11 | 0.10 | 0.20 | 0.28 | 0.33 | 0.55 |
| Wetland Basin | 24 | 4 | 0.03 | 0.03 | 0.05 | 0.10 | 0.10 |
| Wetland Channel | 104 | 7 | 0.04 | 0.08 | 0.10 | 0.15 | 0.31 |

**Table B-4: Nitrite Effluent Only**

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 11 | 1 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 |
| Detention Basin | 22 | 1 | 0.076 | 0.076 | 0.076 | 0.290 | 0.380 |
| Biofilter | 186 | 8 | 0.002 | 0.002 | 0.004 | 0.009 | 0.015 |
| Manufactured Device | 22 | 3 | 0.062 | 0.062 | 0.062 | 0.069 | 0.076 |
| Media Filter | 12 | 2 | 0.006 | 0.006 | 0.009 | 0.014 | 0.014 |
| Retention Pond (Wet Pond) | 106 | 10 | 0.010 | 0.018 | 0.021 | 0.034 | 0.070 |
| Wetland Basin | 29 | 3 | 0.005 | 0.007 | 0.008 | 0.100 | 0.100 |
| Wetland Channel | 18 | 1 | 0.062 | 0.060 | 0.100 | 0.1 | 0.125 |

**Table B-5: TKN Effluent Only**

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 107 | 8 | 0.50 | 0.84 | 1.01 | 1.30 | 3.25 |
| Detention Basin | 178 | 12 | 0.90 | 1.29 | 1.59 | 1.80 | 2.60 |
| Green Roof | 16 | 4 | 1.00 | 0.99 | 1.14 | 1.36 | 1.39 |
| Biofilter | 414 | 29 | 0.38 | 0.77 | 0.84 | 0.94 | 1.50 |
| Manufactured Device | 373 | 25 | 0.71 | 1.23 | 1.40 | 1.50 | 2.32 |
| Media Filter | 263 | 17 | 0.39 | 0.60 | 0.70 | 0.79 | 1.50 |
| Porous Pavement | 62 | 7 | 0.70 | 0.90 | 1.15 | 1.35 | 1.70 |
| Retention Pond (Wet Pond) | 390 | 31 | 0.79 | 1.00 | 1.10 | 1.12 | 1.60 |
| Wetland Basin | 213 | 8 | 0.75 | 0.94 | 1.00 | 1.10 | 1.33 |
| Wetland Channel | 81 | 5 | 0.80 | 1.10 | 1.29 | 1.45 | 1.60 |

## Table B-6: Dissolved Organic Nitrogen Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 57 | 2 | 0.53 | 0.59 | 0.71 | 0.89 | 1.06 |
| Biofilter | 6 | 1 | 0.32 | 0.31 | 0.50 | 0.77 | 0.75 |
| Manufactured Device | 69 | 4 | 0.94 | 1.21 | 1.38 | 1.52 | 1.92 |
| Retention Pond (Wet Pond) | 113 | 5 | 0.27 | 0.38 | 0.44 | 0.49 | 0.64 |
| Wetland Channel | 10 | 2 | 0.40 | 0.38 | 0.53 | 1.59 | 1.40 |

## Table B-7: Total Organic Nitrogen Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 56 | 2 | 0.67 | 1.28 | 2.03 | 2.41 | 3.05 |
| Biofilter | 159 | 4 | 0.15 | 0.25 | 0.30 | 0.35 | 0.48 |
| Manufactured Device | 136 | 6 | 0.32 | 0.45 | 0.56 | 0.62 | 1.13 |
| Media Filter | 51 | 2 | 0.36 | 0.42 | 0.46 | 0.55 | 0.64 |
| Retention Pond (Wet Pond) | 202 | 12 | 0.16 | 0.47 | 0.54 | 0.63 | 0.87 |
| Wetland Basin | 225 | 5 | 0.46 | 0.73 | 0.85 | 0.92 | 1.21 |
| Wetland Channel | 9 | 1 | 0.28 | 0.20 | 0.44 | 1.16 | 1.16 |

## Table B-8: Total Nitrogen Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 151 | 8 | 0.62 | 0.83 | 0.99 | 1.09 | 2.31 |
| Detention Basin | 65 | 3 | 1.19 | 1.75 | 2.48 | 2.74 | 3.42 |
| Biofilter | 208 | 8 | 0.39 | 0.56 | 0.63 | 0.71 | 1.29 |
| Manufactured Device | 149 | 8 | 1.21 | 1.51 | 1.84 | 2.15 | 2.89 |
| Media Filter | 97 | 4 | 0.36 | 0.47 | 0.67 | 0.71 | 1.02 |
| Porous Pavement | 6 | 2 | 1.89 | 1.48 | 2.16 | 2.30 | 2.28 |
| Retention Pond (Wet Pond) | 291 | 19 | 0.85 | 1.16 | 1.26 | 1.35 | 1.76 |
| Wetland Basin | 260 | 6 | 0.88 | 1.06 | 1.16 | 1.23 | 1.57 |
| Wetland Channel | 88 | 6 | 0.58 | 0.90 | 1.25 | 1.50 | 1.86 |

## Table B-9: Suspended Orthophosphate Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 57 | 2 | 0.082 | 0.096 | 0.163 | 0.189 | 0.254 |
| Biofilter | 6 | 1 | 0.018 | 0.007 | 0.042 | 0.080 | 0.071 |

## Table B-10: Total Orthophosphate Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 119 | 8 | 0.05 | 0.11 | 0.15 | 0.23 | 0.59 |
| Detention Basin | 25 | 2 | 0.25 | 0.25 | 0.57 | 1.14 | 1.25 |
| Green Roof | 16 | 4 | 0.25 | 0.25 | 0.37 | 0.52 | 0.60 |
| Biofilter | 339 | 17 | 0.06 | 0.10 | 0.11 | 0.12 | 0.19 |
| Manufactured Device | 185 | 14 | 0.02 | 0.06 | 0.10 | 0.17 | 0.41 |
| Media Filter | 141 | 7 | 0.01 | 0.02 | 0.02 | 0.03 | 0.05 |
| Porous Pavement | 43 | 2 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| Retention Pond (Wet Pond) | 346 | 27 | 0.02 | 0.03 | 0.04 | 0.05 | 0.09 |
| Wetland Basin | 181 | 8 | 0.01 | 0.01 | 0.02 | 0.03 | 0.07 |
| Wetland Channel | 43 | 4 | 0.03 | 0.04 | 0.06 | 0.08 | 0.12 |

