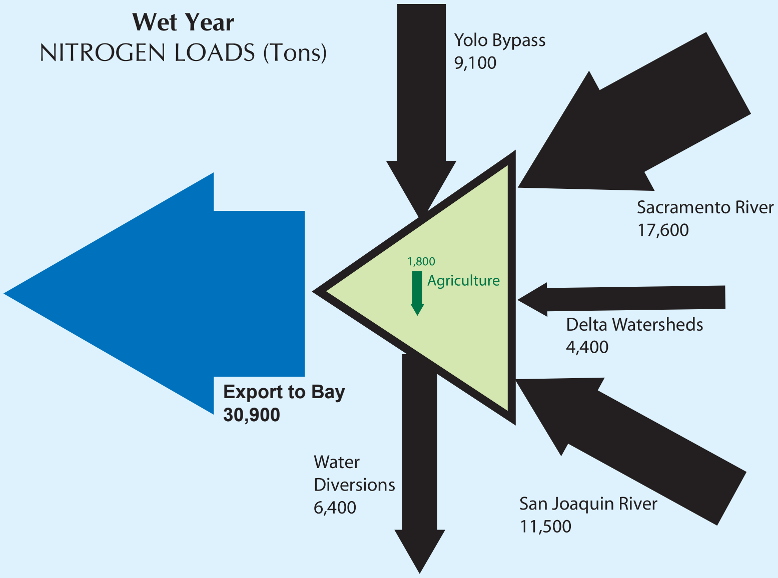
CONCEPTUAL MODEL FOR

NUTRIENTS IN THE CENTRAL VALLEY AND SACRAMENTO – SAN JOAQUIN DELTA

FINAL REPORT

SEPTEMBER 20, 2006



Prepared for:

US Environmental Protection Agency, Region IX

Central Valley Drinking Water Policy Workgroup

Prepared by:

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Prepared by

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September, 2006

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LIST OF ACRONYMS & ABBREVIATIONS

CDF FRAP	California Department of Forestry and Fire Protection Fire and Resource Assessment Program
CVDWPWG	Central Valley Drinking Water Policy Workgroup
cfs	Cubic feet per second
DFG	Department of Fish and Game
DICU	Delta Island Consumptive Use
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DON	Dissolved organic nitrogen
DOP	Dissolved organic phosphorus
DSM	Delta Simulation Model
DWR	Department of Water Resources
gal/year	Gallons per year
GIS	Geographical Information Systems
kg/person/yr	Kilograms per person per year
µg/l	Micrograms per liter
mg/l	Milligrams per liter
MGD	Million gallons per day
MIB	2-Methylisoborneol
MWQI	Municipal Water Quality Investigations
NEMDC	Natomas East Main Drainage Canal
NO3+NO2-N	Nitrate plus nitrite expressed as nitrogen
NO3-N	Nitrate expressed as nitrogen
NWIS	National Water Information System
PN	Particulate nitrogen
PON	Particulate organic nitrogen
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
USGS	United States Geological Survey
WY	Water year

EXECUTIVE SUMMARY

This report presents a conceptual model of nutrients for the Central Valley and the Sacramento-San Joaquin Delta. The conceptual model was based on previously collected data from a variety of sources and can be used to direct future investigations to improve understanding of nutrients sources, transport, and impacts.

Although nutrients are not directly toxic (with the exception of nitrate and nitrite), nutrient levels in water bodies are important for drinking water supply for several reasons. The presence of nutrients in aquatic systems promotes primary productivity through algal and macrophyte growth which adds to the levels of dissolved and total organic carbon in water. Organic carbon in source waters is a constituent of drinking water concern, primarily due to the formation of carcinogenic byproducts during disinfection at water treatment facilities (discussed in greater detail in the organic carbon conceptual model report, prepared as part of this larger study; Tetra Tech, 2006).

In addition to being a source of organic carbon, some species of algae are associated with compounds, such as geosmin and 2-methylisoborneol (MIB) that produce objectionable odors and tastes. Species of cyanobacteria (blue-green algae), such as Microcystis, produce toxins that may be harmful to humans. Recent algal blooms in the Delta have produced measurable levels of microcystin, a common toxin produced by cyanobacteria. There are not currently any drinking water standards for these algae, but cyanobacteria, other freshwater algae, and their toxins are on EPA's Drinking Water Contaminant Candidate List (CCL) for consideration of regulation adoption. The presence of algae in source waters may also decrease filtration efficiency. Finally, the presence of nitrate and nitrite, components of total nitrogen, can exceed current drinking water standards (10 mg/l nitrate as nitrogen and 1 mg/l nitrite as nitrogen) in some of the waste streams that are discharged to surface waters.

From the standpoint of quality of drinking water supplies, low nutrient levels are desirable. However, when other beneficial uses of water bodies are considered, specifically those that relate to ecosystem health, the role of nutrients is more complex. A certain level of nutrients is necessary for biological production and is therefore vital for ecosystem functioning. Excessive nutrients, however, can cause too much production and lead to other adverse impacts. There are no applicable water quality standards for nutrients in general, and appropriate nutrient levels for maintaining a variety of beneficial uses will vary by location and water body characteristics.

Nutrient concentrations across the Central Valley were estimated by averaging time series data at many sampling locations and are represented schematically in Figure ES-1 for nitrogen and ES-2 for phosphorus. The data show substantially higher concentrations in the San Joaquin River basin compared with the Sacramento River basin. Across seasons, the San Joaquin River did not exhibit large variability for either total nitrogen or total phosphorus. The Sacramento River exhibited higher total nitrogen concentrations in the wet months, and total phosphorus concentrations did not show significant inter-seasonal trends. Overall, nutrient concentrations in the San Joaquin Rivers and the Delta are high, and both could be classified as eutrophic waters. The San Joaquin River exhibits many classic symptoms of eutrophication such as low dissolved oxygen levels in deeper waters that adversely affects many beneficial uses. Given the abundance of nutrients, primary productivity in the Delta is fairly low suggesting that factors other than nutrients are limiting, specifically light limitation caused by suspended solids. However, when waters from the Delta are pumped out in aqueducts for transport, or stored in reservoirs along the way, other limiting factors may disappear and high levels of algal growth may result.

In general, average nutrient concentrations at the Banks Pumping Plant, one of the largest diversions from the Delta, lie between average concentrations in the Sacramento and San Joaquin Rivers, except for ammonia-N and total Kjeldahl nitrogen (TKN), where average concentrations at Banks are lower than both Sacramento and San Joaquin River average concentrations. Figure ES-1 and ES-2 illustrate that average total nitrogen (TN) and total phosphorus (TP) concentrations from all water diversions lie between average concentrations in the Sacramento and San Joaquin Rivers.

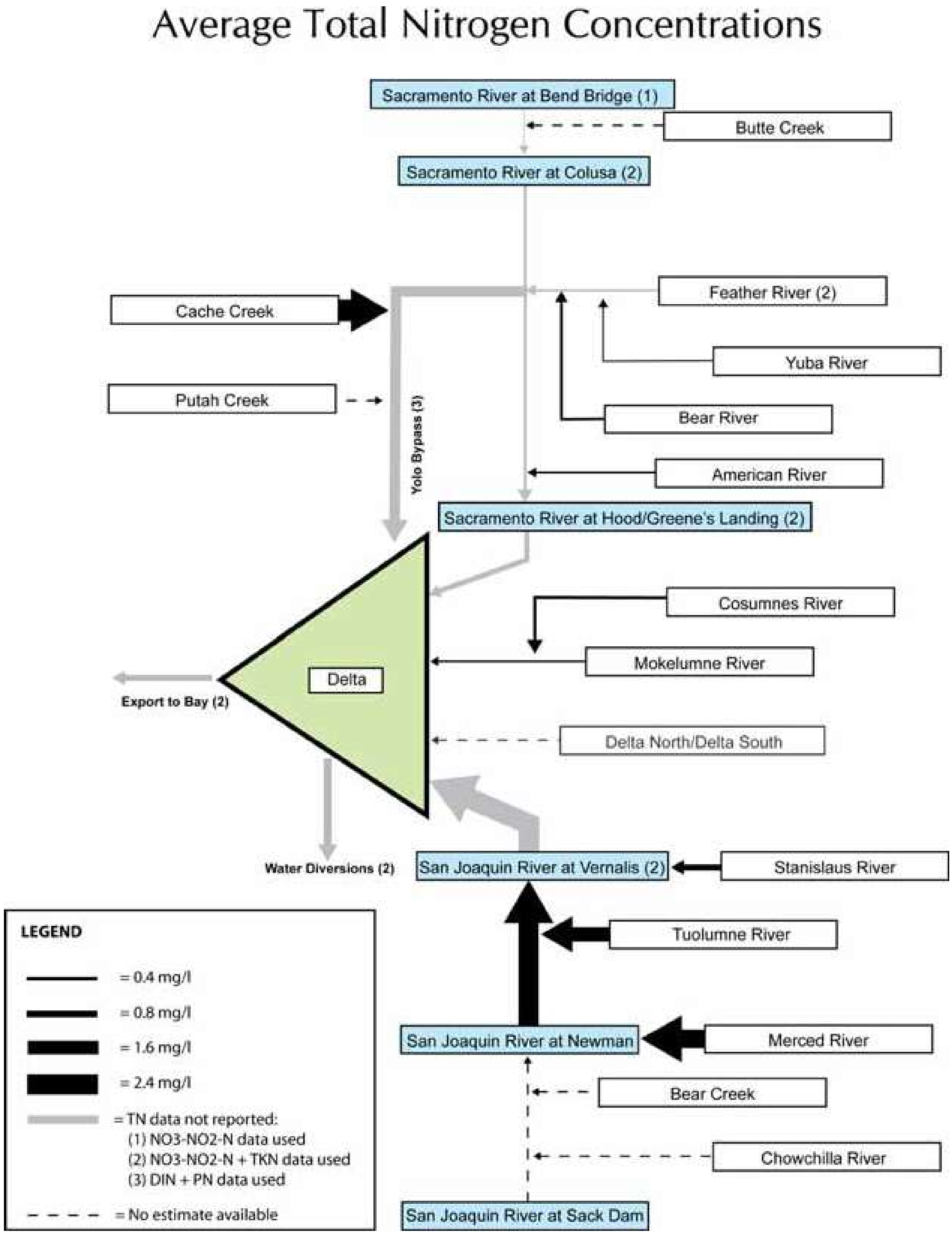

Figure ES-1. **Average concentrations of total nitrogen in the Central Valley and Delta. Other important tributary sources of nutrient loads (Mud Slough, Salt Slough) are discussed further in Chapter 4.**

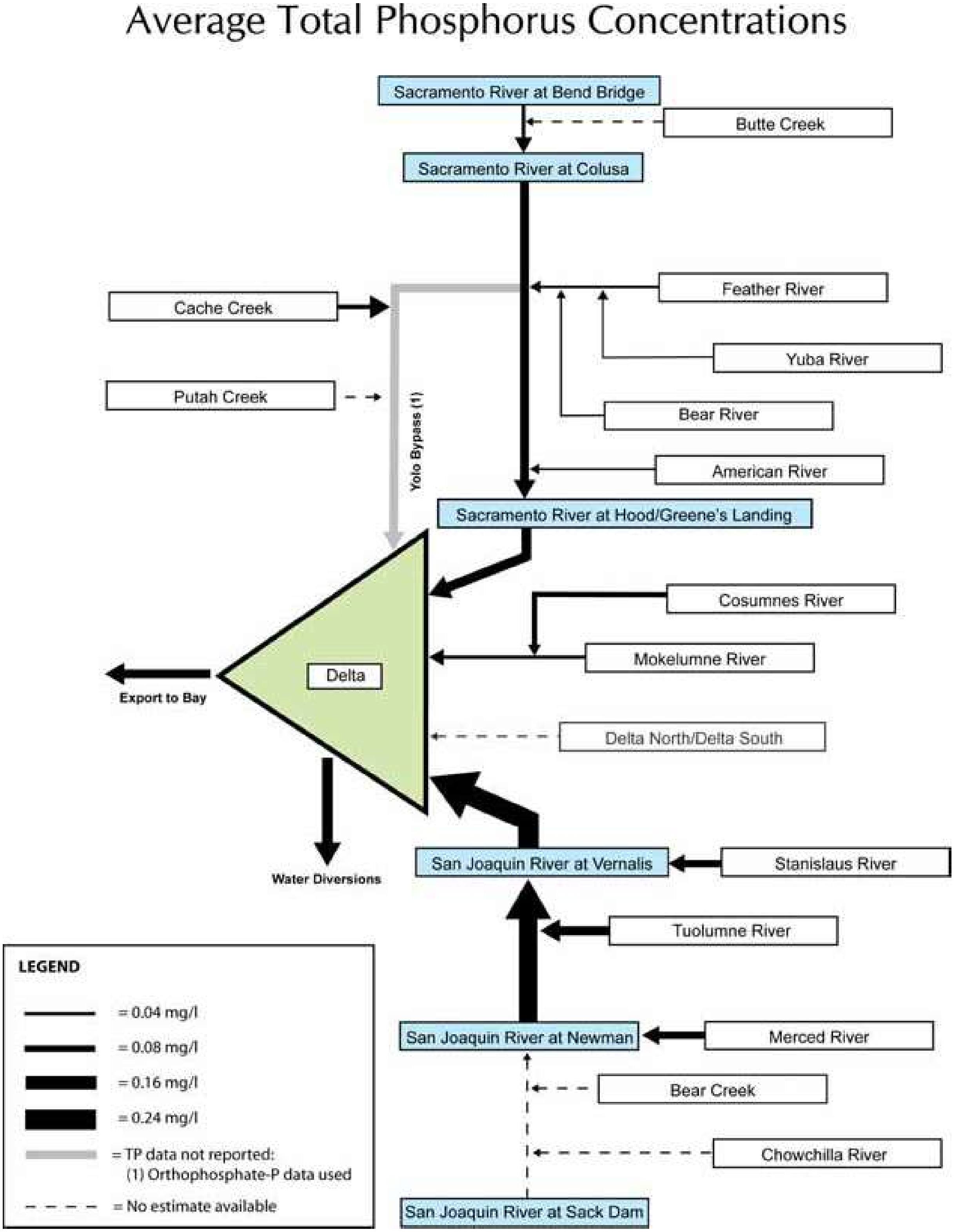

Figure ES-2. **Average concentrations of total phosphorus in the Central Valley and Delta. Other important tributary sources of nutrient loads (Mud Slough, Salt Slough) are discussed further in Chapter 4.**

Although water quality impacts are usually related to concentrations of constituents of concern, load estimates that aggregate concentrations and flows allow identification of important sources. Nutrient loads at various locations were estimated using historical monthly average flow data and average monthly concentrations (Figure ES-3 and ES-4 for nitrogen and phosphorus, respectively). Tributary loads were found to vary significantly between wet and dry years, with loads from the Sacramento River exceeding the San Joaquin River loads by nearly a factor of two or greater, especially in dry years. Despite the higher concentrations found in the San Joaquin River Basin (Figures ES-1 and ES-2), average annual runoff is up to 10 times higher in the Sacramento River, which contributes to higher loads from the Sacramento River compared to the San Joaquin River.

The loads transported in streams were compared to estimated nitrogen and phosphorus export rates from different land uses (Figures ES-3 and ES-4). Export rates (mass of either nitrogen or phosphorus transported in streams per unit area per year) were computed for key land uses: urban land, agricultural land, wetlands, and natural areas (including forests, shrubland, and rangeland). Preliminary conclusions based on the export rates are as follows. For nitrogen, forest/rangeland loads may dominate the overall loads for the Sacramento Basin and agricultural loads may dominate in the overall loads to the San Joaquin Basin, particularly for wet years. Point source loads from wastewater discharges may contribute nearly half or more of the overall nitrogen and phosphorus loads during dry years in both basins, and possibly during wet years for phosphorus in the San Joaquin Basin.

The calculated total watershed exports matched well with the stream loads at key locations (such as Sacramento River at Hood/Greene’s Landing and San Joaquin River at Vernalis) although not at all locations considered. These differences highlight the need for greater data collection, both to characterize stream loads and to better understand the sources of nutrients in the watersheds of the Central Valley and Delta.

Current estimates for in-Delta contribution of nutrients from agriculture on the Delta islands are small compared to tributary sources. The nutrient export loads in water diversions are relatively uniform from year to year, particularly when compared with the tributary loads, and are of the same magnitude as those loads estimated from the immediate watershed of the Delta. In dry years, the export loads of nitrogen and phosphorus in water diversions are similar in magnitude to their export to the Bay (Figure ES-5).

Uncertainties exist in the data used to calculate the loads presented herein. Data at some tributary locations are sparse, especially at upstream locations. Due to a lack of monitored data representing a single landuse type, export rates used to calculate loads are uncertain. In-delta sources of nutrients, primarily agricultural drainage, are not well quantified. Nutrient loads from fish hatcheries and nutrient concentrations in reservoirs are unknown. Data gaps can be addressed in future work, primarily through targeted monitoring.