## Table B-11: Dissolved Organic Phosphorus Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 17 | 2 | 0.024 | 0.012 | 0.077 | 0.120 | 0.140 |
| Biofilter | 6 | 1 | 0.023 | 0.019 | 0.043 | 0.134 | 0.116 |
| Manufactured Device | 69 | 4 | 0.045 | 0.052 | 0.071 | 0.086 | 0.157 |
| Retention Pond (Wet Pond) | 71 | 2 | 0.004 | 0.006 | 0.008 | 0.009 | 0.012 |
| Wetland Basin | 7 | 1 | 0.061 | 0.050 | 0.081 | 0.083 | 0.086 |

## Table B-12: Suspended Phosphorus Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Detention Basin | 8 | 1 | 0.102 | 0.08 | 0.125 | 0.21 | 0.205 |
| Retention Pond (Wet Pond) | 59 | 2 | 0.008 | 0.01 | 0.014 | 0.022 | 0.0425 |
| Wetland Basin | 66 | 2 | 0.0199 | 0.0257 | 0.0341 | 0.0393 | 0.0476 |
| Wetland Channel | 9 | 1 | 0.0408 | 0.0199 | 0.0797 | 0.198 | 0.198 |

## Table B-13: Total Phosphorus Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 234 | 13 | 0.095 | 0.180 | 0.207 | 0.270 | 0.759 |
| Detention Basin | 266 | 20 | 0.124 | 0.190 | 0.213 | 0.240 | 0.349 |
| Green Roof | 16 | 4 | 0.335 | 0.320 | 0.435 | 0.600 | 0.712 |
| Biofilter | 462 | 33 | 0.125 | 0.194 | 0.210 | 0.220 | 0.387 |
| Manufactured Device | 456 | 41 | 0.075 | 0.128 | 0.141 | 0.160 | 0.362 |
| Media Filter | 314 | 21 | 0.056 | 0.082 | 0.100 | 0.108 | 0.190 |
| Porous Pavement | 65 | 6 | 0.059 | 0.074 | 0.098 | 0.107 | 0.140 |
| Retention Pond (Wet Pond) | 577 | 40 | 0.056 | 0.090 | 0.110 | 0.120 | 0.217 |
| Wetland Basin | 279 | 13 | 0.040 | 0.065 | 0.077 | 0.087 | 0.142 |
| Wetland Channel | 117 | 8 | 0.100 | 0.130 | 0.146 | 0.153 | 0.242 |

## Table B-14: Dissolved Chloride Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Manufactured Device | 41 | 3 | 2.67 | 49.5 | 158 | 476 | 928 |

## Table B-15: Total Chloride Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 79 | 4 | 1.33 | 2.75 | 5.95 | 20.1 | 94.7 |
| Biofilter | 55 | 3 | 1.02 | 1.18 | 1.57 | 1.9 | 2.78 |
| Manufactured Device | 156 | 14 | 9.2 | 25.5 | 44.8 | 52.6 | 140 |
| Media Filter | 71 | 3 | 2.5 | 2.55 | 5.11 | 7.25 | 37.4 |
| Porous Pavement | 9 | 3 | 12.0 | 10.0 | 24.7 | 649 | 649 |
| Retention Pond (Wet Pond) | 281 | 13 | 5.9 | 11.0 | 15.0 | 17.0 | 97.1 |
| Wetland Basin | 27 | 2 | 2.52 | 2.5 | 3.0 | 34.4 | 88.9 |
| Wetland Channel | 53 | 2 | 2.4 | 2.44 | 3.06 | 4.38 | 8.1 |

## Table B-16: Total Dissolved Solids Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 72 | 2 | 36.4 | 52.1 | 61.4 | 70.6 | 109 |
| Detention Basin | 69 | 7 | 66.0 | 76.0 | 100 | 120 | 175 |
| Green Roof | 16 | 4 | 2.0 | 2.0 | 67.0 | 105 | 112 |
| Biofilter | 227 | 23 | 50.0 | 74.0 | 82.0 | 88.0 | 120 |
| Manufactured Device | 207 | 19 | 48.0 | 72.0 | 87.0 | 122 | 386 |
| Media Filter | 131 | 13 | 34.0 | 46.0 | 54.0 | 58.0 | 98.5 |
| Retention Pond (Wet Pond) | 107 | 9 | 14.0 | 79.8 | 136 | 170 | 344 |
| Wetland Basin | 10 | 2 | 80.0 | 20.0 | 82.0 | 92.0 | 92.0 |
| Wetland Channel | 9 | 1 | 98.8 | 97.7 | 145 | 512 | 512 |

## Table B-17: Specific Conductance Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 82 | 2 | 42.0 | 53.2 | 60.8 | 67.9 | 85.5 |
| Detention Basin | 147 | 10 | 80.5 | 104 | 117 | 140 | 174 |
| Green Roof | 16 | 4 | 59.3 | 57.5 | 79.3 | 101 | 104 |
| Biofilter | 241 | 24 | 69.0 | 91.0 | 103 | 110 | 169 |
| Manufactured Device | 117 | 12 | 36.0 | 52.0 | 61.0 | 73.0 | 151 |
| Media Filter | 227 | 13 | 60.0 | 80.0 | 95.0 | 109 | 129 |
| Retention Pond (Wet Pond) | 280 | 13 | 214 | 326 | 364 | 421 | 670 |
| Wetland Basin | 58 | 4 | 0.05 | 0.05 | 0.075 | 39.0 | 110 |
| Wetland Channel | 48 | 2 | 111 | 114 | 124 | 127 | 162 |

## Table B-18: *E. Coli* Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 14 | 1 | 5 | 3 | 19 | 30 | 30 |
| Detention Basin | 33 | 2 | 100 | 118 | 430 | 720 | 2,800 |
| Green Roof | 16 | 4 | 4 | 3 | 7 | 48 | 59 |
| Biofilter | 40 | 6 | 1,200 | 2,200 | 3,950 | 5,900 | 9,500 |
| Media Filter | 5 | 1 | 72 | 5 | 98 | 160 | 160 |
| Retention Pond (Wet Pond) | 32 | 2 | 20 | 50 | 170 | 690 | 895 |
| Wetland Basin | 12 | 3 | 22 | 7.5 | 281 | 1,110 | 1,480 |

### Table B-19: *Enterococcus* Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 10 | 1 | 1850 | 1700 | 14000 | 52000 | 74500 |
| Detention Basin | 13 | 1 | 1120 | 400 | 2420 | 3000 | 4200 |
| Manufactured Device | 69 | 8 | 1300 | 1700 | 5000 | 8000 | 24200 |
| Media Filter | 10 | 1 | 200 | 200 | 300 | 850 | 875 |

### Table B-20: Fecal Coliform Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Bioretention | 33 | 3 | 50 | 50 | 190 | 2,300 | 3,000 |
| Detention Basin | 174 | 14 | 72 | 465 | 700 | 1,560 | 5,390 |
| Green Roof | 14 | 4 | 3 | 2 | 7 | 38 | 60 |
| Biofilter | 88 | 18 | 758 | 2,300 | 4,200 | 4,900 | 16,300 |
| Manufactured Device | 105 | 10 | 300 | 800 | 2,300 | 2,600 | 11,000 |
| Media Filter | 106 | 14 | 25 | 150 | 200 | 210 | 650 |
| Retention Pond (Wet Pond) | 68 | 6 | 6 | 19 | 39 | 87 | 380 |
| Wetland Basin | 5 | 1 | 18 | 5 | 23 | 1,900 | 1,900 |

### Table B-21: Total Coliform Effluent Only

| BMP | Count | | 25th Percentile | Median | Median 95% confidence bounds | | 75th Percentile |
|---|---|---|---|---|---|---|---|
| | Results | Studies | | | | | |
| Media Filter | 19 | 2 | 260 | 220 | 540 | 900 | 1700 |
| Retention Pond (Wet Pond) | 35 | 3 | 192 | 238 | 860 | 1330 | 3400 |

## Calibration Targets for Characterization and Control of Urban Runoff in WARMF Model

| Scenario | Dry Weather Flows | Wet Weather Flows | |
|---|---|---|---|
| | ***Runoff and Water Quality*** | ***Runoff*** | ***Water Quality*** |
| **1) Existing Conditions** | (1) Assume dry weather flow rates during the dry season (April 1 to September 30), are in the range of 4E-4 cfs per acre. This assumption is based on the 2007 *Stormwater Quality Design Manual for the Sacramento and South Placer Regions*, Table DB-2. (See **Table 1** below for basis of dry weather flow values.)<br><br>(1) Assume dry weather flow rates during the wet season (October 1 to March 31), in between storm events, are in the range of 5E-4 cfs per acre.<br><br>(2) Assume dry weather water quality to be the average of the Strong Ranch Slough and Sump 104 dry weather median concentrations (See **Table 6**). | | (3) In order to address effects of controls since 1996, calibrate WARMF so effluent concentration is a weighted average based on percent development pre- and post-1996. This weighted average is based on an analysis of 1988-2008 Sacramento County Farmlands Mapping data for Sacramento County. These data indicate that 80% of current development is pre-1996 and 20% is post 1996.<br><br>(2) For wet weather water quality for the period pre-1996, use Sump 111 median concentrations for industrial land uses, and average of Strong Ranch Slough and Sump 104 median concentrations for residential and commercial land uses (See **Table 7** to **10** below).<br>(2) For period after 1996, use average of wet weather median effluent/outlet concentration data from Natomas and bioretention (or if data not available media filter) (See **Tables 3 & 12** ). |

| Scenario | Dry Weather Flows | Wet Weather Flows | |
|---|---|---|---|
| **2) Planned Changes** | ***Runoff Reduction*** | ***Runoff Reduction*** | ***Treatment*** |
| ***New Development and Redevelopment*** | (1) Assume 10% reduction in dry weather flows<br>(i.e. controlled dry weather flow = 0.9 * Natomas dry weather of 4E-4 cfs/acre). | (4) Assume a median runoff reduction of 5% (Sac) and 10% (SJV) based on assumed implementation of a mix of LID type BMPs and extent of A&B soils in each valley<br>(See **Table 11** below for measured volume reductions achieved in each BMP type). | **Organic Carbon** **(5)** – Median effluent quality equals average of median effluent concentration for Natomas and media filter<br>(See **Tables 3 & 12**).<br><br>**Nutrient** – Median effluent quality equals average of median effluent concentration for Natomas and bioretention<br>(See **Tables 3** & **12**).<br><br>**Salts** – Assume no change from implementation of BMPs. |
| ***Existing Development*** | (1) Assume 10% reduction in dry weather flows<br>(i.e. controlled flow = 0.9 * Natomas dry weather of 4E-4 flow). | | |

| Scenario | Dry Weather Flows | Wet Weather Flows | |
|---|---|---|---|
| **3) Probable Future** | ***Runoff Reduction*** | ***Runoff Reduction*** | ***Treatment*** |
| ***New Development and Redevelopment*** | (1) Assume 20% reduction in dry weather flows<br>(i.e. controlled flows = 0.80 * Natomas of 4E-4 flow). | (4)Assume a median runoff reduction of 10% (SAC) and 25% (SJV), using bioretention BMPs as the representative BMP and considering soil infiltrative conditions in each valley. (See **Table 11**) | **Organic Carbon** **(5)** – Median effluent quality equals average of median effluent concentration for Natomas and media filters<br>(See **Tables 3** & **12**).<br><br>**Nutrient NELs** **(7)** – For San Joaquin Valley only, assume treated discharge for TN = 2 mg/L and TP = 0.2 mg/L. This is based on an analysis of the 2006 Final Report, *Conceptual Model for nutrients in the Central valley and Sacramento – San Joaquin Delta*. (See **Table 13** for measured data). For Sacramento Valley, same as Planned Changes Scenario.<br><br>**Salts** - Assume no change from implementation of BMPs. |
| ***Existing Development*** | (1) Assume 20% reduction in dry weather flows<br>(i.e. 0.8 * Natomas of 4E-4 flow) | | |