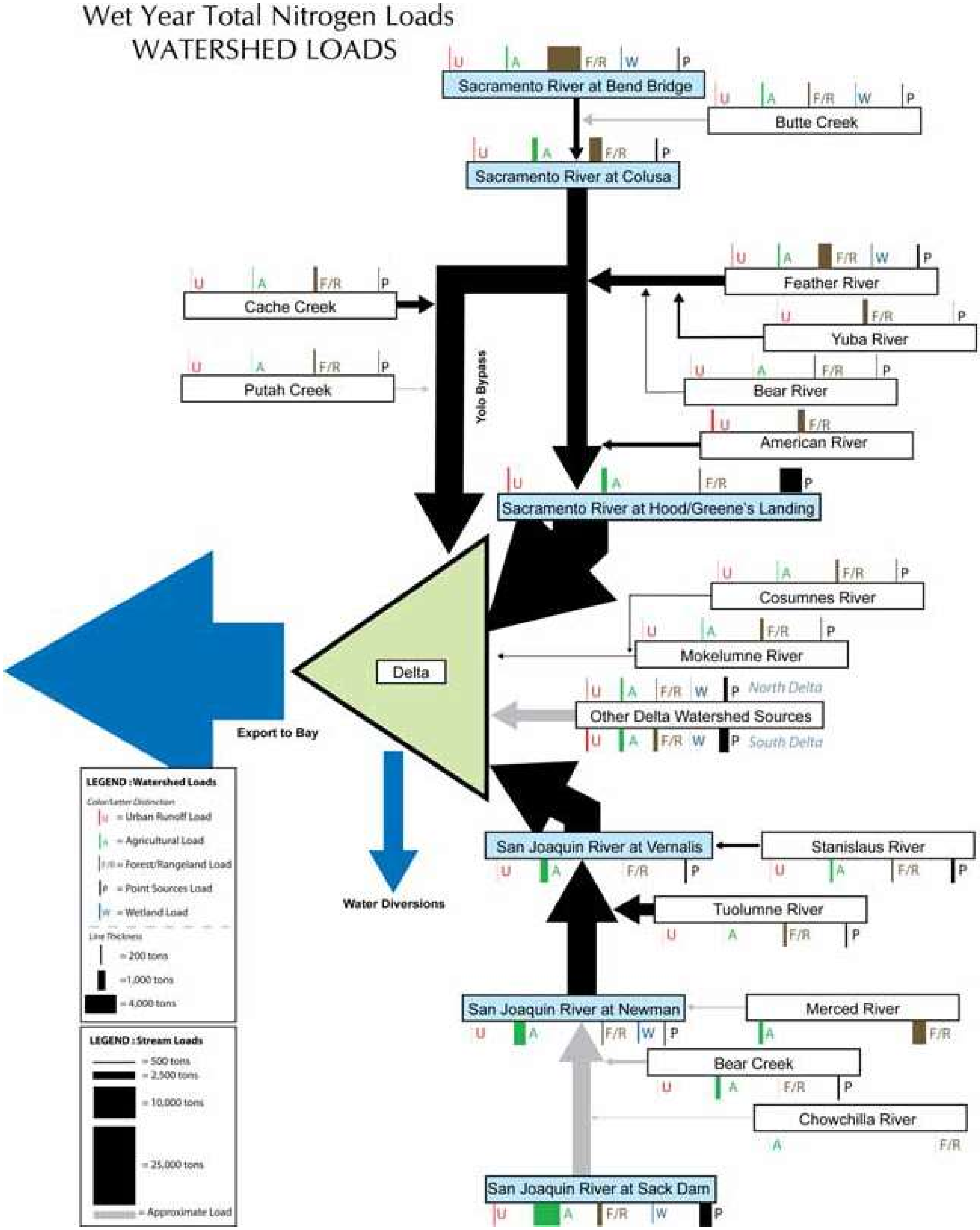

Figure ES-3. Watershed and outflow loads for the Central Valley and Delta for average wet years for total nitrogen. Arrow thicknesses are proportional to stream loads. See Chapter 4 for dry year loads.

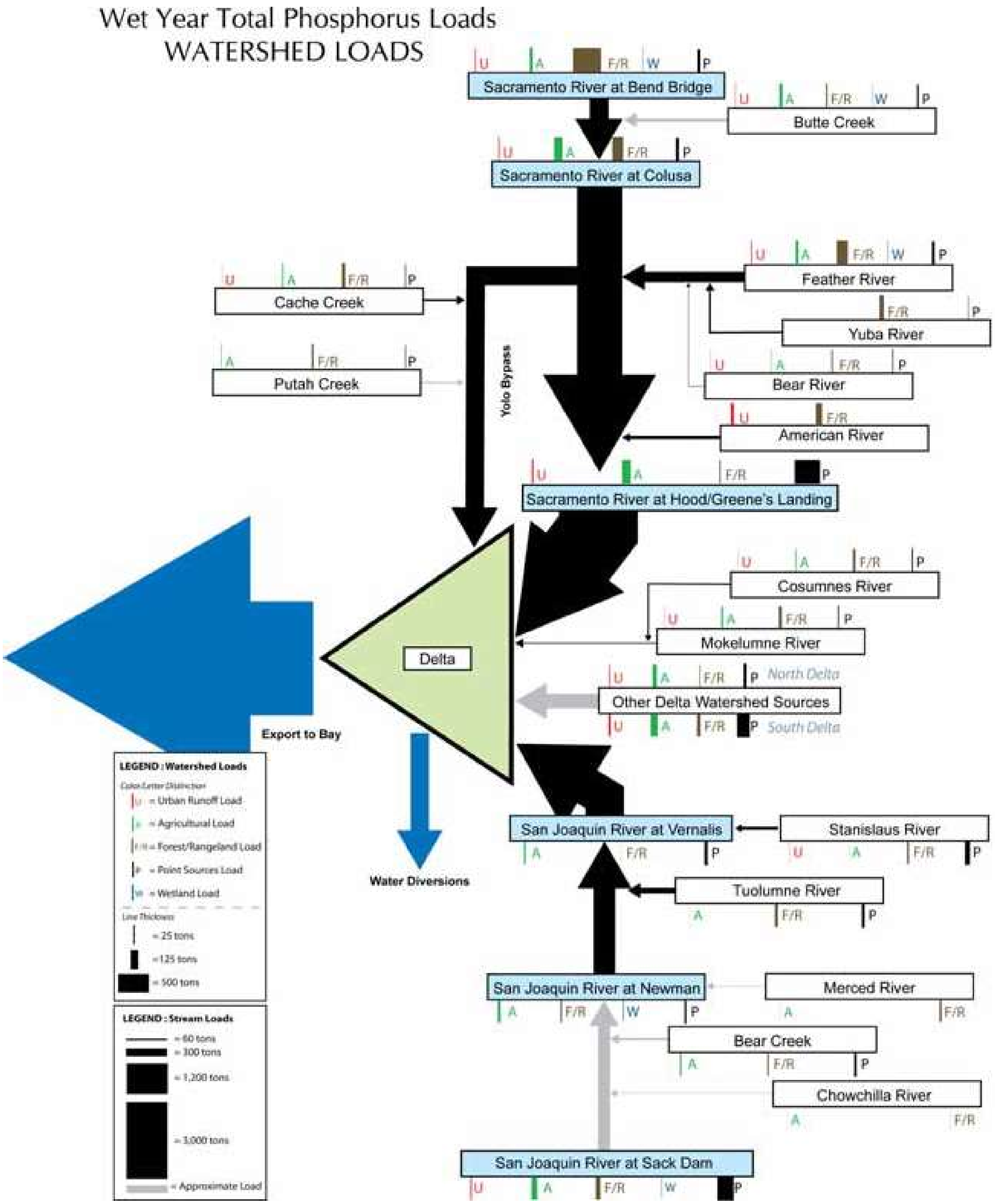

Figure ES-4. **Watershed and outflow loads for the Central Valley and Delta for average wet years for total phosphorus. Arrow thicknesses are proportional to stream loads. See Chapter 4 for dry year loads.**

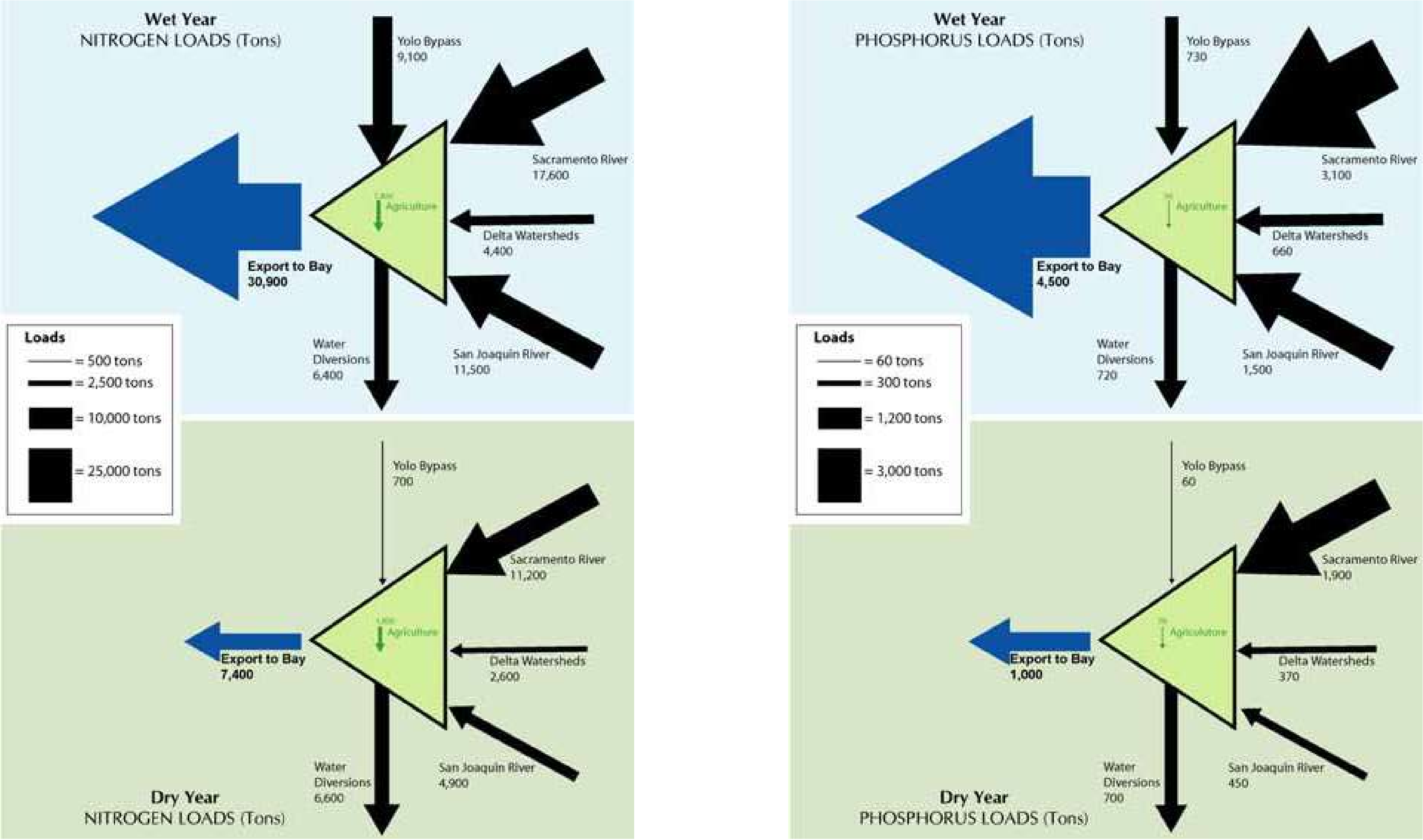

Figure ES-5. **The major tributary loads for total nitrogen and total phosphorus shown in Figure ES-3 and ES-4, along with the internal loads from in-Delta sources and exports from the Delta into San Francisco Bay and into the aqueducts.**

CHAPTER 1.0
INTRODUCTION

The Central Valley, comprising the Sacramento and San Joaquin River watersheds, is a vital source of drinking water in California. Many Central Valley communities rely on water from the Sacramento and San Joaquin rivers or their tributaries. The Sacramento-San Joaquin Delta (hereafter referred to as the Delta) provides source water to more than 23 million people in the Southern California, Central Coast, and San Francisco Bay regions (CALFED Water Quality Program Plan, 2000). The tributaries of the Sacramento and San Joaquin rivers that originate in the Sierra Nevada Mountains generally have high quality water; however, as the tributaries flow into lower elevations, they are affected by urban, industrial, and agricultural land uses, natural processes, and a highly managed water supply system.

The Central Valley Drinking Water Policy Workgroup (CVDWPWG) is working with the Central Valley Regional Water Quality Control Board (Regional Board) to conduct the technical studies needed to develop a policy that will ensure reasonable protection to drinking water supplies in the Central Valley. The policy is initially focused on five categories of constituents: organic carbon, nutrients, salinity, bromide, and pathogens and indicator organisms. This conceptual model report is focused on nutrients. Typically, the elements nitrogen and phosphorus are referred to as nutrients for photosynthesis, although depending on the context, other elements may also be included (such as silicon and other trace elements). For the purpose of this report, when we refer to nutrients, we refer only to nitrogen and phosphorus.

Nutrients are vital to the functioning of aquatic ecosystems, and, in their absence, there can be no aquatic life. Aquatic systems, depending on location and type, can have a range of natural background nutrient levels, and it is difficult to define generally applicable standards for “acceptable” nutrient levels. It is generally understood, however, that elevation of nutrients above natural levels, can result in adverse impacts that are caused by increased productivity and discussed in more detail in the following chapter.

Nutrient levels in water bodies are important for drinking water supply for several reasons. The presence of nutrients in aquatic systems promotes primary productivity (through increased algal and macrophyte growth) which adds to the levels of dissolved and total organic carbon in water. Organic carbon in source waters is a constituent of drinking water concern, primarily due to the formation of carcinogenic byproducts during disinfection at water treatment facilities (discussed in greater detail in the organic carbon conceptual model report, prepared as part of this larger study; Tetra Tech, 2006). In addition to being a source of organic carbon, some species of algae are associated with compounds, such as geosmin and 2-methylisoborneol (MIB) that produce objectionable odors and tastes. Species of cyanobacteria (blue-green algae), produce toxins that may be harmful to humans. Recent algal blooms in the Delta have produced measurable levels of microcystin, the most common toxin produced by cyanobacteria. There are not currently any drinking water standards for these algae, but cyanobacteria, other freshwater algae, and their toxins are on EPA's Drinking Water Contaminant Candidate List (CCL) for consideration of regulation adoption.[1] The presence of algae in source waters may also decrease filtration efficiency by causing clogging of pores. Finally, the presence of nitrate and nitrite, components of total nitrogen, can exceed current drinking water standards (10 mg/l nitrate as nitrogen and 1 mg/l nitrite as nitrogen) in some of the waste streams that are discharged to surface waters. Although the toxicity associated with nitrate and nitrite is an important concern, it should be noted that these are very high concentrations for nitrogen in general, and many ecosystem-related impacts may occur at much lower nitrogen levels (1 to 10 mg/l) than the toxicity impacts.

This report presents a conceptual model of nitrogen and phosphorus, summarizing current knowledge of the sources, transformation processes, and transport of these elements in the waters of the Central Valley and Delta. The conceptual model is intended to form the basis for identifying data needed to better understand the sources of nutrients, the relationship between drinking water concerns and ecosystem concerns, and the ability to control nutrients in the Delta and its watersheds. Changes that may impact nutrient levels in the waters of the Central Valley include increases in developed land, population, and concomitant increases in wastewater and urban runoff discharges.

The contents of the chapters that follow are briefly summarized as follows:

- Chapter 2 presents a summary of the key processes associated with nutrient cycling in terrestrial and aquatic systems, and the relationship to organic matter production.

- Chapter 3 summarizes the information on nutrient-related parameters in the database developed by the Central Valley Drinking Water Policy Workgroup. Spatial and temporal trends in concentration data are presented. This database

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[1] Because of its toxicity to humans, there is a World Health Organization provisional guideline for microcystin of 1 μg/l in drinking water (Hoeger et al., 2005). Current water treatment processes remove some fraction of this toxin from drinking water supplies.

is the primary source of information for the development of this conceptual model. Additional sources of data used for this assessment are also identified.

- Using the data summarized in Chapter 3, Chapter 4 provides an estimate of the flows and nitrogen and phosphorus loads transported from the tributaries to the Delta in wet and dry years. Sources of nutrients from key non-point and point sources are estimated on a unit basis (e.g., per unit area or per unit population) to compare stream loads to watershed inputs.

- Chapter 5 presents an overview of nutrient concentrations and sources within the Delta boundaries. Loads internal to the Delta are presented along with tributary sources discussed in Chapter 4.

- Chapter 6 identifies recommendations for data collection to better understand the sources and potential impacts of nutrients loads on municipal supplies and highlights the key findings of the analysis presented in this conceptual model.