| Scenario | Dry Weather Flows | Wet Weather Flows | |
|---|---|---|---|
| **4) Outer Boundary Future** | ***Runoff Reduction*** | ***Runoff Reduction*** | ***Treatment*** |
| ***New Development and Redevelopment*** | [(1)] Assume 60% reduction in dry weather flows. | Assume a median runoff reduction of 20% (SAC) and 50% (SJV), using bioretention BMPs as the representative BMP And extent of A&B soils in each valley (See **Table 11**). | **<u>Organic Carbon</u>** **[(5)]** – Assume median effluent quality equals average of median effluent concentration for Natomas and media filters (See **Tables 3** & **12**).<br><br>**<u>Nutrients</u>** **[(7)]** – For SJV, assume treated discharge equals TN = 1 mg/L and TP = 0.1 mg/L<br>(See **Table 13** below for sampled nutrient concentrations).<br>For Sacramento Valley, same as for Probable Future Scenario.<br><br>**<u>Salts</u>** - Assume no change in dissolved solids. |
| ***Existing Development*** | [(1)] Assume 60% reduction in dry weather flows. | | **<u>Organic Carbon</u>** **[(5)]** – Assume industrial land use subject to retrofitting with effluent concentrations from media filters (**Table 12**)<br><br>**<u>Nutrients</u>** **[(7)]** – In SJV assume treated discharge for TN = 1 mg/L and TP = 0.1 mg/L<br>(**Table 13**) In Sacramento Valley no change from baseline.<br><br>**<u>Salts</u>** - Assume no change in dissolved solids. |

**References:**


(1) County of Sacramento, 2007. Stormwater Quality Design Manual for the Sacramento and South Placer Regions, Final Report, May 2007. See Table DB-2. Dry Weather Design Flows.
(2) Sacramento Stormwater Quality Partnership Discharge Characterization Study.
(3) Sacramento Country. 2010. Farmland Mapping and monitoring program, California Department of Conservation, 1988-2008 Land Use Summary.
(4) Wright Water Engineers, Inc. and Geosyntec Consultants, 2010. International Stormwater Best Management Practices (BMP) Database, Pollutant Category Summary: Nutrients. October 2010.
(5) 2010. International Stormwater Best Management Practices (BMP) Database. 2010.
(6) NewFields. 2010. Data Analysis.
(7) Tetra Tech, 2006. Conceptual Model for Nutrients in the Central Valley and Sacramento – San Joaquin Delta, Final Report, September 20, 2006.

## Table 1. Dry Weather Design Flows

| Basin | Area (Acres) | Dry Weather Flow (MGal/Week) | Land Use | MGal/Week (Per Acre Shed) | CFS (Per Acre Shed) | Ac-Ft/Day (Per Acre Shed) |
|---|---|---|---|---|---|---|
| **Summary of City of Sacramento Drainage Sump Stations Used** | | | | | | |
| **Residential and Residential/Other** | | | | | | |
| 33 | 684 | 1.07 | Residential/Commercial | 0.0016 | 0.000354 | 0.0007 |
| 34 | 687 | 1.25 | Residential | 0.0018 | 0.000398 | 0.0008 |
| 63 | 481 | 1.71 | Residential | 0.0036 | 0.000796 | 0.0016 |
| 67 | 896 | 3.10 | Residential/Commercial | 0.0035 | 0.000774 | 0.0015 |
| 69 | 1115 | 4.5 | Residential | 0.0040 | 0.000884 | 0.0018 |
| 129 | 1356 | 3.53 | Mix (Mostly Residential) | 0.0026 | 0.000575 | 0.0011 |
| 132 | 2044 | 8.83 | Residential | 0.0043 | 0.000950 | 0.0019 |
| 159 | 573 | 1.48 | Residential/Commercial | 0.0026 | 0.000575 | 0.0011 |
| | | | ***Average*** | ***0.00300*** | ***0.000663*** | ***0.001313*** |
| | | | ***Median*** | ***0.00305*** | ***0.000674*** | ***0.001300*** |
| | | | | | | |
| **Just Residential** | | | | | | |
| 34 | 687 | 1.25 | Residential | 0.0018 | 0.000398 | 0.0008 |
| 63 | 481 | 1.71 | Residential | 0.0036 | 0.000796 | 0.0016 |
| 69 | 1115 | 4.5 | Residential | 0.0040 | 0.000884 | 0.0018 |
| 132 | 2044 | 8.83 | Residential | 0.0043 | 0.000950 | 0.0019 |
| | | | ***Average*** | ***0.00335*** | ***0.000740*** | ***0.001313*** |
| | | | ***Median*** | ***00.0023*** | ***0.000508*** | ***0.001300*** |
| | | | | | | |
| **Commercial/Industrial/Mix** | | | | | | |
| 66 | 443 | 1.72 | Industrial | 0.0039 | 0.000862 | 0.0017 |
| 96 | 1308 | 1.33 | Mix | 0.0010 | 0.000221 | 0.0004 |
| 116 | 197 | 0.30 | Industrial | 0.0015 | 0.000332 | 0.0007 |
| 151 | 1058 | 3.24 | Mix | 0.0031 | 0.000685 | 0.0013 |
| 152 | 1479 | 13.6 | Mix | 0.0092 | 0.002034 | 0.0040 |
| 154 | 662 | 0.92 | Commercial/Industrial | 0.0014 | 0.000309 | 0.0006 |
| | | | ***Average*** | ***0.00345*** | ***0.0007570*** | ***0.001525*** |
| | | | ***Median*** | ***0.00380*** | ***0.0008399*** | ***0.001700*** |

## Reference:

County of Sacramento, 2007. Stormwater Quality Design Manual for the Sacramento and South Placer Regions, Final Report, May 2007. See Table DB-2. Dry Weather Design Flows.

## Table 2: Natomas Basin 4 - Dry Weather Drinking Water COC Monitoring Data

| Monitoring Location | Constituent Class | Constituent | Dry Weather Samples | Percent Detected | Median | Mean | Units |
|---|---|---|---|---|---|---|---|
| Influent | Organics | Dissolved Organic Carbon | 2 | 100% | 5.40 | 5.40 | mg/L |
| | | Total Organic Carbon | 4 | 100% | 6.20 | 6.35 | mg/L |
| | Nutrients | Ammonia (as N) | 4 | 100% | 0.280 | 0.270 | mg/L |
| | | Nitrate (as N) | 2 | 100% | 0.450 | 0.450 | mg/L |
| | | Nitrite (as N) | 2 | 100% | 0.020 | 0.020 | mg/L |
| | | Nitrogen, Nitrate-Nitrite | 2 | 100% | 0.510 | 0.510 | mg/L |
| | | Total Dissolved Phosphorus | 3 | 100% | 0.250 | 0.267 | mg/L |
| | | Total Kjeldahl Nitrogen | 4 | 100% | 1.17 | 1.23 | mg/L |
| | | Total Orthophosphate as P | 3 | 100% | 0.290 | 0.290 | mg/L |
| | | Total Phosphorus as P | 4 | 100% | 0.300 | 0.298 | mg/L |
| | Dissolved Solids | Conductivity | 2 | 100% | 240 | 240 | umhos/cm |
| | | Total Dissolved Solids | 4 | 100% | 178 | 170 | mg/L |
| | | Turbidity | 2 | 100% | 2.10 | 2.10 | NTU |
| | Bacteria | E. coli | 4 | 100% | 1200 | 1410 | MPN/100mL |
| | | Fecal Coliform | 2 | 100% | 4,000 | 3,870 | MPN/100mL |
| | | Total Coliform | 2 | 100% | 100,500 | 92,400 | MPN/100mL |
| Effluent | Organics | Dissolved Organic Carbon | 2 | 100% | 8.65 | 8.65 | mg/L |
| | | Total Organic Carbon | 4 | 100% | 7.85 | 8.40 | mg/L |
| | Nutrients | Ammonia (as N) | 4 | 100% | 0.130 | 0.130 | mg/L |
| | | Nitrate (as N) | 2 | 100% | 0.050 | 0.050 | mg/L |
| | | Nitrite (as N) | 2 | 0% | ND | ND | mg/L |
| | | Nitrogen, Nitrate-Nitrite | 2 | 100% | 0.110 | 0.110 | mg/L |
| | | Total Dissolved Phosphorus | 3 | 100% | 0.210 | 0.210 | mg/L |
| | | Total Kjeldahl Nitrogen | 4 | 100% | 1.4 | 1.50 | mg/L |
| | | Total Orthophosphate as P | 3 | 100% | 0.210 | 0.180 | mg/L |
| | | Total Phosphorus as P | 4 | 100% | 0.230 | 0.230 | mg/L |
| | Dissolved Solids | Conductivity | 2 | 100% | 250 | 250 | umhos/cm |
| | | Total Dissolved Solids | 4 | 100% | 166 | 161 | mg/L |
| | | Turbidity | 2 | 100% | 4.35 | 4.35 | NTU |
| | Bacteria | E. coli | 4 | 100% | 296 | 180 | MPN/100mL |
| | | Fecal Coliform | 2 | 100% | 270 | 140 | MPN/100mL |
| | | Total Coliform | 2 | 100% | 4,550 | 4,400 | MPN/100mL |

**Reference:**
Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 3: Natomas Basin 4 – Wet Weather Drinking Water COC Monitoring Data

| Monitoring Location | Constituent Class | Constituent | Wet Weather Samples | Percent Detected | Median | Mean | Units |
|---|---|---|---|---|---|---|---|
| **Inlet** | **Organics** | Dissolved Organic Carbon | 6 | 100% | 6.1 | 5.8 | mg/L |
| | | Total Organic Carbon | 8 | 100% | 6.8 | 7.0 | mg/L |
| | **Nutrients** | Ammonia (as N) | 9 | 100% | 0.42 | 0.40 | mg/L |
| | | Dissolved Orthophosphate as P | 2 | 100% | 0.22 | 0.22 | mg/L |
| | | Nitrate (as N) | 2 | 100% | 0.45 | 0.45 | mg/L |
| | | Nitrite (as N) | 2 | 100% | 0.07 | 0.07 | mg/L |
| | | Nitrogen, Nitrate-Nitrite | 6 | 100% | 0.78 | 0.77 | mg/L |
| | | Total Dissolved Phosphorus | 5 | 100% | 0.24 | 0.28 | mg/L |
| | | Total Kjeldahl Nitrogen | 8 | 100% | 1.4 | 1.6 | mg/L |
| | | Total Orthophosphate as P | 5 | 100% | 0.19 | 0.22 | mg/L |
| | | Total Phosphorus as P | 8 | 100% | 0.35 | 0.34 | umhos/cm |
| | **Dissolved Solids** | Conductivity | 6 | 100% | 120 | 119 | mg/L |
| | | Total Dissolved Solids | 9 | 100% | 83 | 97 | NTU |
| | **Bacteria** | E. coli | 9 | 100% | 23,000 | 22,400 | MPN/100mL |
| | | Fecal Coliform | 5 | 100% | 23,000 | 29,900 | MPN/100mL |
| | | Total Coliform | 4 | 100% | 146,000 | 108,400 | MPN/100mL |
| **Outlet** | **Organics** | Dissolved Organic Carbon | 6 | 100% | 6.5 | 6.5 | mg/L |
| | | Total Organic Carbon | 8 | 100% | 5.8 | 6.8 | mg/L |
| | **Nutrients** | Ammonia (as N) | 9 | 100% | 0.29 | 0.34 | mg/L |
| | | Dissolved Orthophosphate as P | 2 | 100% | 0.22 | 0.22 | mg/L |
| | | Nitrate (as N) | 2 | 100% | 0.62 | 0.62 | mg/L |
| | | Nitrite (as N) | 2 | 100% | 0.07 | 0.07 | mg/L |
| | | Nitrogen, Nitrate-Nitrite | 6 | 100% | 0.59 | 0.52 | mg/L |
| | | Total Dissolved Phosphorus | 4 | 100% | 0.26 | 0.25 | mg/L |
| | | | | | | | |
| | | Total Kjeldahl Nitrogen | 8 | 100% | 1.3 | 1.2 | mg/L |
| | | Total Orthophosphate as P | 5 | 100% | 0.22 | 0.22 | mg/L |
| | | Total Phosphorus as P | 8 | 100% | 0.35 | 0.35 | umhos/cm |
| | **Dissolved Solids** | Conductivity | 6 | 100% | 130 | 150 | mg/L |
| | | Total Dissolved Solids | 9 | 100% | 87 | 127 | NTU |
| | **Bacteria** | E. coli | 8 | 100% | 3,000 | 3,800 | MPN/100mL |
| | | Fecal Coliform | 4 | 100% | 4,000 | 4,300 | MPN/100mL |
| | | Total Coliform | 4 | 100% | 152,000 | 86,700 | MPN/100mL |