CHAPTER 2.0

NUTRIENTS IN AQUATIC SYSTEMS AND RELATIONSHIP TO DRINKING WATER QUALITY

Phosphorus and nitrogen are the key nutrients that control primary productivity in many water bodies, especially when other factors, such as light, temperature, turbidity, and other micronutrients are not limiting. The limiting nutrient in a particular water body is the nutrient that is present in the lowest level relative to the cellular needs of the algae. For the purpose of this report, we focus only on nitrogen and phosphorus as nutrients of interest, although, depending on the overall water quality, other elements may become limiting for algal growth. For algal biomass, theoretical nitrogen requirements are about 7.2 times the phosphorus requirements on a weight basis (this is termed the Redfield ratio). If total nitrogen in the water is more than 7 times the total phosphorus, then phosphorus will be in low supply and limit algal growth. If the nitrogen is less than 7 times the phosphorus, then nitrogen will be limiting. However, the Redfield ratio is only a starting point for evaluation of limiting nutrients: the actual nutrient stoichiometry of algae varies somewhat between species, and more importantly with nutrient supply due to processes such as luxury consumption, which is the excess uptake and storage of nutrients when they are abundant to provide a temporary cellular supply for later deficiencies.

Depending on the water body, either nitrogen or phosphorus can be the limiting element for algal growth. As a general rule, lakes and reservoirs are found to be phosphorus limited more often than nitrogen limited, so efforts to control nutrient-related productivity are often focused on phosphorus alone. However, some lakes/reservoirs are nitrogen limited, and many are approximately balanced with nitrogen-to-phosphorus ratios close to 7. In addition, the N/P ratio often varies seasonally due to variations in external loads, internal loads from the sediments, and other internal biogeochemical cycling processes within water bodies that deplete or augment one nutrient relative to the other (e.g., phosphorus coprecipitation and adsorption on calcium carbonate, nitrogen fixation from the atmosphere by blue-green algae). Therefore, the limiting nutrient may change seasonally throughout the year, or from one year to another. Small streams are typically not nutrient limited because nutrients are efficiently retained and recycled, although larger streams may exhibit nutrient limitation, with nitrogen often being more important as a limiting element (e.g., Welch et al. 1989).

2.1 IMPACTS OF INCREASED PHOSPHORUS AND NITROGEN ON SURFACE WATER BODIES

Phosphorus and nitrogen are vital for biological growth and, if other factors such as light, turbidity, other micronutrients, are not limiting, their levels have a major effect on the functioning of aquatic ecosystems. In general, phosphorus and nitrogen are vital for ecosystem functioning, and in their absence, there can be no aquatic life. Most designated used of water bodies, especially recreational and wildlife uses, depend on there being a certain level of nutrients (which may vary by location). However, a significant concern in surface waters over the past few decades is the process of eutrophication, which refers to increased primary productivity and associated impacts as a result of human-induced increases in nutrient supply over natural levels. The most conspicuous effect of increasing levels of nitrogen and phosphorus is an increase in biomass production, typically algae and macrophytes (Wetzel, 2001). The death and decay of this biomass typically creates an oxygen demand in sediments that lowers dissolved oxygen levels in the water column. Low oxygen levels adversely impact all other species in the water body, especially invertebrates and fish. The increased sediment oxygen demand may also be responsible for sulfate reduction and production of odorous substances such as hydrogen sulfide. Changing turbidity as a result of eutrophic conditions changes the balance of benthic and planktonic productivity and may also be associated with more subtle changes, such as shifts in the abundance of plants and wildlife species in water bodies.

Overall, increased primary production as a result of nutrients has the potential to impair a wide variety of beneficial uses of surface water, including recreational, wildlife, fishery, and drinking water uses. The last of these, the focus of this conceptual model, is discussed in more detail below. The USEPA has prepared guidelines for developing nutrient criteria for streams (USEPA, 2000a), and lakes/reservoirs (USEPA, 2000b) with the eventual goal of having nutrient standards for water bodies.

2.2 EFFECT OF PHOSPHORUS AND NITROGEN ON DRINKING WATER SUPPLIES

In general, elevated levels of nutrients increase the risk for greater organic carbon fixation through photosynthesis (of phytoplankton, macrophytes, and benthic algae), although other factors, noted above, may also be limiting. Increased photosynthesis results in a greater supply of organic carbon both during the live and senescing stages of plant matter. As discussed in the organic carbon conceptual model report (Tetra Tech, 2006), elevated organic carbon negatively impacts drinking water supply because it may results in the creation of harmful byproducts during chlorination, if the organic matter is not removed through prior treatment steps. High algae levels in source water are also an adverse impact because they can clog filters and reduce the efficiency of filtration during water treatment. Higher algal production creates the risk of stimulating the growth of algal species, specifically some species of blue-green algae that are associated with the production of compounds such as geosmin and 2-methylisoborneol (MIB) that impart objectionable odors and tastes to waters, even at very low concentrations. Other species of blue green algae, in particular *Anabaena flos-aquae*, *Microcystis aeruginosa*, and *Aphanizomenon flos-aquae*, which could grow under higher nutrient levels, produce neurotoxins that can affect humans, fish, and wildlife. Higher nutrient levels increase the risk of producing these compounds at levels that are objectionable or harmful. Finally, nitrate and nitrite, significant components of total nitrogen in natural waters, have been linked to methemoglobinemia (blue-baby) syndrome in human infants at high levels. Current drinking water standards are of 10 mg/l of nitrate-nitrogen and 1 mg/l of nitrite-nitrogen (EPA, 1986).

Unlike other designated uses of waters (specifically those related recreation and wildlife), it appears that there is no lower threshold for nutrient concentrations for drinking water uses, i.e., extremely low values will not adversely impact drinking water quality. However, very low values of nutrients could adversely affect recreational and wildlife uses. Any efforts to manage nutrient levels in water bodies must balance the ecosystem needs against drinking water needs.

In the San Joaquin River and the Delta, existing data show that the nutrient concentrations are high enough to classify these waters as eutrophic water bodies. The San Joaquin River exhibits symptoms of eutrophic conditions, notably low dissolved oxygen concentrations that impairs migration of cold and warm freshwater species (Jassby, 2005). However, despite high nutrient concentrations, primary production in the Delta is fairly low (Jassby et al., 2002), indicating evidence of other limitations such as light limitation by high suspended solids. However, the water that is pumped out from the Delta and transported in aqueducts, or stored in reservoirs for future use, may not have this crucial limitation, and relatively high levels of primary productivity, with the associated impacts discussed above, such as algal blooms and low dissolved oxygen levels in deeper waters, can result. Methods to control algal growth in conveyance systems, such as the addition of copper sulfate, may create problems elsewhere, such as high copper concentrations in water treatment sludge.

2.3 PHOSPHORUS CYCLE IN LAKES, RESERVOIRS, AND STREAMS

Phosphorus is the key variable most commonly used to characterize the trophic status of lakes and reservoirs. Phosphorus is present in both dissolved and particulate forms. The particulate forms include organic phosphorus incorporated in living plankton, organic phosphorus in dead organic matter, inorganic mineral phosphorus in suspended sediments, phosphate adsorbed to inorganic particles and colloids such as clays and precipitated carbonates and hydroxides, phosphate adsorbed to organic particles and colloids, and phosphate coprecipitated with chemicals such as iron and calcium. The dissolved forms include dissolved organic phosphorus (DOP), orthophosphate, and polyphosphates. The organic forms of phosphorus can be separated into two functional fractions. The labile fraction cycles rapidly, with particulate organic phosphorus quickly being converted to soluble low-molecular-weight compounds. The refractory fraction of the colloidal and dissolved organic phosphorus cycles more slowly, regenerating orthophosphate at a much lower rate. Figure 2-1 illustrates the phosphorus cycle.

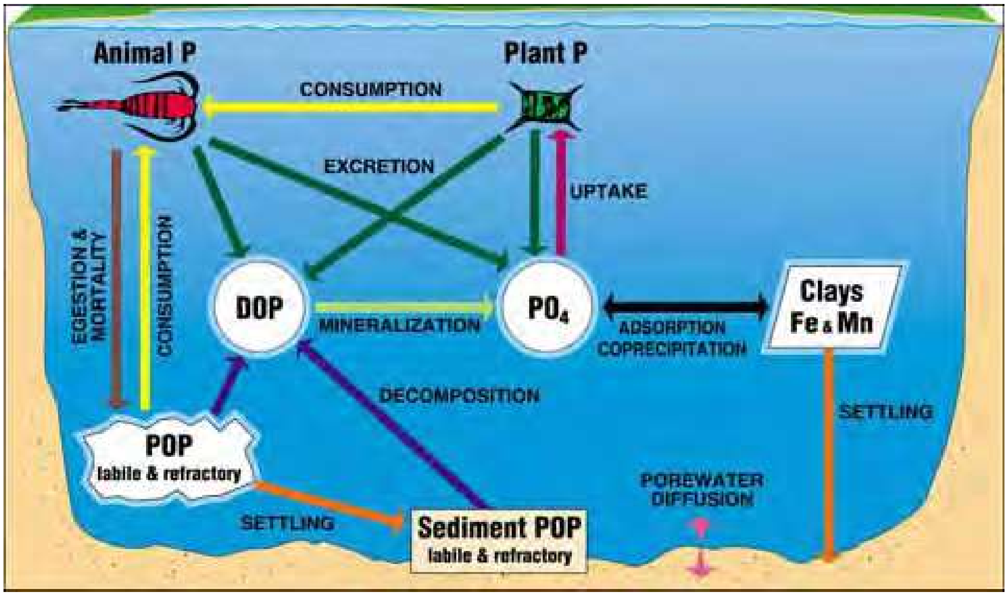


Figure 2-1. Phosphorus cycle in aquatic ecosystems.

Dissolved phosphorus may be reported as total dissolved phosphorus, total phosphate, orthophosphate, and dissolved organic phosphorus. Care must be taken in interpreting monitoring data to determine if a reported total phosphorus value represents both dissolved and particulate forms (unfiltered sample), or only total dissolved forms (filtered sample). Confusion is also common in interpreting phosphate data, since it may not be clear if it represents only orthophosphate, or orthophosphate plus polyphosphates. The latter should be reported as total dissolved phosphates.

Dissolved orthophosphate, sometimes reported as soluble reactive phosphorus, is the only form that is generally considered to be available for algal and plant uptake. Although this is the primary bioavailable form, total phosphorus, including all dissolved and particulate forms, is a better determinant of lake and reservoir productivity. This is because most of the phosphorus is tied up in plankton and organic particles during periods of high productivity. Often more than 95% of the total phosphorus is incorporated in organisms, especially algae (Wetzel, 2001). Any orthophosphate released by excretions, decomposition of organic matter, and mineralization of dissolved organic phosphorus is immediately taken up by phytoplankton. Phosphorus uptake and turnover rates are extremely fast, on the order of 5 to 100 minutes, during summer periods of high productivity (Wetzel, 2001). Therefore, the dissolved orthophosphate concentrations in the water column are often very low in highly productive systems. Phosphorus uptake and turnover rates are much slower during the winter due to the colder temperatures and lower light intensities. Uptake rates and optimum phosphate concentrations for growth vary among algal species, so seasonal changes in phosphate influence the structure and seasonal succession of phytoplankton communities.

Phosphorus concentrations and distributions between phosphorus forms vary both spatially and seasonally and can change rapidly due to both biogeochemical cycling processes and seasonal variations in phosphorus loading. The major cycling processes include algal and plant assimilation of orthophosphate, decomposition of organic detritus, mineralization of DOP, DOP and phosphate excretions by aquatic organisms, phosphate adsorption/desorption to suspended particulates and sediments, coprecipitation of phosphate, sediment release, macrophyte release, and sedimentation of plankton and other particulate forms of phosphorus. The external load sources include inflowing rivers and streams, direct runoff from the surrounding watershed, groundwater inflows, atmospheric deposition, and waste discharges. The phosphorus loads from the watershed depend on the phosphorus contents of the soils and parent rock material, vegetation characteristics including surface detritus and organic content of the soils, the amounts of animal wastes present, and human activities in the watershed such as fertilization and detergent use.

Total phosphorus can range from <5 ug/l in very unproductive lakes to >100 ug/l in very eutrophic lakes, although the usual range is between 10 and 50 ug/l in uncontaminated systems (Wetzel, 2001). Typical average total phosphorus concentrations for different trophic categories are 8 ug/l in oligotrophic lakes, 27 ug/l in mesotrophic lakes, and 84 ug/l in eutrophic lakes (Vollenweider, 1979; Wetzel, 2001). The 1986 EPA Water Quality Criteria recommend a maximum total phosphorus concentration of 25 ug/l in lakes to prevent eutrophication problems, and maximum concentrations of 50 ug/l in streams that enter lakes. Although inflow phosphorus concentrations drop in lakes due to phytoplankton uptake and settling, they may not drop 50 percent unless the residence is very long. This is particularly true if internal loads from sediments and macrophytes are important. Therefore, the 50 ug/l recommendation for inflowing streams may not adequately protect lakes. It is anticipated that, in coming years, new phosphorus criteria will be developed that vary by region and implement recent USEPA guidelines on nutrient criteria (USEPA 2000a, 2000b).

The dynamics of phosphorus limitation in flowing water bodies, such as streams and aqueducts, is not as straightforward as that for lake environments. Unlike lake and reservoir environments where phosphorus is often bound and tightly cycled within the biota, stream environments are open and therefore continually receive phosphorus from upstream, groundwater, or runoff. Current also helps reduce limitation by reducing diffusion barriers. Under natural conditions, much of the phosphorus delivered to streams is bound in organic forms (e.g., in leaves, woody debris, invertebrates, etc.) and is then transferred between and among the different trophic levels within the lotic ecosystem. The role of macroinvertebrates in this transformation process is very important. Ward (1989) states that invertebrates may act as temporal mediators; their feeding activities result in a more constant supply of detritus to downstream communities by reducing the buildup of benthic detritus below levels subject to episodic transport during high flow events.

When human-derived sources of phosphorus are delivered to a stream, such as wastewater and stormwater runoff, the ratio of dissolved phosphorus immediately available to algae may be high relative to particulate forms of phosphorus such as those attached to soil particles (Robinson et al. 1992). However, the discharged phosphorus cycles rapidly between abiotic and biotic phases, and after some distance of transport from the discharge point, the bioavailability of the newly introduced phosphorus may be no different from that previously in the stream.

2.4 NITROGEN CYCLE IN LAKES, RESERVOIRS, AND STREAMS

Nitrogen occurs in numerous dissolved and particulate forms. The particulate forms include organic nitrogen incorporated in living plankton, organic nitrogen in dead organic matter, and ammonia adsorbed to inorganic particles and colloids. The dissolved forms include dissolved organic nitrogen, ammonia, nitrite, nitrate, and dissolved molecular nitrogen gas (N_2). The organic forms of nitrogen include many compounds such as amino acids, ammines, nucleotides, proteins, and humic compounds (Wetzel, 2001). The nitrogen cycle is illustrated in Figure 2-2.

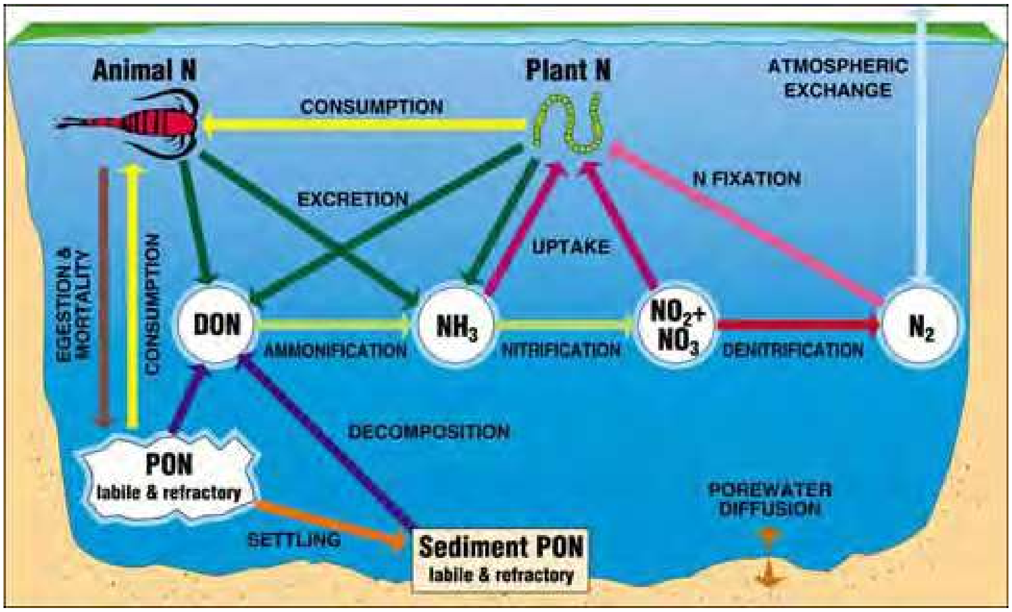


Figure 2-2. Nitrogen cycle in aquatic ecosystems.

Dissolved nitrogen may be reported as total dissolved nitrogen, total nitrogen, ammonia, nitrite, nitrate, nitrate plus nitrite, total Kjeldahl nitrogen (TKN), and dissolved organic nitrogen (DON). TKN represents organic nitrogen plus ammonia nitrogen. Care must be taken in interpreting monitoring data to determine if a reported total nitrogen or TKN value represents both dissolved and particulate forms (unfiltered sample), or only dissolved forms (filtered sample).