## Table 4: Strong Ranch Slough - Dry Weather Drinking Water COC Monitoring Data

| Constituent Class | Constituent | Number of Dry Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 18 | 10.4 | 12.2 | mg/l |
| | Total Organic Carbon | 18 | 9.5 | 13.0 | mg/l |
| Nutrients | Ammonia as N | 6 | 0.20 | 0.20 | mg/L |
| | Nitrate as N | 6 | 0.10 | 0.28 | mg/L |
| | Nitrate as NO3 | 2 | 0.67 | 0.67 | mg/L |
| | Nitrite as N | 8 | 0.10 | 0.12 | mg/L |
| | Nitrate plus Nitrite as N | 10 | 0.10 | 0.12 | mg/L |
| | Total Kjeldahl Nitrogen | 14 | 1.05 | 1.09 | mg/L |
| | Phosphorus | 17 | 0.20 | 0.26 | mg/L |
| Dissolved Solids | Specific Conductance | 6 | 310 | 292 | µmhos/cm |
| | Specific Conductance (field) | 5 | 296 | 311 | µmhos/cm |
| | Solids Total Dissolved | 17 | 250 | 295 | mg/l |
| Bacteria | Escherichia Coli | 12 | 1,550 | 78,700 | MPN/100 mL |
| | Fecal Coliform | 15 | 3,000 | 65,300 | MPN/100 mL |
| | Total Coliform | 13 | 30,000 | 151,400 | MPN/100 mL |

**Reference:**

Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 5: Sump 104 - Dry Weather Drinking Water COC Monitoring Data

| Constituent Class | Constituent | Number of Dry Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 13 | 6.0 | 8.8 | mg/L |
| | Total Organic Carbon | 13 | 9.0 | 8.9 | mg/L |
| Nutrients | Ammonia as N | 9 | 0.40 | 0.60 | mg/L |
| | Nitrate as N | 8 | 2.25 | 2.41 | mg/L |
| | Nitrate as NO3 | 2 | 3.50 | 3.50 | mg/L |
| | Nitrite as N | 9 | 0.15 | 0.27 | mg/L |
| | Nitrate plus Nitrite as N | 8 | 1.80 | 2.00 | mg/L |
| | Total Kjeldahl Nitrogen | 13 | 1.00 | 1.17 | mg/L |
| | Dissolved Phosphorus | 1 | 0.50 | 0.50 | mg/L |
| | Total Phosphorus | 17 | 0.40 | 0.40 | mg/L |
| Dissolved Solids | Specific Conductance | 4 | 450 | 450 | µmhos/cm |
| | Specific Conductance (field) | 3 | 416 | 431 | µmhos/cm |
| | Solids Total Dissolved | 17 | 310 | 316 | mg/l |
| Bacteria | Escherichia Coli | 10 | 3,000 | 8,200 | MPN/100 mL |
| | Fecal Coliform | 14 | 6,000 | 23,000 | MPN/100 mL |
| | Fecal Streptococcus | 2 | 67 | 67 | MPN/100 mL |
| | Total Coliform | 14 | 65,000 | 167,200 | MPN/100 mL |

**Reference:**

Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 6: Strong Ranch Slough and Sump 104 - Dry Weather Median Data Summary

| Constituent Class | Constituent | Strong Ranch Slough Median | Sump 104 Median | Average of Medians | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 10.4 | 6.0 | 8.20 | mg/L |
| | Total Organic Carbon | 9.5 | 9.0 | 9.25 | mg/L |
| Nutrients | Ammonia as N | 0.20 | 0.40 | 0.30 | mg/L |
| | Nitrate as N | 0.10 | 2.25 | 1.18 | mg/L |
| | Nitrate as NO3 | 0.67 | 3.50 | 2.09 | mg/L |
| | Nitrite as N | 0.10 | 0.15 | 0.13 | mg/L |
| | Nitrate plus Nitrite as N | 0.10 | 1.80 | 0.95 | mg/L |
| | Total Kjeldahl Nitrogen | 1.05 | 1.00 | 1.03 | mg/L |
| | Dissolved Phosphorus | --- | 0.50 | 0.5 | mg/L |
| | Total Phosphorus | 0.20 | 0.40 | 0.3 | mg/L |
| Dissolved Solids | Specific Conductance | 310 | 450 | 380 | µmhos/cm |
| | Specific Conductance (field) | 296 | 416 | 356 | µmhos/cm |
| | Solids Total Dissolved | 250 | 310 | 280 | mg/l |
| Bacteria | Escherichia Coli | 1,550 | 3,000 | 2275 | MPN/100 mL |
| | Fecal Coliform | 3,000 | 6,000 | 4,500 | MPN/100 mL |
| | Fecal Streptococcus | --- | 67 | 67 | MPN/100 mL |
| | Total Coliform | 30,000 | 65,000 | 47,5000 | MPN/100 mL |