Nitrogen concentrations and distributions between nitrogen forms vary both spatially and seasonally and can change rapidly due to both biogeochemical cycling processes and seasonal variations in nitrogen loading. The major cycling processes include algal and plant assimilation of nitrate and ammonia, decomposition of organic detritus, deamination and ammonification, nitrification, denitrification, nitrogen fixation by blue-green algae and bacteria, DON and ammonia excretions by aquatic organisms, ammonia adsorption/desorption to suspended inorganic particulates and sediments, sediment decomposition and release, macrophyte decomposition and release, sedimentation of plankton and other particulate forms of nitrogen, and gaseous exchange with the atmosphere.

Nitrate and ammonia, the major dissolved inorganic forms of nitrogen, are the only forms that are available for algal and plant uptake. Most algae preferentially uptake ammonia over nitrate since more energy must be expended to reduce nitrate to ammonia before it can be biologically assimilated. Therefore, uptake and photosynthesis rates are higher for ammonia than nitrate at the same concentrations. However, very high ammonia concentrations can have a toxic effect and inhibit photosynthetic uptake, particularly at high pH. Under these conditions, nitrate uptake rates may exceed ammonia uptake rates.

The main source of ammonia in lakes and rivers is the decomposition of organic matter (proteins, other organic compounds) by heterotrophic bacteria. Aquatic animals also excrete ammonia, but this source is small relative to decomposition. Intermediate dissolved organic nitrogen compounds are also released, but they do not accumulate to high levels because deamination and ammonification by bacteria is rapid (Wetzel, 2001). However, some of the dissolved organic nitrogen compounds are more resistant to bacterial degradation than others.

Nitrate and nitrite are generated through nitrification of ammonia. In aerobic waters, bacterial nitrification oxidizes ammonia to nitrate in a two-stage reaction in which ammonia is first oxidized to nitrite, and then nitrite is oxidized to nitrate. Nitrite oxidation is very fast, so nitrite levels in lakes and rivers are usually very low unless the waterbody is very nutrient enriched. Nitrate is the dominant oxidized form in lakes and rivers. Highest nitrite concentrations are typically found in areas where there is a transition from aerobic to anaerobic conditions, such as the metalimnion or upper hypolimnion of lakes, or the sediment interstitial waters near the lower boundary of the oxidized microzone. These represent areas that have low enough oxygen levels to slow down the nitrification reactions, but still high enough to prevent significant denitrification reactions. In addition to nitrification as a nitrate source, nitrate is also often the dominant dissolved nitrogen form in external loads from surface waters, groundwater, and the atmosphere. The riparian zone, through which groundwater and surface runoff enters streams, plays a very important role in the nitrogen cycle as both aerobic and anaerobic conditions are usually present. Green and Kauffmann (1989) indicate that riparian zones are important for denitrification.

In anaerobic waters and sediments, bacterial denitrification rapidly reduces nitrate and nitrite to nitrogen gas (N_2). Nitrate is used as a hydrogen acceptor during the oxidation of organic matter under anaerobic conditions. Some of the N2 produced during denitrification leaves the lake through outgassing, and some is fixed by blue-green algae and bacteria.

Particulate organic nitrogen in plankton and detritus is removed from the water column through sedimentation. Bacterial activity in the sediments decomposes the particulate organic nitrogen to release dissolved organic nitrogen and ammonia. Since most of the sediments are anaerobic, nitrification cannot occur, so ammonia levels increase in the sediment porewaters. Nitrification does occur in the oxidized microzone at the top of the sediments. Any nitrate or nitrite that diffuses into the anaerobic sediments from the water column or oxidized microzone is quickly denitrified to N_2. Ammonia sorbs to sediment particles under aerobic conditions in the oxidized microzone. Once the hypolimnion becomes anaerobic and the oxidized microzone disappears, the adsorptive capacity of the sediments diminishes, and sediment release of ammonia increases substantially.

Dissolved nitrogen gas (N_2) enters lakes and rivers through both atmospheric exchange and denitrification reactions. Both blue-green algae and bacteria can fix N_2, although nitrogen fixation by blue-green algae is usually greater than by bacteria. However, N_2 fixation requires more energy than assimilation of ammonia or nitrate, so blue-green algae typically fix nitrogen when ammonia and nitrate concentrations are low (Wetzel, 2001). Blue-green algae dominate the phytoplankton during periods when nitrate and ammonia are depleted by algal uptake because of their ability to fix nitrogen. Nitrogen fixed by bacteria in wetlands surrounding lakes or inflowing streams can also be a significant nitrogen source in some situations. In some cases, certain riparian plants, such as alder, can add nitrogen to riverine ecosystems by fixing atmospheric nitrogen.

Total nitrogen can range from 0.3 mg/l in very unproductive lakes to >2000 mg/l in very eutrophic lakes (Wetzel, 2001). Typical average total nitrogen concentrations for different trophic categories are 0.66 mg/l in oligotrophic lakes, 0.75 mg/l in mesotrophic lakes, and 1.9 mg/l in eutrophic lakes (Wetzel, 2001). It is anticipated that, in coming years, new nitrogen criteria will be developed that vary by region and implement recent USEPA guidelines on nutrient criteria (USEPA 2000a, 2000b).

In lakes, the seasonal dynamics of the nitrogen cycle along with the effects of stratification and dissolved oxygen profiles determine the temporal and spatial variations of the different nitrogen forms in the water column. However, the nitrogen speciation of major external load sources, and whether they enter the epilimnion or hypolimnion, can also play an important role, particularly if the external loads are high and the lake residence time is low.

As with phosphorus, the external nitrogen sources to lakes and rivers include inflowing rivers and streams, direct runoff from the surrounding watershed, groundwater inflows, atmospheric deposition, and waste discharges. In addition, nitrogen also enters lakes and rivers though atmospheric exchange and nitrogen fixation. The nitrogen loads from the watershed depend on the nitrogen contents of the soils and parent rock material, vegetation characteristics including surface detritus and organic content of the soils, the amounts of animal wastes present, and human activities in the watershed such as fertilization. Septic systems can also be significant sources since organic nitrogen and ammonia in the septic fields are oxidized to nitrate, which is highly mobile in soils. Therefore, it can enter lakes through shallow groundwater flows directly to the lake or through stream inflows from the watershed. In contrast, phosphate tends to be retained in soils by adsorption, so septic systems are not such a large phosphorus source unless they are situated close to receiving waters or are not operating properly. Atmospheric deposition is also more significant for nitrogen than for phosphorus in most areas due to contamination by combustion emission products.

The temporal dynamics of the nitrogen cycle make it more appropriate to use total nitrogen (dissolved and particulate), rather than only the bioavailable forms such as ammonia and nitrate, in identifying impacts on lakes and rivers. Ammonia and nitrate are typically very low and sometimes immeasurable during the peak growing season of highly productive lakes. Ammonia and nitrate are rapidly taken up by phytoplankton, so much of the nitrogen is bound in plankton and organic detritus. In rivers, Dodds, et al., (1997) report that total nitrogen concentrations were more indicative of the nitrogen form that is ultimately bioavailable for benthic algal growth (periphyton) than dissolved nitrogen.

2.5 MEASUREMENT OF NUTRIENTS

There are two ‘phases’ of nutrients that are commonly measured in water: soluble and particulate. Within each phase, particular chemical species are identified. In some instances, measurements of nutrient concentrations in biota, specifically algae and macrophytes, can also be performed, but these are typically not relevant for drinking water supply concerns. Figure 2-3 shows the various species of nitrogen and phosphorus that are present in water samples, some of which are measured analytically and some of which are estimated by difference. For nitrogen species, total ammonia includes both the ionized (NH_4^+) and unionized (NH_3) forms. Dissolved nitrite and nitrate are often combined, as the concentration of nitrite in natural waters is generally small. Dissolved organic nitrogen can be obtained from the difference between Kjeldahl nitrogen and total ammonia. Kjeldahl nitrogen combines both organic nitrogen and total ammonia. Adding Kjeldahl nitrogen to dissolved nitrite + nitrate yields total dissolved nitrogen. For phosphorus species, the commonly reported quantities are soluble reactive phosphorus, a measure of the most biologically available fraction, total dissolved phosphorus, and total phosphorus.

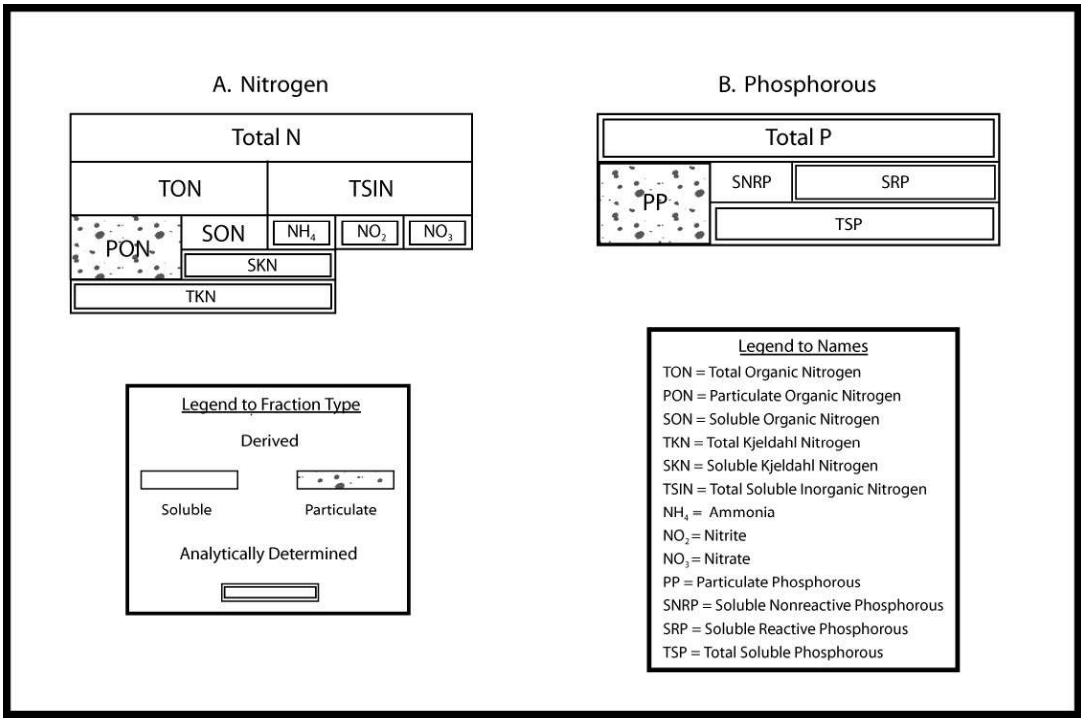


Figure 2-3. Nutrient species found in water bodies. Some are analytically determined (indicated by double-lined boxes), and the others calculated by difference. The species identified in this Figure can be related to data presented in Chapters 3, 4, and 5. In particular, soluble reactive phosphorus is synonymous with orthophosphate.

CHAPTER 3.0

OVERVIEW OF DATA USED FOR ANALYSIS

The conceptual model for nutrients developed in this report is based largely on a database of nutrients and other constituents compiled by the Drinking Water Policy Workgroup in 2004-2005. Data in the database originate from a variety of agricultural, urban, point source, and surface water monitoring programs throughout the watersheds of the Sacramento and San Joaquin Rivers. The database was supplemented with data from Department of Water Resource's (DWR) Municipal Water Quality Investigations (MWQI) Program and the United States Geological Survey's (USGS) National Water Information System (NWIS) database.

This chapter provides an overview of the nutrient data contained in the database, notably the forms measured, the quantity and spatial distribution of the data, and the concentrations observed at various stations. The plots in this chapter present an informative snapshot of the available data, and set the stage for loading analyses in the next two chapters. Figure 3-1 illustrates stream reaches and key sampling locations in the Central Valley and Delta referred to in this and subsequent chapters. Figure 3-2 presents a close up of the Delta, including Delta islands and Delta pumping stations. Also note that three new Delta intakes are planned: by the Contra Costa Water District in Victoria Canal, by the City of Stockton in the San Joaquin River near Empire Tract, and by the Solano County Water Agency (Delta Region Drinking Water Quality Management Plan, 2005).

Figure 3-1. Surface water features and sampling locations in the Central Valley and Delta.

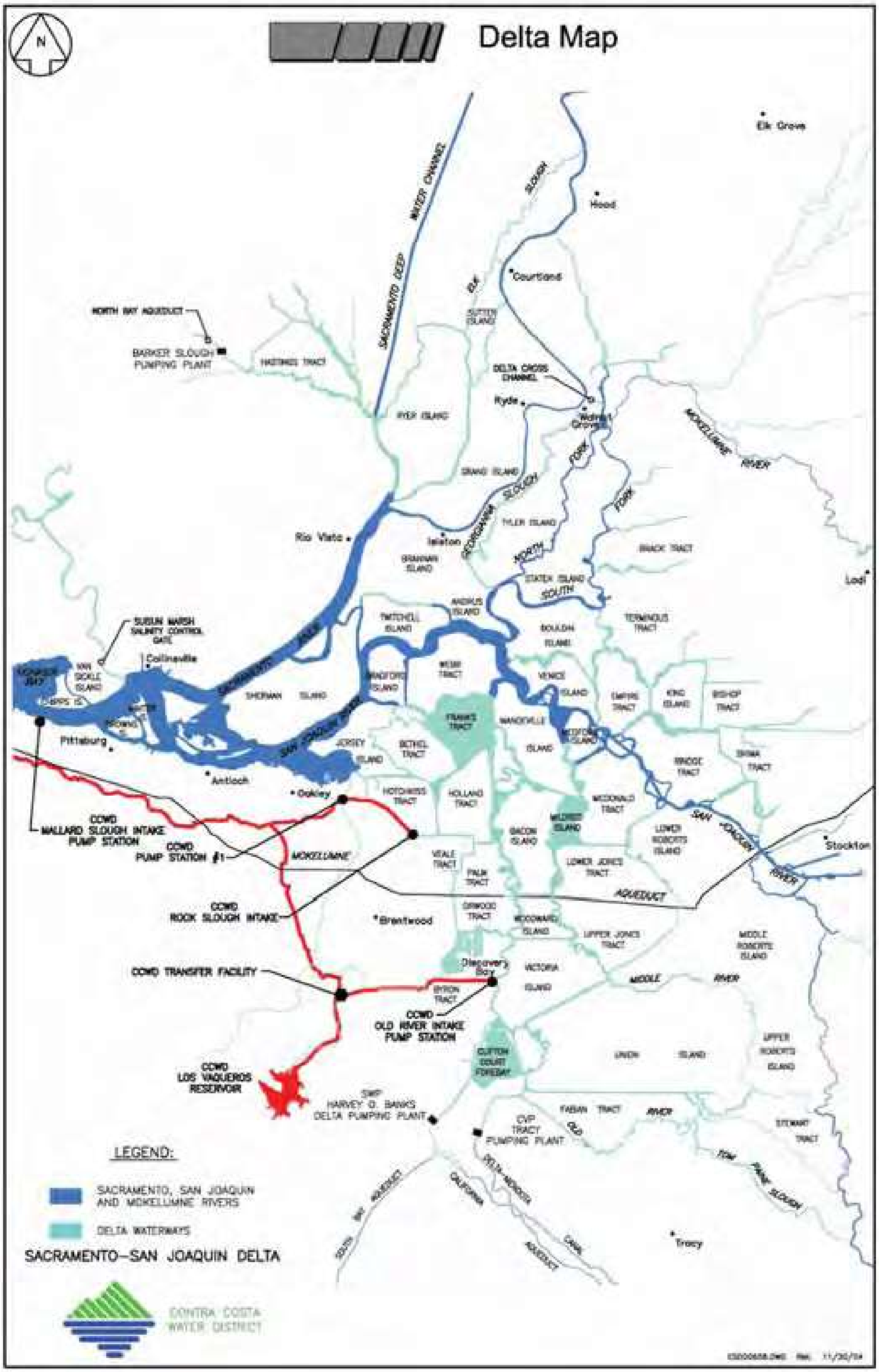


Figure 3-2. Key locations in the Sacramento-San Joaquin Delta. Map provided by Contra Costa Water District (CCWD).

3.1 OVERVIEW OF CONCENTRATION DATA

In addition to the Drinking Water Policy Database, a major additional source of chemistry data was the MWQI Program, from which data for stations in the Delta (Sacramento River at Hood, Sacramento River at Greene's Landing, San Joaquin River at Vernalis, and Delta drinking water intakes) were obtained electronically for this task from http://wdl.water.ca.gov/wq-gst/. MWQI data through 2000 were included in the Drinking Water Policy Database, however data from 2000 to the present were not available in the database. The MWQI Program obtains grab sample data on nitrate plus nitrite (NO3+NO2-N), ammonia-N, TKN, orthophosphate-P and total phosphorus (TP) concentrations at 10 locations around the Delta.

Other chemistry data were obtained from the USGS NWIS, available at http://nwis.waterdata.usgs.gov/usa/nwis/qwdata. This program reports all six nutrient constituents examined in this study. Data presented in this chapter from NWIS include nutrient data from stations on the mainstems of the Sacramento and San Joaquin Rivers and on major tributaries for which loading analyses were completed.

Maps showing the distribution of data in the Central Valley are presented in Figures 3-3 through 3-6 for nitrogen species (NO3+NO2-N, ammonia-N, TKN, and TN, respectively) and 3-7 and 3-8 for phosphorus species (orthophosphate-P and TP, respectively). Much of the data were collected along the main stems of the Sacramento and San Joaquin Rivers and in the Delta. There were limited data for the tributaries to the Sacramento and San Joaquin Rivers. An exception to this rule is noted for TN, for which much of the data are upstream of the Delta on the main stems of the Sacramento and San Joaquin Rivers. Over 90% of the TN data are from a US Fish and Wildlife Services and UC Davis Nutrient Study. Of all of the nutrient species, the least amount of data are available for TN. This is typical of water quality sampling programs. Approximately half the stations in the database had no coordinate information and are not shown in these maps; these data were not used in this analysis. Based on a spatial evaluation of the data, it appears that all of the nutrient data are measured widely enough for watershed-wide analysis. For the loading analysis, the TN data were supplemented with other nitrogen species data where TN data were not available.

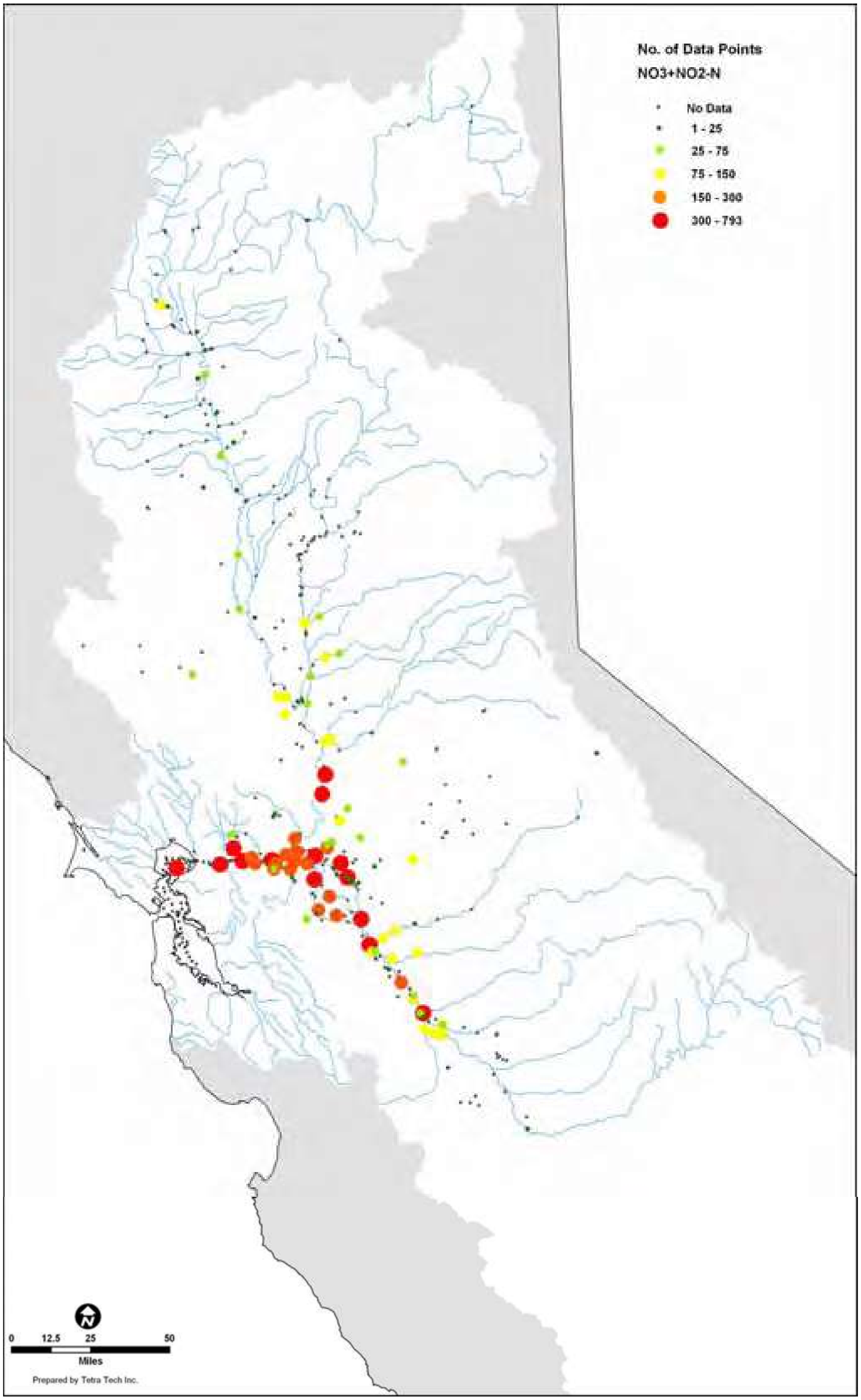


Figure 3-3. Number of NO3+NO2-N data points at each station in the Central Valley and Delta.

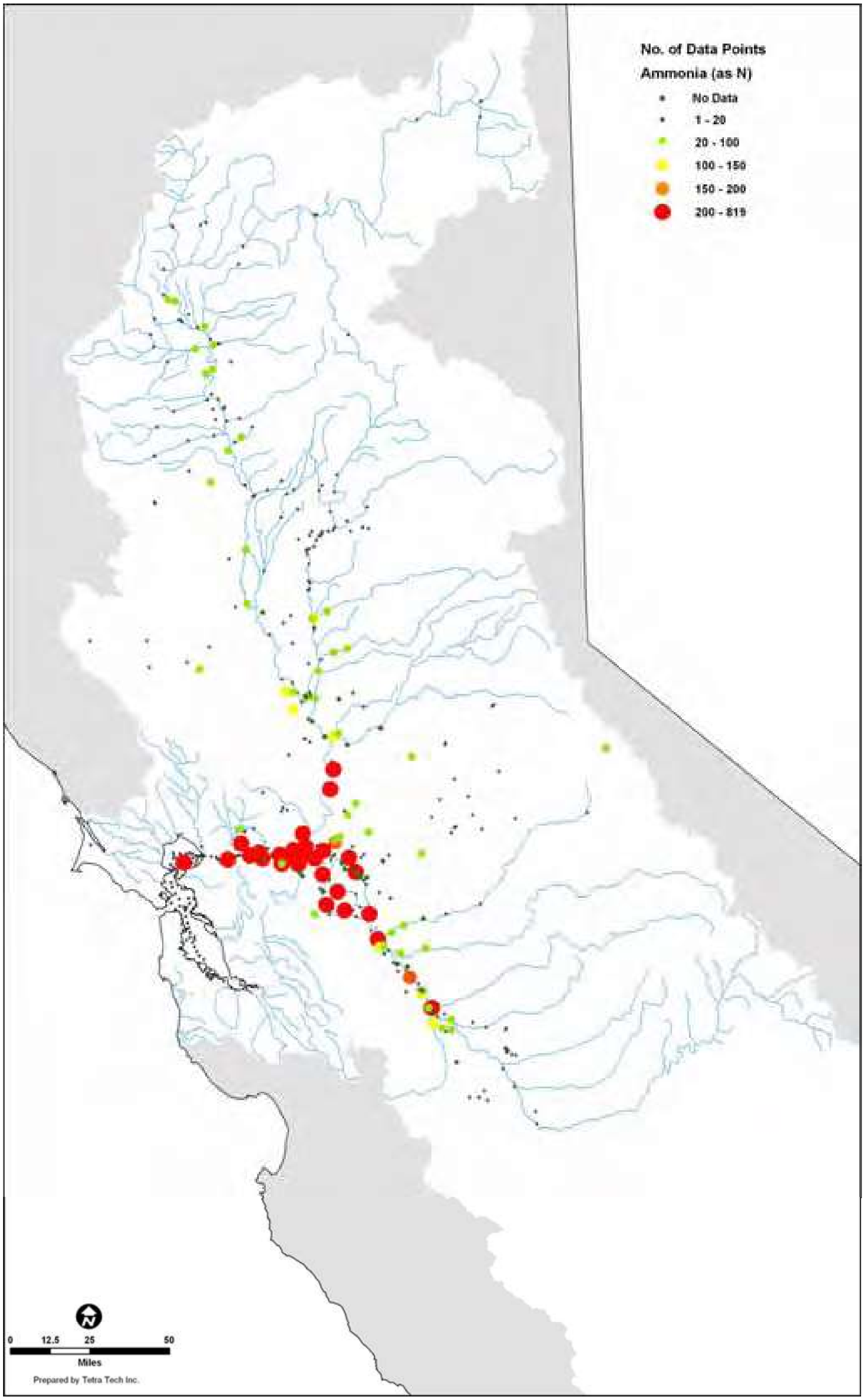


Figure 3-4. Number of Ammonia-N data points at each station in the Central Valley and Delta.

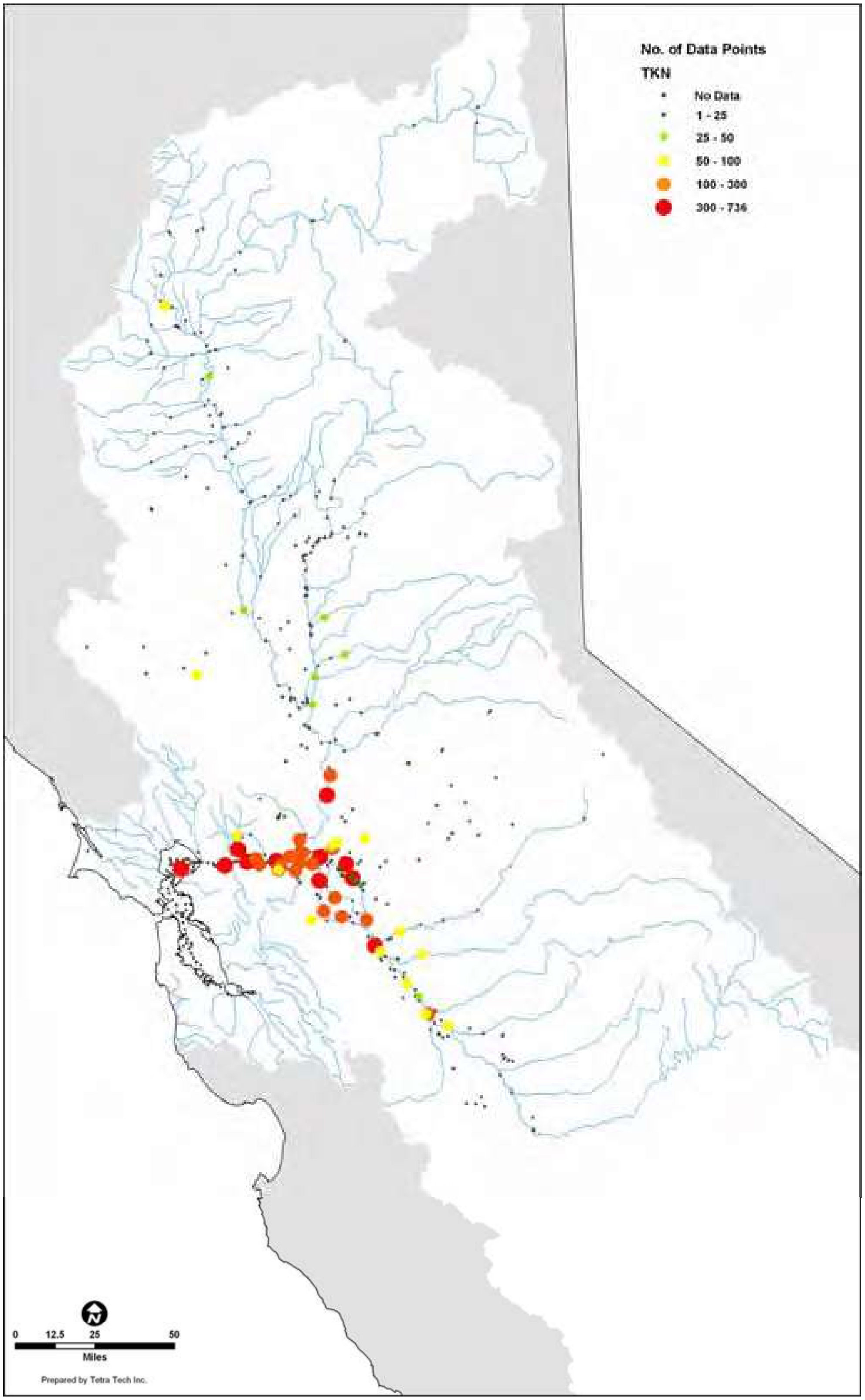


Figure 3-5. Number of TKN data points at each station in the Central Valley and Delta.

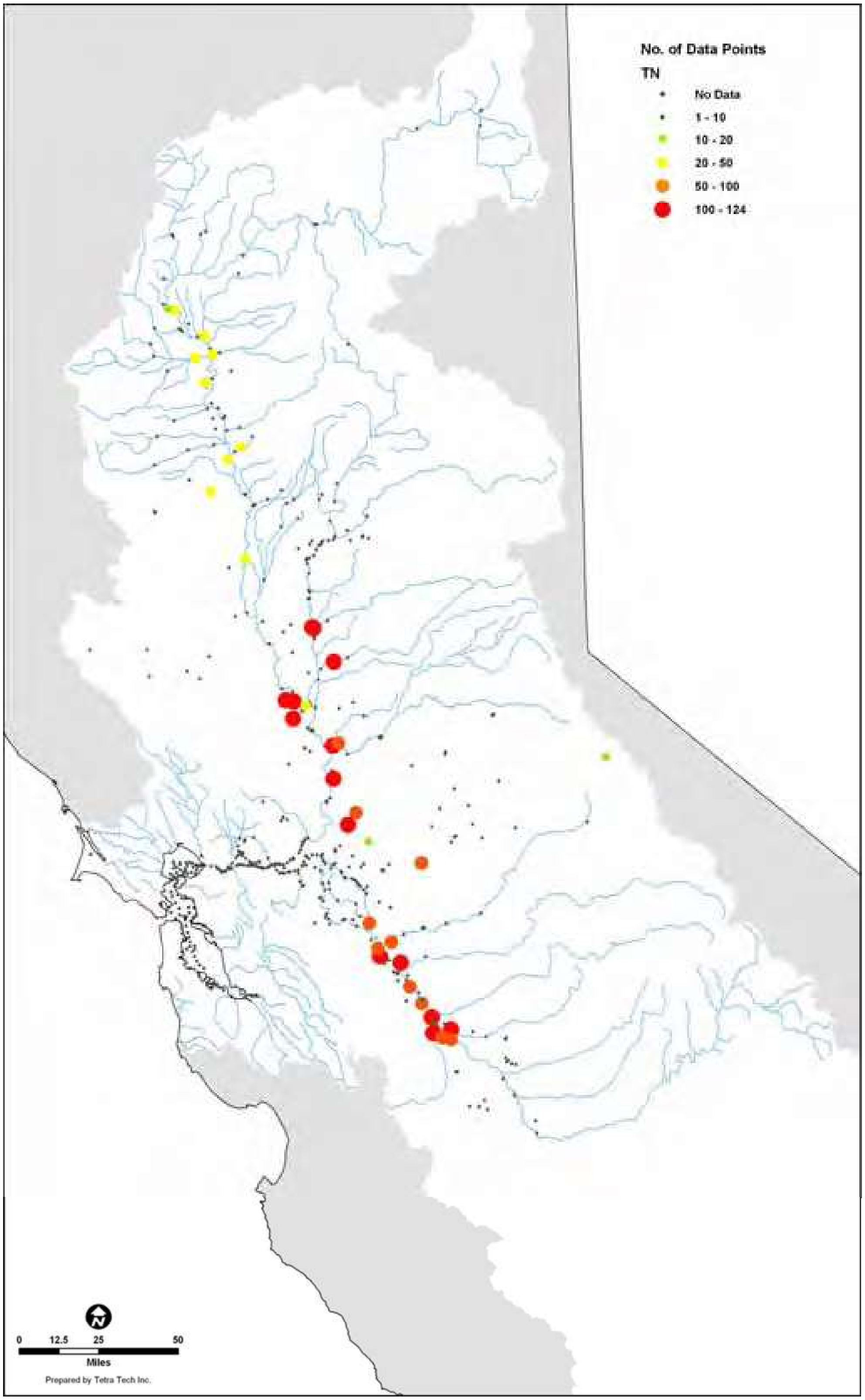


Figure 3-6. Number of TN data points at each station in the Central Valley and Delta.