**Reference:**
Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 7: Sump 111- Wet Weather Drinking Water COC Monitoring Data

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| **Organics** | Dissolved Organic Carbon | 31 | 7.9 | 10.9 | mg/l |
| | Total Organic Carbon | 33 | 9.5 | 13.3 | mg/l |
| **Nutrients** | Ammonia as N | 24 | 0.51 | 0.50 | mg/l |
| | Nitrate as N | 17 | 0.56 | 0.75 | mg/l |
| | Nitrate as NO3 | 11 | 2.7 | 2.7 | mg/l |
| | Nitrite as N | 28 | 0.1 | 0.10 | mg/l |
| | Nitrate plus Nitrite as N | 23 | 0.65 | 0.72 | mg/l |
| | Total Kjeldahl Nitrogen | 33 | 1.6 | 2.1 | mg/l |
| | Orthophosphate as P | 2 | 0.16 | 0.16 | mg/l |
| | Dissolved Phosphorus | 10 | 0.11 | 0.13 | mg/l |
| | Phosphorus Total | 49 | 0.25 | 0.34 | mg/l |
| **Dissolved Solids** | Specific Conductance | 11 | 49 | 57.2 | µmhos/cm |
| | Specific Conductance (field) | 9 | 67.5 | 84.5 | µmhos/cm |
| | Solids Total Dissolved | 50 | 43.5 | 56.2 | mg/l |
| **Bacteria** | Escherichia Coli | 21 | 3,000 | 5,180 | MPN/100 mL |
| | Fecal Coliform | 46 | 13,000 | 110,600 | MPN/100 mL |
| | Fecal Streptococcus | 21 | 30,000 | 147,800 | MPN/100 mL |
| | Total Coliform | 40 | 160,000 | 421,100 | MPN/100 mL |

**Reference:**

Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 8: Strong Ranch Slough – Wet Weather Drinking Water COC Monitoring Data

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| **Organics** | Dissolved Organic Carbon | 33 | 8.9 | 13.1 | mg/l |
| | Total Organic Carbon | 35 | 11 | 16.7 | mg/l |
| **Nutrients** | Ammonia as N | 13 | 0.4 | 0.52 | mg/l |
| | Nitrate as N | 6 | 0.59 | 0.53 | mg/l |
| | Nitrate as NO3 | 12 | 2.1 | 2.2 | mg/l |
| | Nitrite as N | 18 | 0.15 | 0.13 | mg/l |
| | Nitrate plus Nitrite as N | 19 | 0.54 | 0.61 | mg/l |
| | Total Kjeldahl Nitrogen | 23 | 1.8 | 2.8 | mg/l |
| | Orthophosphate as P | 2 | 0.26 | 0.26 | mg/l |
| | Phosphorus Total | 35 | 0.5 | 0.72 | mg/l |
| **Dissolved Solids** | Specific Conductance | 11 | 69 | 86.9 | mg/l |
| | Specific Conductance (field) | 9 | 62.7 | 84.6 | µmhos/cm |
| | Solids Total Dissolved | 34 | 56.5 | 66.1 | µmhos/cm |
| **Bacteria** | Escherichia Coli | 22 | 13,000 | 24,900 | mg/l |
| | Fecal Coliform | 32 | 22,000 | 47,900 | MPN/100 mL |
| | Fecal Streptococcus | 7 | 230,000 | 489,100 | MPN/100 mL |
| | Total Coliform | 26 | 170,000 | 658,100 | MPN/100 mL |

### Reference:
Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 9: Sump 104 – Wet Weather Drinking Water COC Monitoring Data

| Constituent Class | Constituent | Number of Wet Weather Samples | Median | Mean | Units |
|---|---|---|---|---|---|
| Organics | Dissolved Organic Carbon | 26 | 9.4 | 14.2 | mg/L |
| | Total Organic Carbon | 29 | 11.0 | 18.5 | mg/L |
| Nutrients | Ammonia as N | 22 | 0.53 | 0.60 | mg/L |
| | Nitrate as N | 16 | 0.80 | 1.1 | mg/L |
| | Nitrate as NO3 | 11 | 3.2 | 3.0 | mg/L |
| | Nitrite as N | 28 | 0.11 | 0.12 | mg/L |
| | Nitrate plus Nitrite as N | 17 | 0.72 | 0.98 | mg/L |
| | Total Kjeldahl Nitrogen | 28 | 1.7 | 2.8 | mg/L |
| | Orthophosphate as P | 2 | 0.37 | 0.37 | mg/L |
| | Dissolved Phosphorus | 10 | 0.14 | 0.17 | mg/L |
| | Phosphorus Total | 41 | 0.40 | 0.54 | mg/L |
| Dissolved Solids | Specific Conductance | 5 | 92 | 408 | µmhos/cm |
| | Specific Conductance (field) | 4 | 58.1 | 105 | µmhos/cm |
| | Solids Total Dissolved | 46 | 71.5 | 90.8 | mg/l |
| Bacteria | Escherichia Coli | 15 | 22,000 | 103,133 | MPN/100 mL |
| | Fecal Coliform | 41 | 70,000 | 476,073 | MPN/100 mL |
| | Fecal Streptococcus | 20 | 225,000 | 709,165 | MPN/100 mL |
| | Total Coliform | 40 | 280,000 | 1,772,175 | MPN/100 mL |