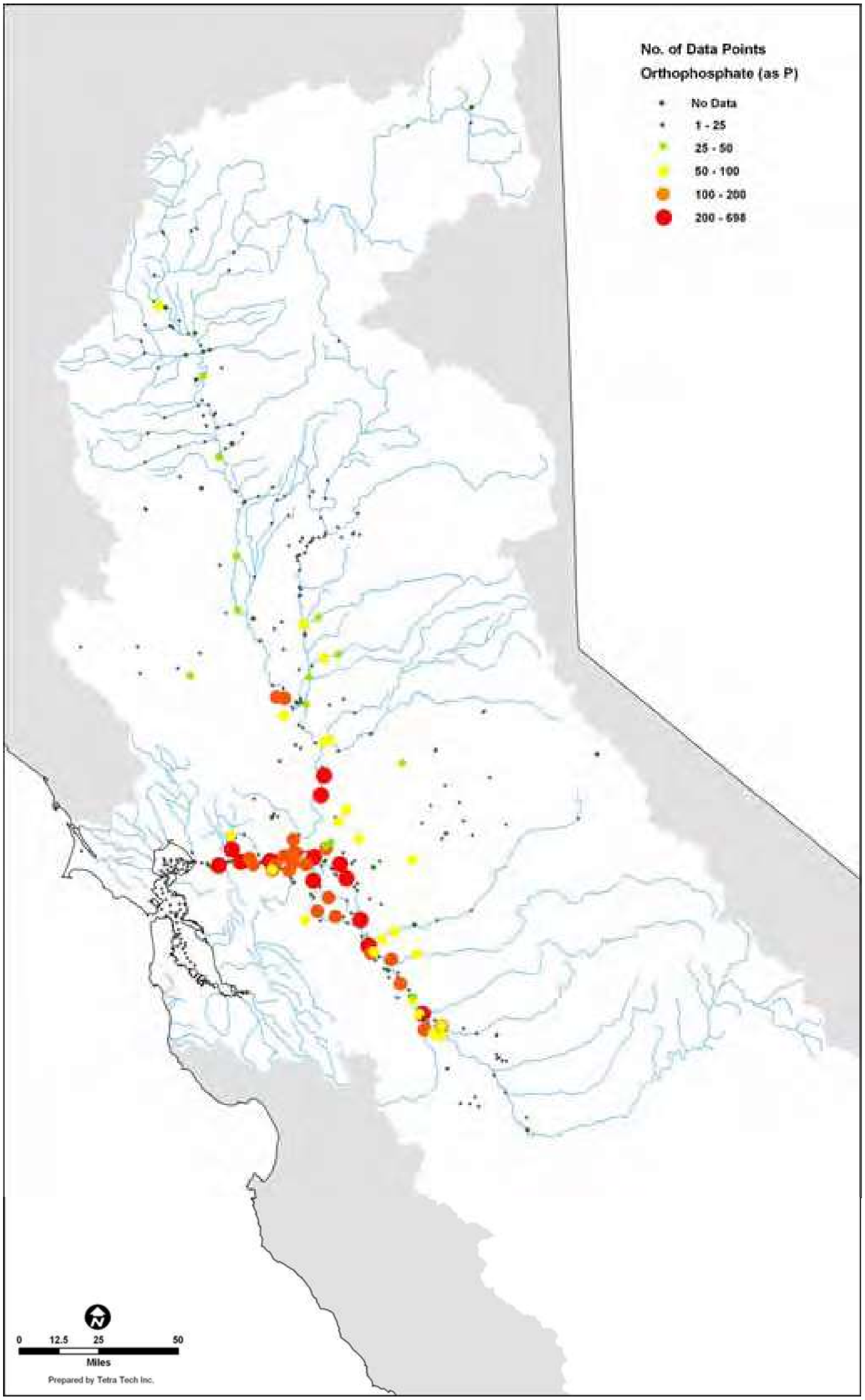


Figure 3-7. Number of Orthophosphate-P data points at each station in the Central Valley and Delta.

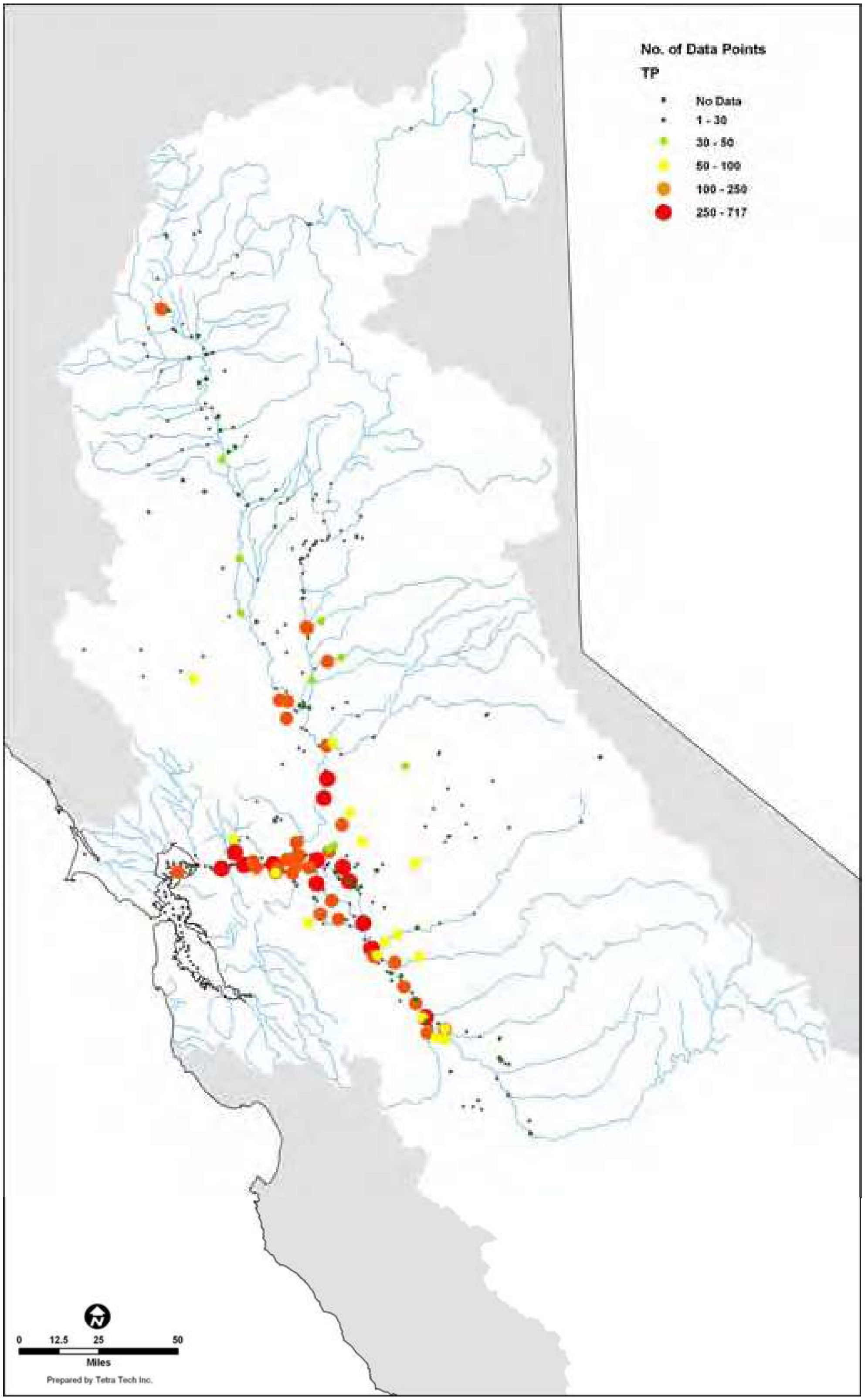


Figure 3-8. Number of TP data points at each station in the Central Valley and Delta.

Appendix A contains a listing of all stations with nutrient data, including the number of data points for each parameter (NO3+NO2-N, ammonia-N, TKN, TN, orthophosphate-P and TP), and the period over which sampling was conducted. This listing can be used as a reference to identify the quantity of relevant data associated with specific stations in the database, particularly for future work to identify patterns at greater spatial detail than presented in this report. Review of Appendix A shows that stations with the largest number of data points are those on the main stem of the Sacramento and San Joaquin Rivers, especially at stations near the Delta. Some locations had measurements of only one of the constituents, and data for all parameters were available for a small number of stations. The table illustrates the relative lack of TN data. It was further noted that many stations appeared in the database under different, slightly varying names. For this table, such stations were merged with a set of consistent names. It was also noted during the course of this work that nutrient species names and units were widely variable. For quality assurance, it is recommended that for future sampling efforts, a consistent, standardized set of nutrient species are requested for analysis and reporting.

A series of box plots was used to describe the range and number of nutrient concentrations at various locations in the watershed. Data from wastewater effluent and from urban runoff were excluded from these plots (these are presented in Chapter 4). Figures 3-9 to 3-12 show the nitrogen species (NO3+NO2-N, ammonia-N, TKN, and TN, respectively) concentrations by station, and Figures 3-13 and 3-14 show the phosphorus species (orthophosphate-P and TP, respectively) concentrations by station. In each figure, the data are shown on both a linear scale plot and log scale plot. All stations are shown in alphabetic order.

Nutrient data from Delta island agricultural drains (see Figure 3-2) are available in the database for NO3-N only. These data are shown graphically in Figure 3-15. In general, the data show the same range of NO3-N values as seen for the stations on Figure 3-9.

Figures 3-16 to 3-21 show a spatial overview for each of the nutrient species. These figures illustrate that concentrations are typically higher in the San Joaquin River Basin than in the Sacramento River basin.

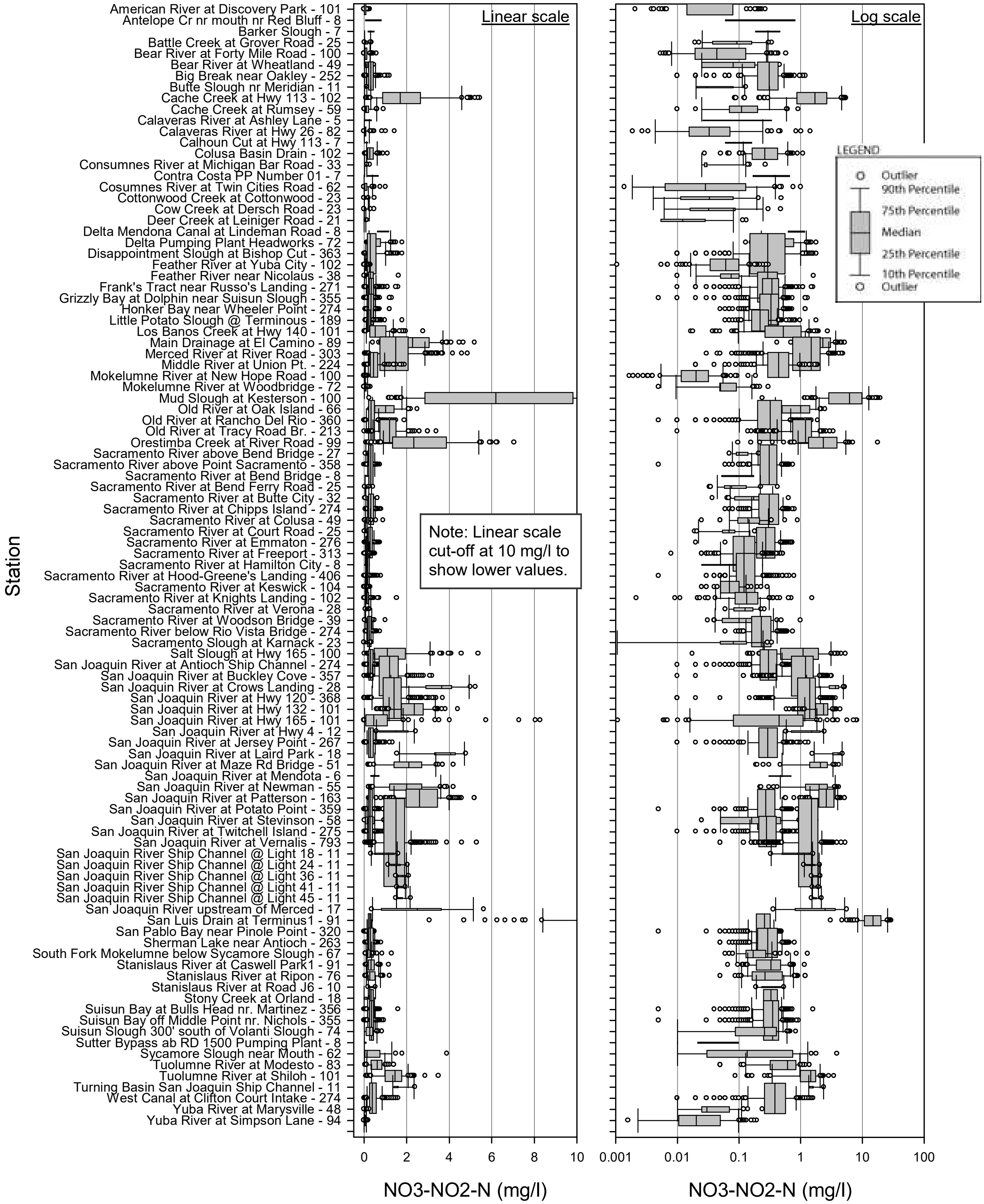


Figure 3-9. The range of NO3+NO2-N concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.

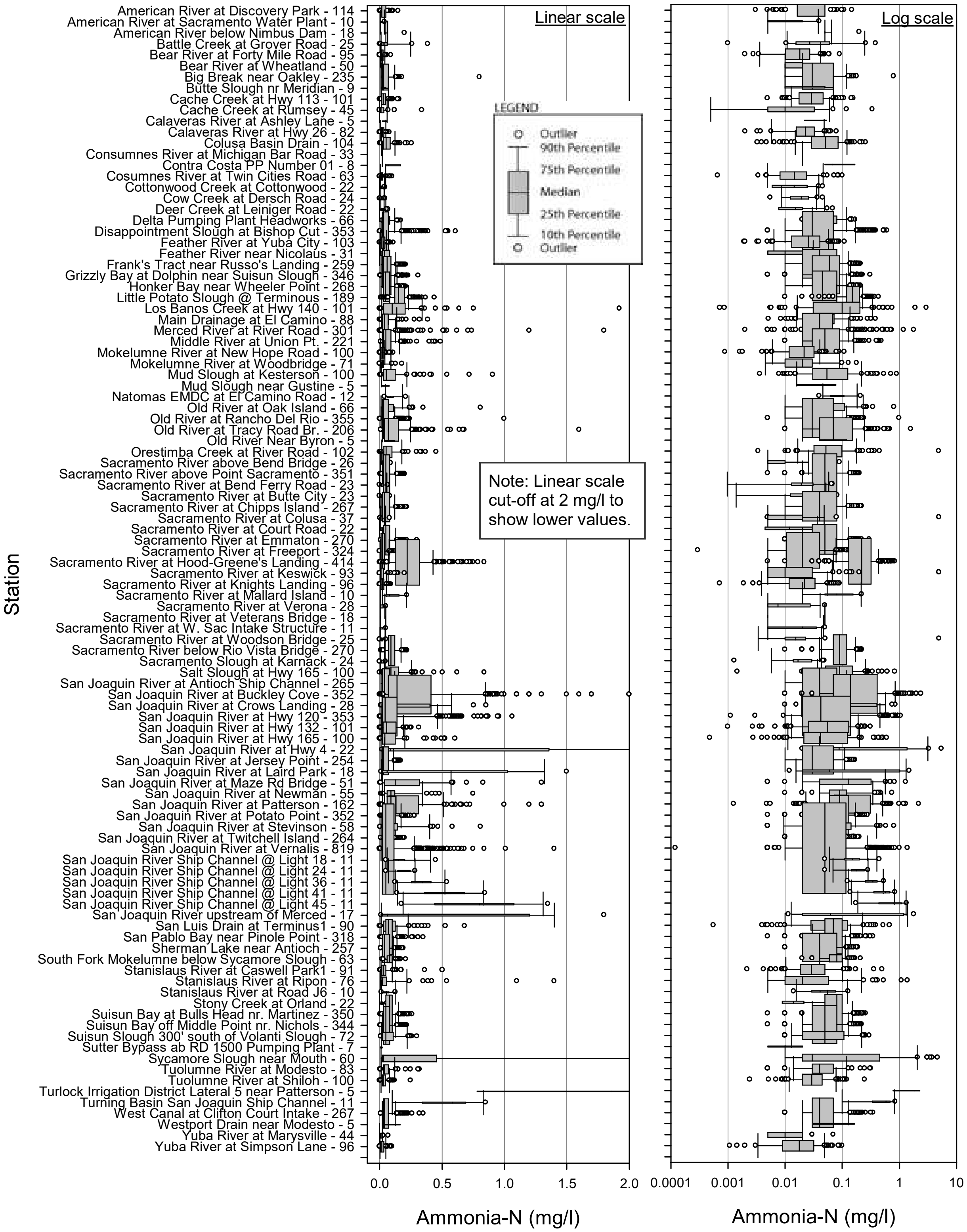
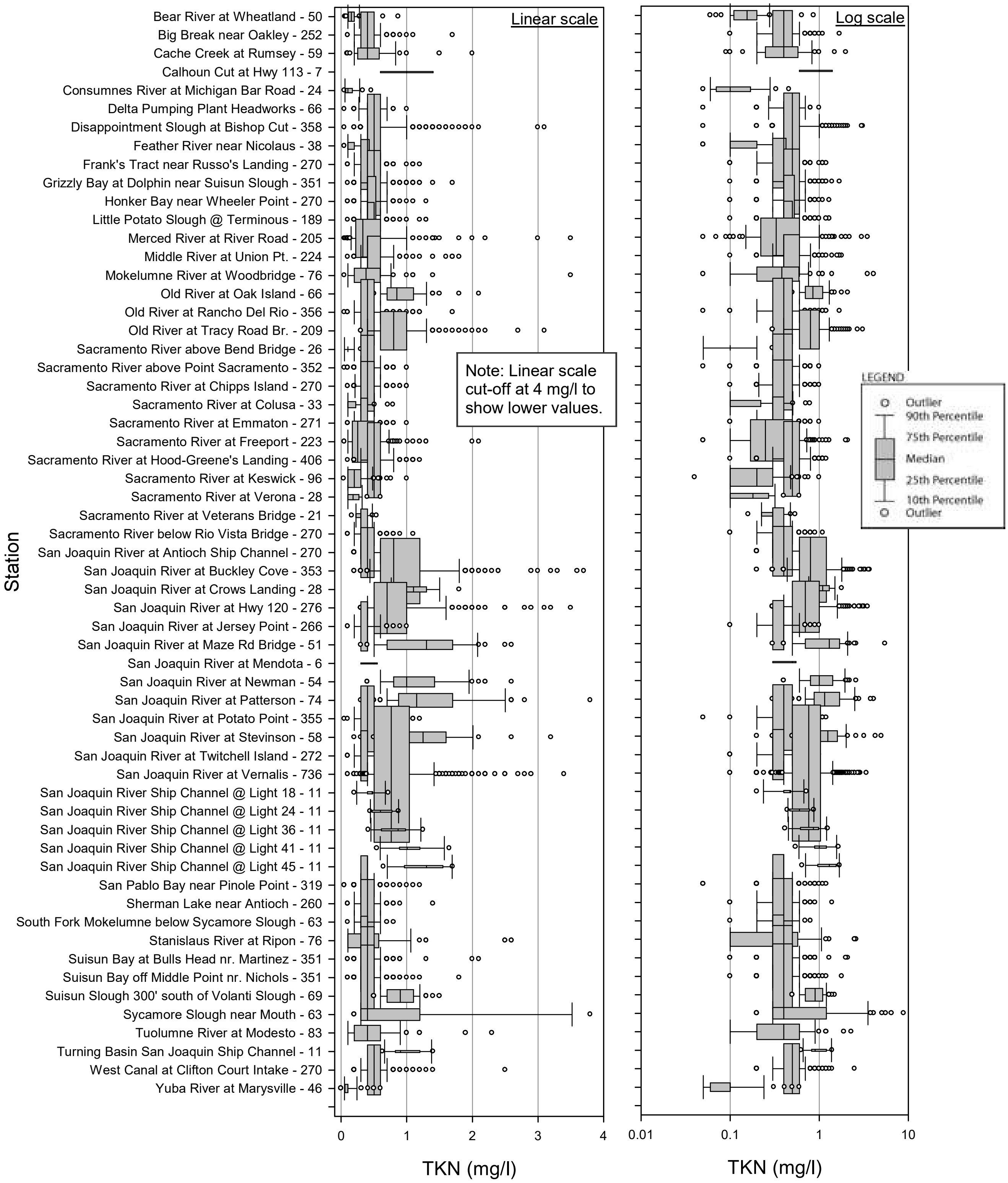


Figure 3-10. The range of Ammonia-N concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.



Note: Linear scale cut-off at 4 mg/l to show lower values.

Figure 3-11. The range of TKN concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.

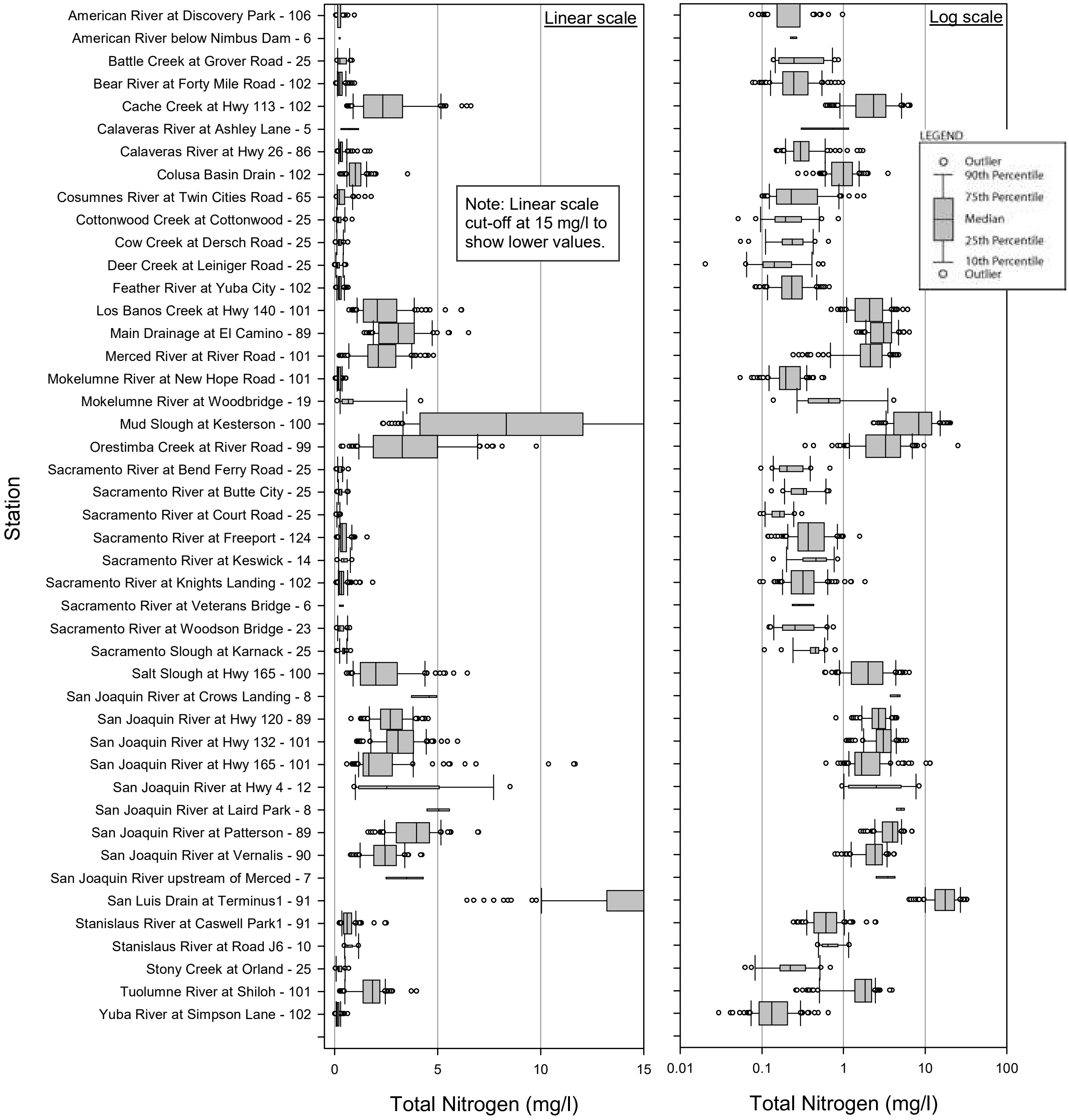


Figure 3-12. The range of TN concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.

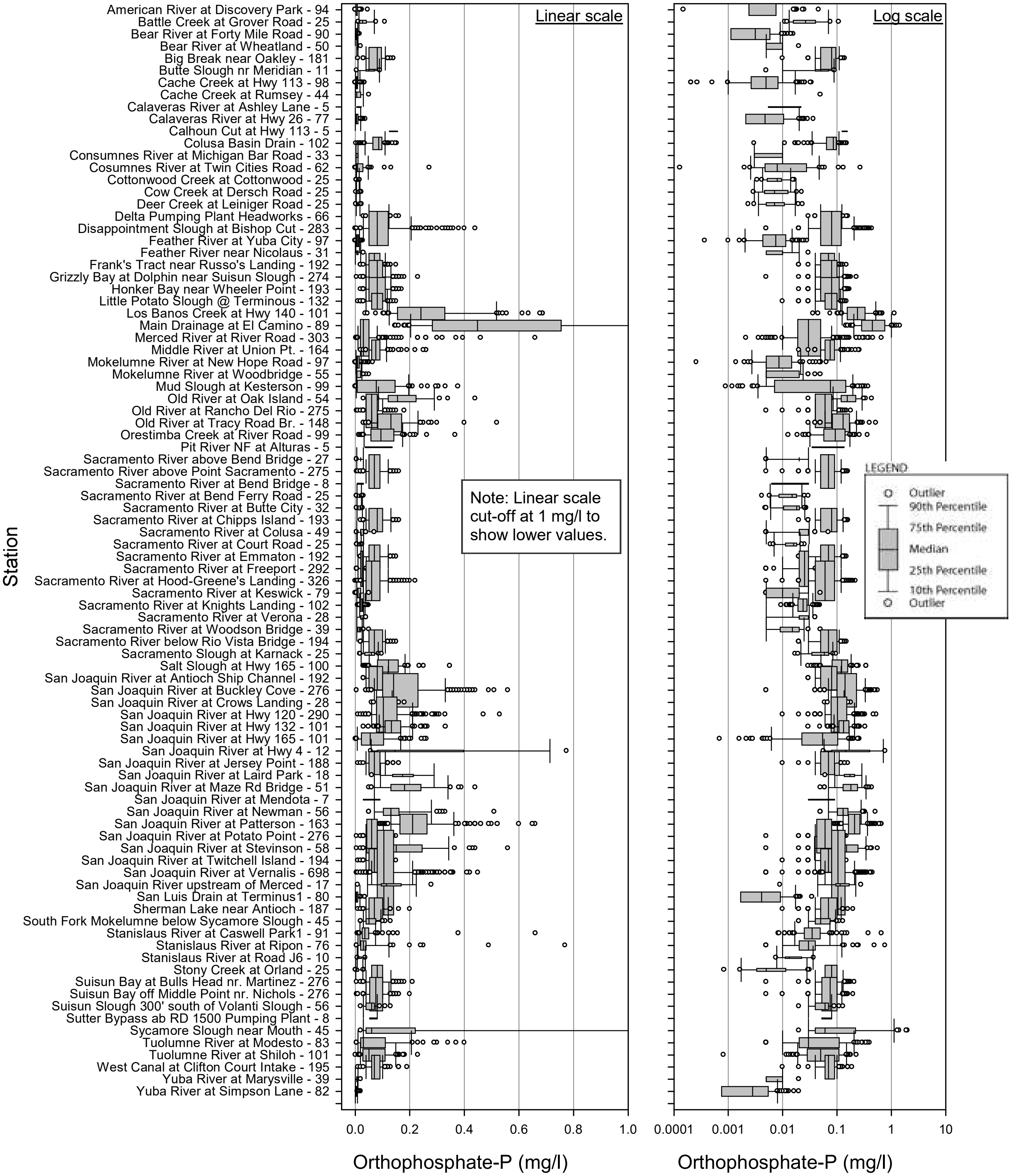


Figure 3-13. The range of Orthophosphate-P concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.

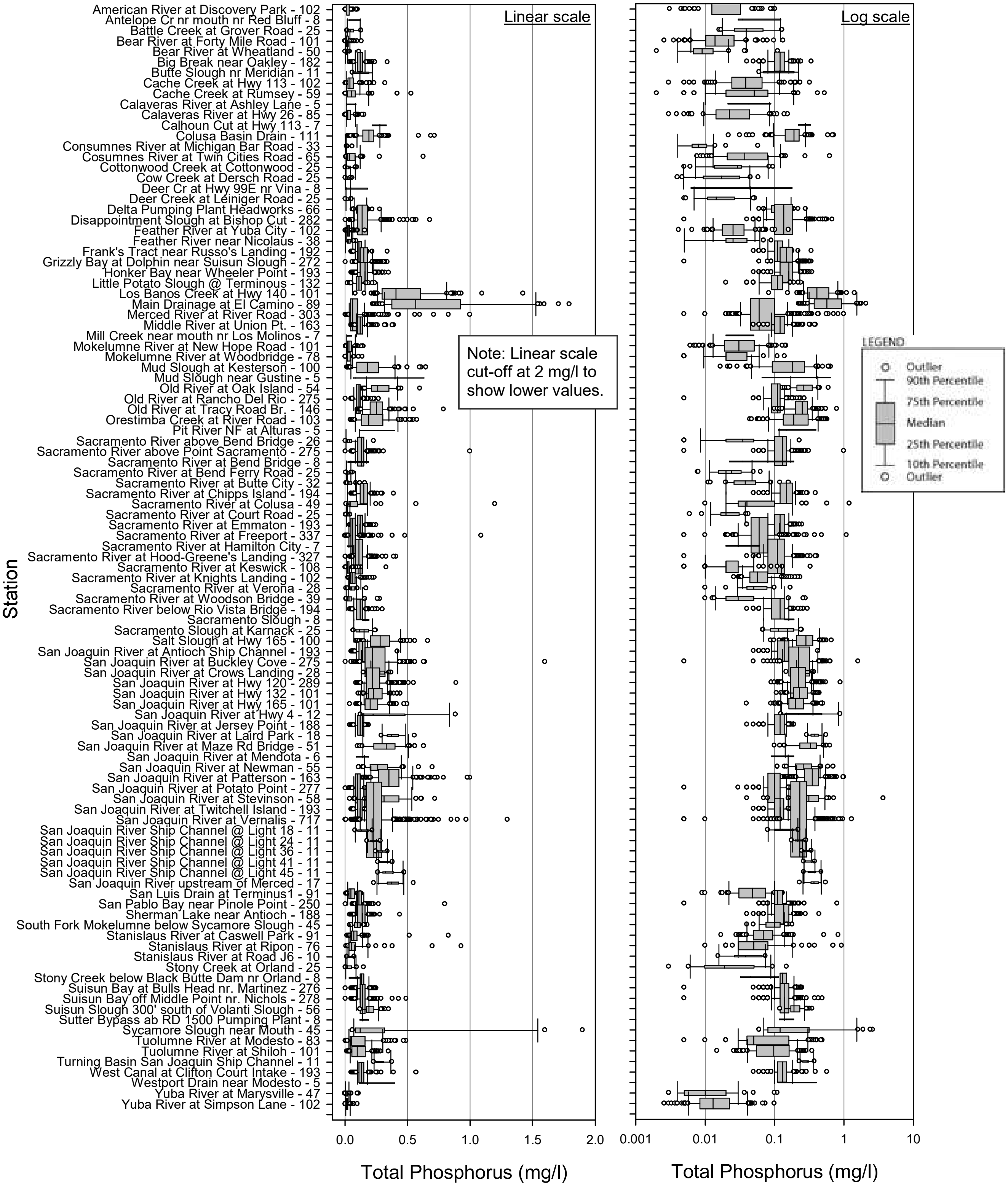


Figure 3-14. The range of TP concentrations observed at different stations in the Central Valley and Delta. Box widths are proportional to the number of data points, shown next to station name.

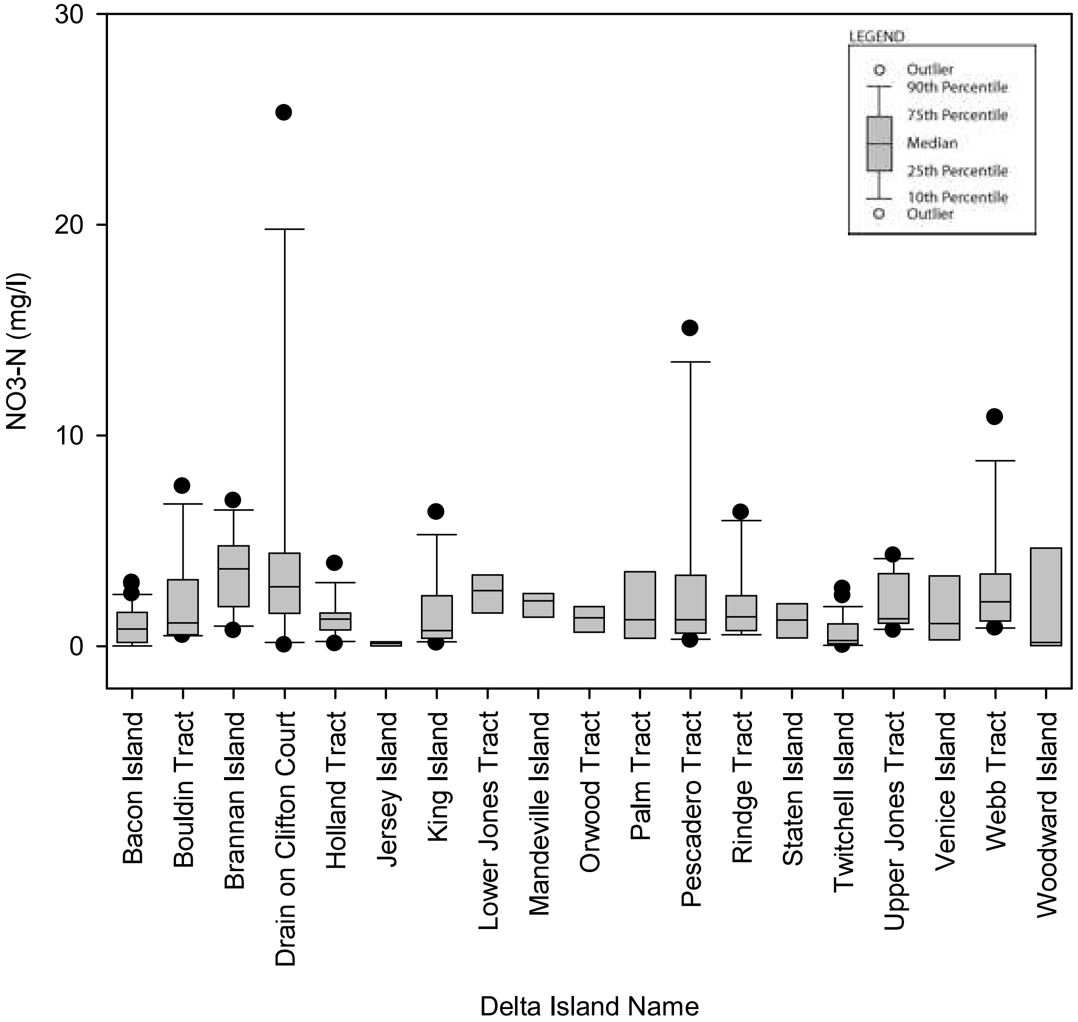


Figure 3-15. The range of NO3-N concentrations observed in Delta island agricultural drains.