**Reference:**

Sacramento Stormwater Quality Partnership Discharge Characterization Study

## Table 10: Strong Ranch Slough and Sump 104 - Wet Weather Median Data Summary

| Constituent Class | Constituent | Strong Ranch Slough Median | Sump 104 Median | Average of Medians | Units |
|---|---|---|---|---|---|
| **Organics** | Dissolved Organic Carbon | 8.9 | 9.4 | 9.2 | mg/l |
| | Total Organic Carbon | 11.0 | 11.0 | 11.0 | mg/l |
| **Nutrients** | Ammonia as N | 0.4 | 0.53 | 0.47 | mg/l |
| | Nitrate as N | 0.59 | 0.80 | 0.70 | mg/l |
| | Nitrate as NO3 | 2.1 | 3.2 | 2.65 | mg/l |
| | Nitrite as N | 0.15 | 0.11 | 0.13 | mg/l |
| | Nitrate plus Nitrite as N | 0.54 | 0.72 | 0.63 | mg/l |
| | Total Kjeldahl Nitrogen | 1.8 | 1.7 | 1.75 | mg/l |
| | Orthophosphate as P | 0.26 | 0.37 | 0.32 | mg/l |
| | Dissolved Phosphorus | --- | 0.14 | 0.14 | mg/l |
| | Phosphorus Total | 0.5 | 0.40 | 0.45 | mg/l |
| **Dissolved Solids** | Specific Conductance | 69 | 92 | 80.5 | µmhos/cm |
| | Specific Conductance (field) | 62.7 | 58.1 | 60.4 | µmhos/cm |
| | Solids Total Dissolved | 56.5 | 71.5 | 64.0 | mg/l |
| **Bacteria** | Escherichia Coli | 13,000 | 22,000 | 17,500 | MPN/100 mL |
| | Fecal Coliform | 22,000 | 70,000 | 46,000 | MPN/100 mL |
| | Fecal Streptococcus | 230,000 | 225,000 | 227,500 | MPN/100 mL |
| | Total Coliform | 170,000 | 280,000 | 225,000 | MPN/100 mL |

**Reference:**

Sacramento Stormwater Quality Partnership Discharge Characterization Study

**Table 11: BMP Percent Volume Reductions**

| BMP Category | No. of Monitoring Studies | 25th Percentile (%) | Median (%) | 75th Percentile (%) | Average (%) |
|---|---|---|---|---|---|
| **Biofilter – Grass Strips** | 16 | 18 | 34 | 54 | 38 |
| **Biofilter – Grass Swales** | 13 | 35 | 42 | 65 | 48 |
| **Bioretention with Underdrains** | 7 | 45 | 57 | 74 | 61 |
| **Detention Basin – Surface, Grass Lined** | 11 | 26 | 33 | 43 | 33 |
| **Wet Retention Ponds – Surface** | 20 | 2 | 11 | 18 | 13 |
| **Wetland Basins/Channels** | 11 | 3 | 4 | 5 | 9 |

## Reference:

Wright Water Engineers, Inc. and Geosyntec Consultants, 2010. International Stormwater Best Management Practices (BMP) Database, Pollutant Category Summary: Nutrients. October 2010.

## Table 12: Nutrients and Organic Carbon Median Effluent Concentrations from BMPs

| BMP | Nitrate (NO3-N) | Nitrite (NO2-N) | Total Kjehdahl Nitrogen (TKN) | Dissolved Organic Nitrogen | Total Organic Nitrogen | Total Nitrogen (TN) | Suspended Ortho-phosphate | Dissolved Ortho-phosphate | Ortho-phosphate | Dissolved Organic Phos-phorus | Suspended Phos-phorus | Total Phos-phorus (TP) | Dissolved Organic Carbon | Total Organic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| Bioretention | 0.170 | 0.012 | 0.84 | --- | --- | 0.83 | --- | --- | 0.111 | --- | --- | 0.180 | --- | --- |
| Detention Basin | 0.440 | 0.076 | 1.29 | 0.59 | 1.28 | 1.75 | 0.096 | 0.004 | 0.250 | 0.012 | 0.080 | 0.190 | 8.8 | 11.0 |
| Green Roof | 0.025 | | 0.99 | --- | --- | --- | --- | --- | 0.250 | --- | --- | 0.320 | --- | --- |
| Biofilter | 0.355 | 0.002 | 0.77 | 0.31 | 0.25 | 0.56 | 0.007 | 0.021 | 0.097 | 0.019 | --- | 0.194 | 11.0 | 12.0 |
| Manufactured Device | 0.430 | 0.062 | 1.23 | 1.21 | 0.45 | 1.51 | --- | --- | 0.062 | 0.052 | --- | 0.128 | 19.0 | 19.0 |
| Media Filter | 0.370 | 0.006 | 0.60 | --- | 0.42 | 0.47 | --- | --- | 0.017 | --- | --- | 0.082 | 5.35 | 7.65 |
| Porous Pavement | 0.269 | --- | 0.90 | --- | --- | 1.48 | --- | --- | 0.059 | --- | --- | 0.074 | --- | 7.0 |
| Retention Pond (Wet Pond) | 0.200 | 0.018 | 1.00 | 0.38 | 0.47 | 1.16 | --- | --- | 0.034 | 0.006 | 0.010 | 0.090 | 10.0 | 10.0 |
| Wetland Basin | 0.035 | 0.007 | 0.94 | | 0.73 | 1.06 | --- | --- | 0.015 | 0.050 | 0.026 | 0.065 | --- | 16.0 |
| Wetland Channel | 0.081 | 0.060 | 1.10 | 0.38 | 0.20 | 0.90 | --- | --- | 0.042 | --- | 0.020 | 0.130 | --- | 8.0 |

## Reference:

International Stormwater Best Management Practices (BMP) Database. 2010.

**Table 13: Average Nutrient Concentrations at Key Delta Locations**

| Constituent (mg/L) | Sacramento at Hood/Greene's Landing | San Joaquin at Vernalis | Banks Pumping Plant |
|---|---|---|---|
| **Total Nitrogen** | 0.64 | 2.5 | 1.1 |
| **NO3+NO2-N** | 0.14 | 1.5 | 0.61 |
| **Ammonia-N** | 0.23 | 0.1 | 0.064 |
| **TKN** | 0.50 | 0.85 | 0.44 |
| **Total Phosphorus** | 0.12 | 0.25 | 0.12 |
| **Orthophosphate** | 0.07 | 0.12 | 0.071 |

**Reference:**

Tetra Tech, 2006. Conceptual Model for Nutrients in the Central Valley and Sacramento – San Joaquin Delta, Final Report, September 20, 2006.