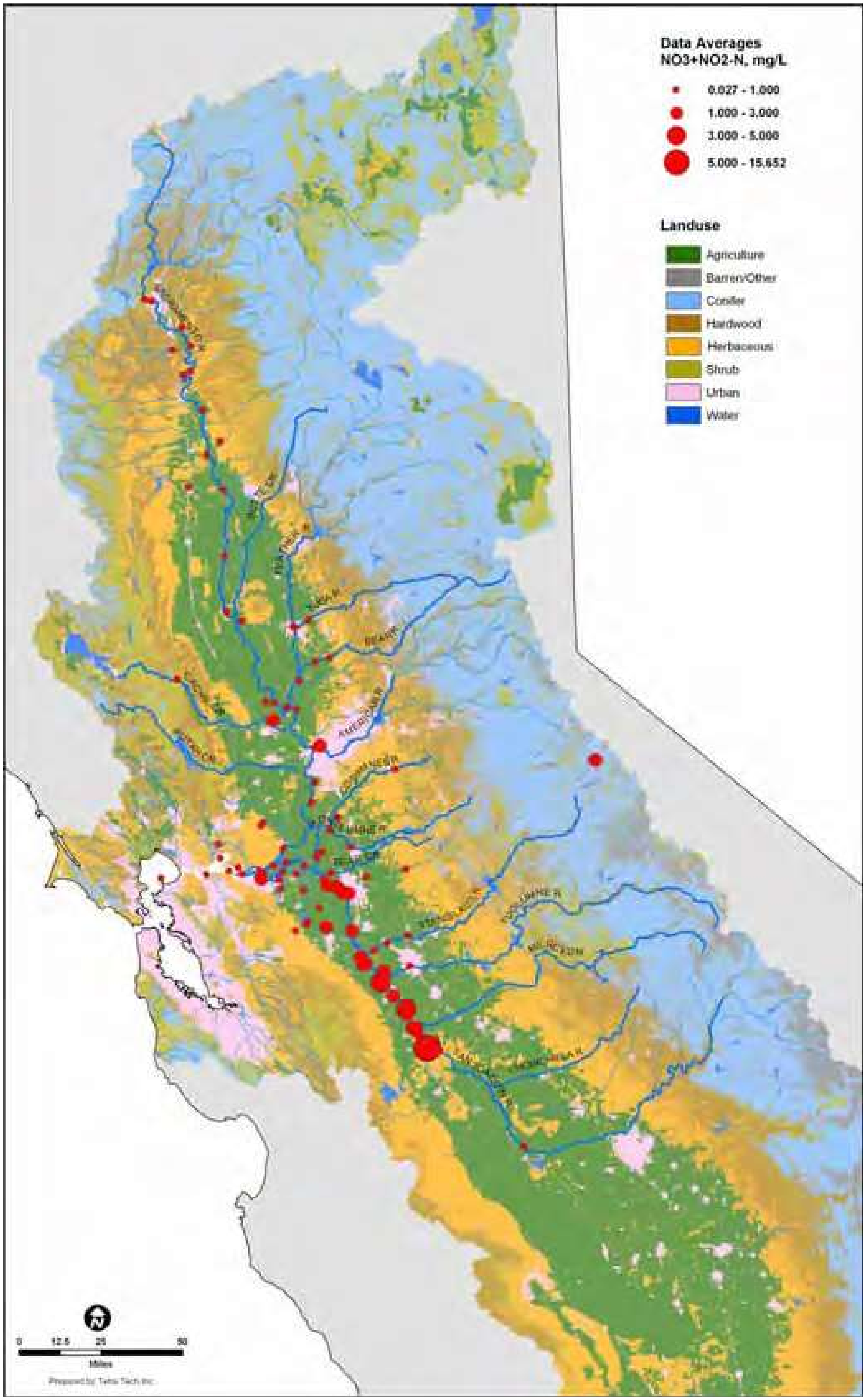


Figure 3-16. NO3+NO2-N concentrations in the Central Valley and Delta.

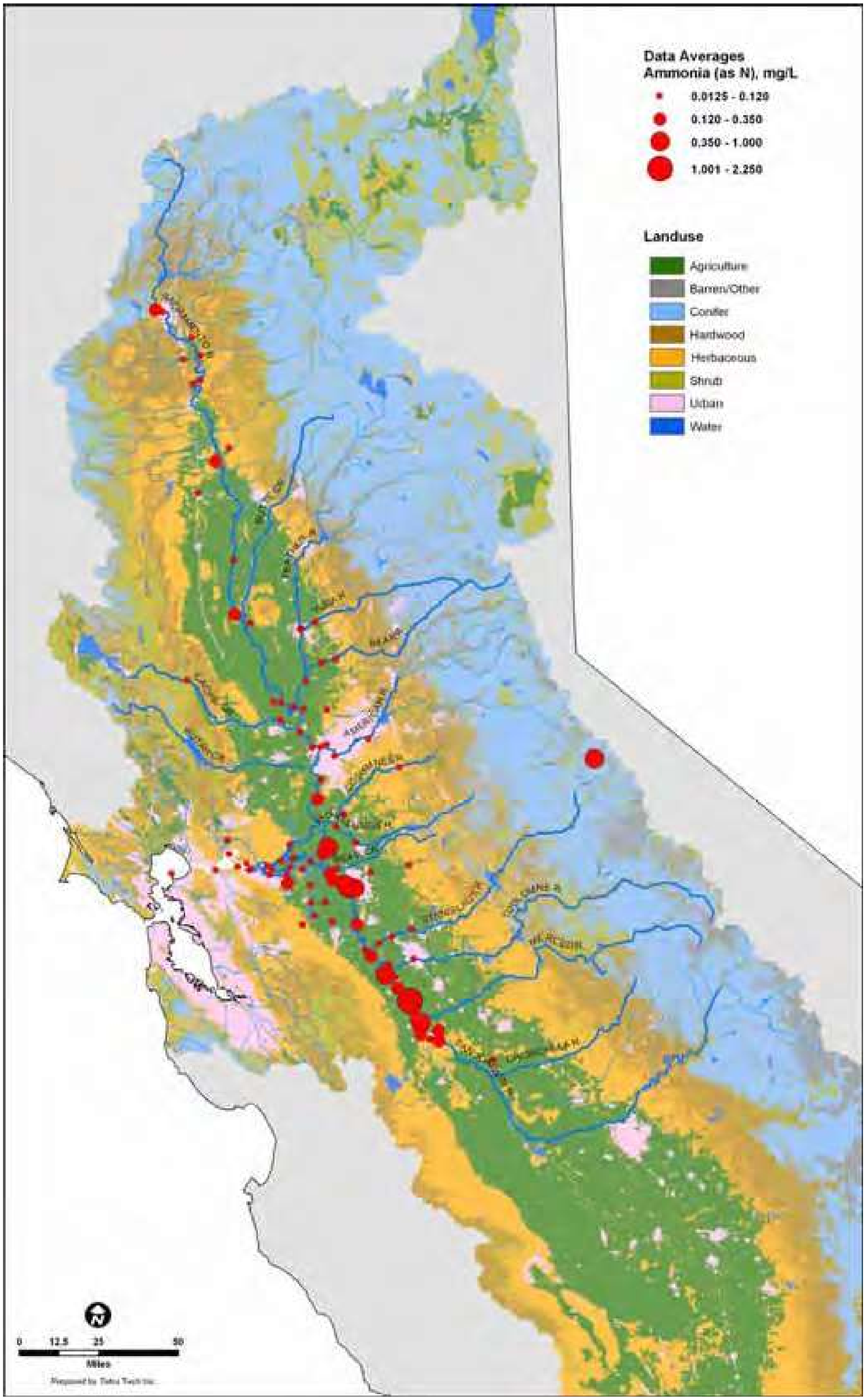


Figure 3-17. Ammonia-N concentrations in the Central Valley and Delta.

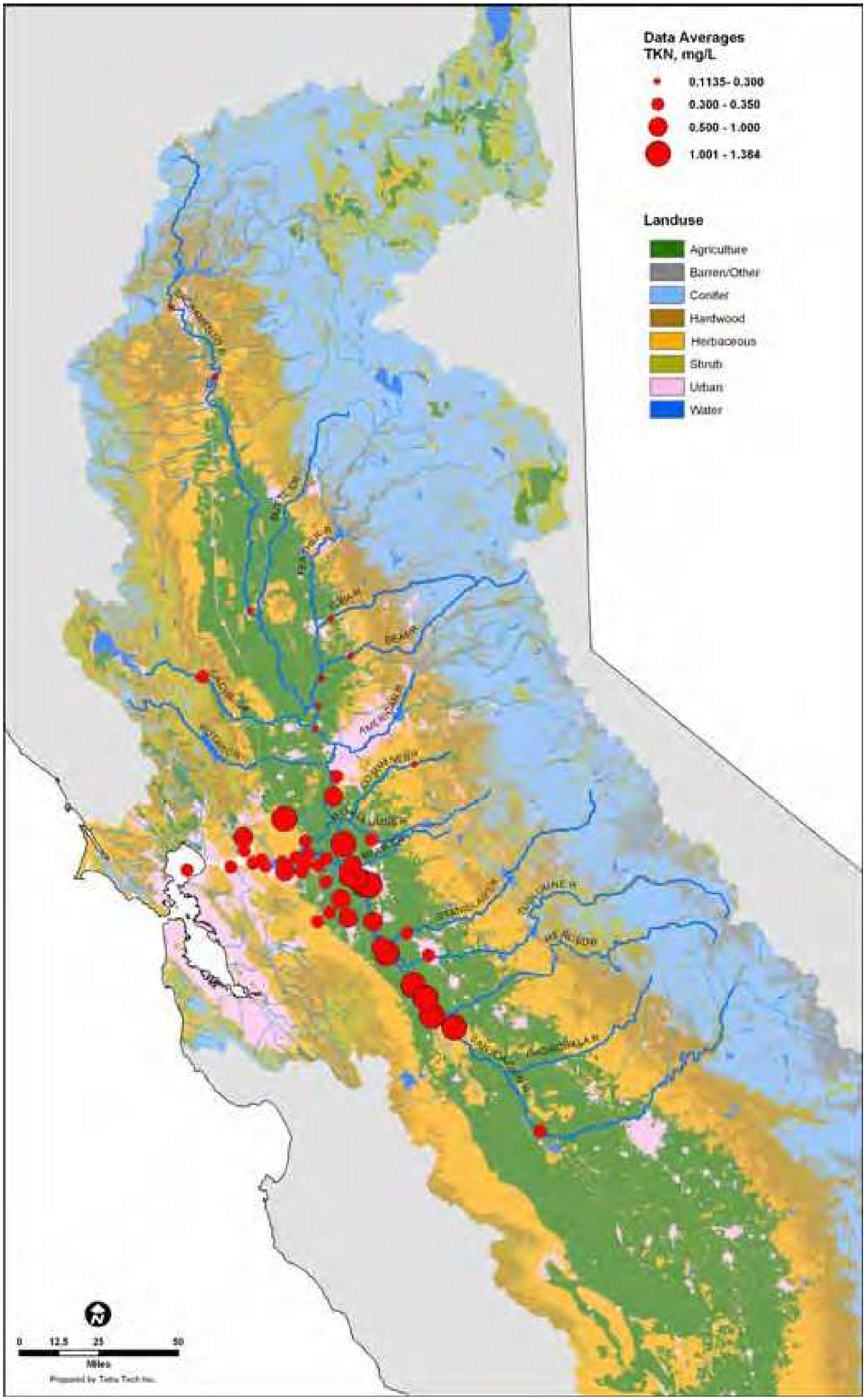


Figure 3-18. TKN concentrations in the Central Valley and Delta.

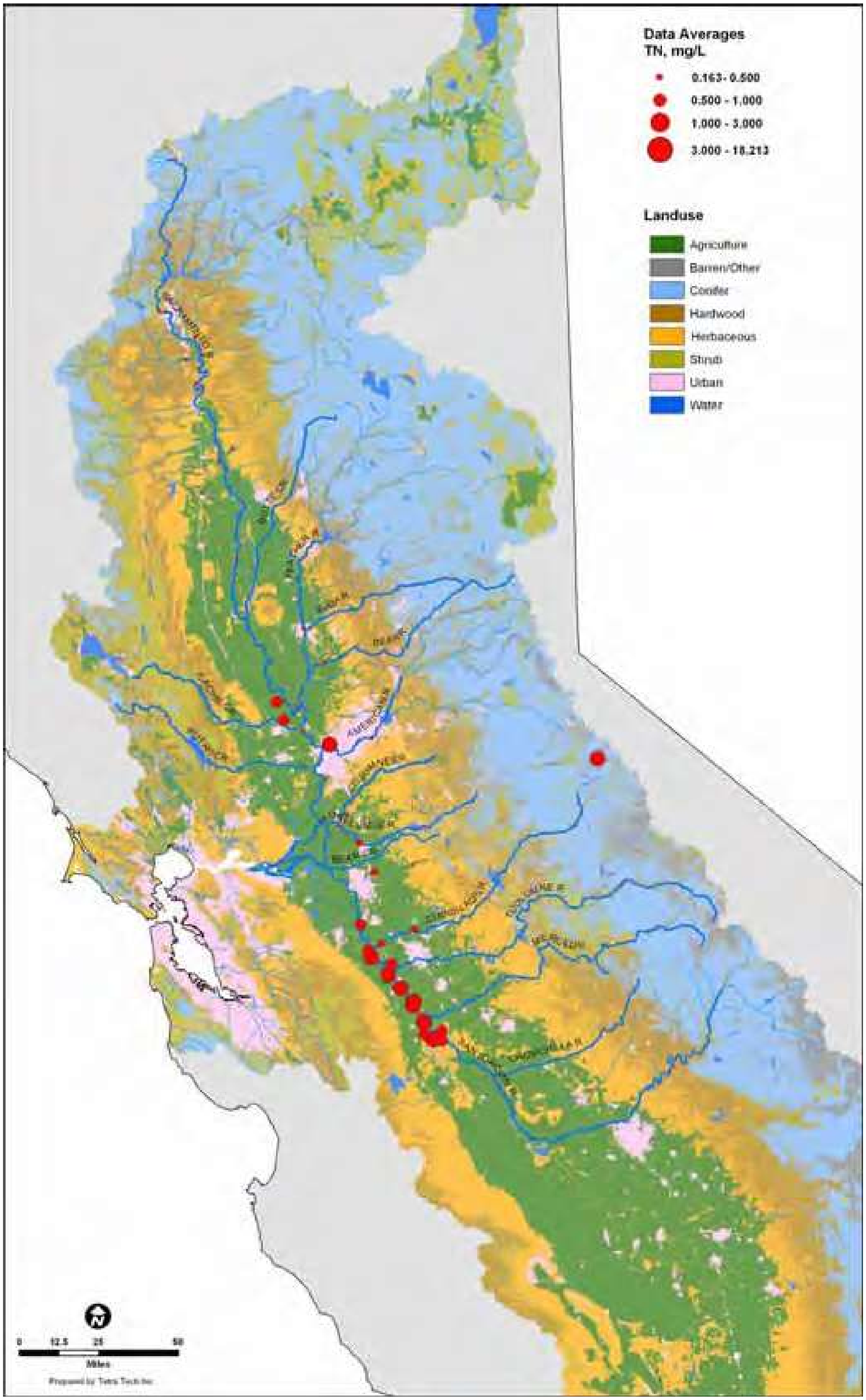


Figure 3-19. TN concentrations in the Central Valley and Delta.

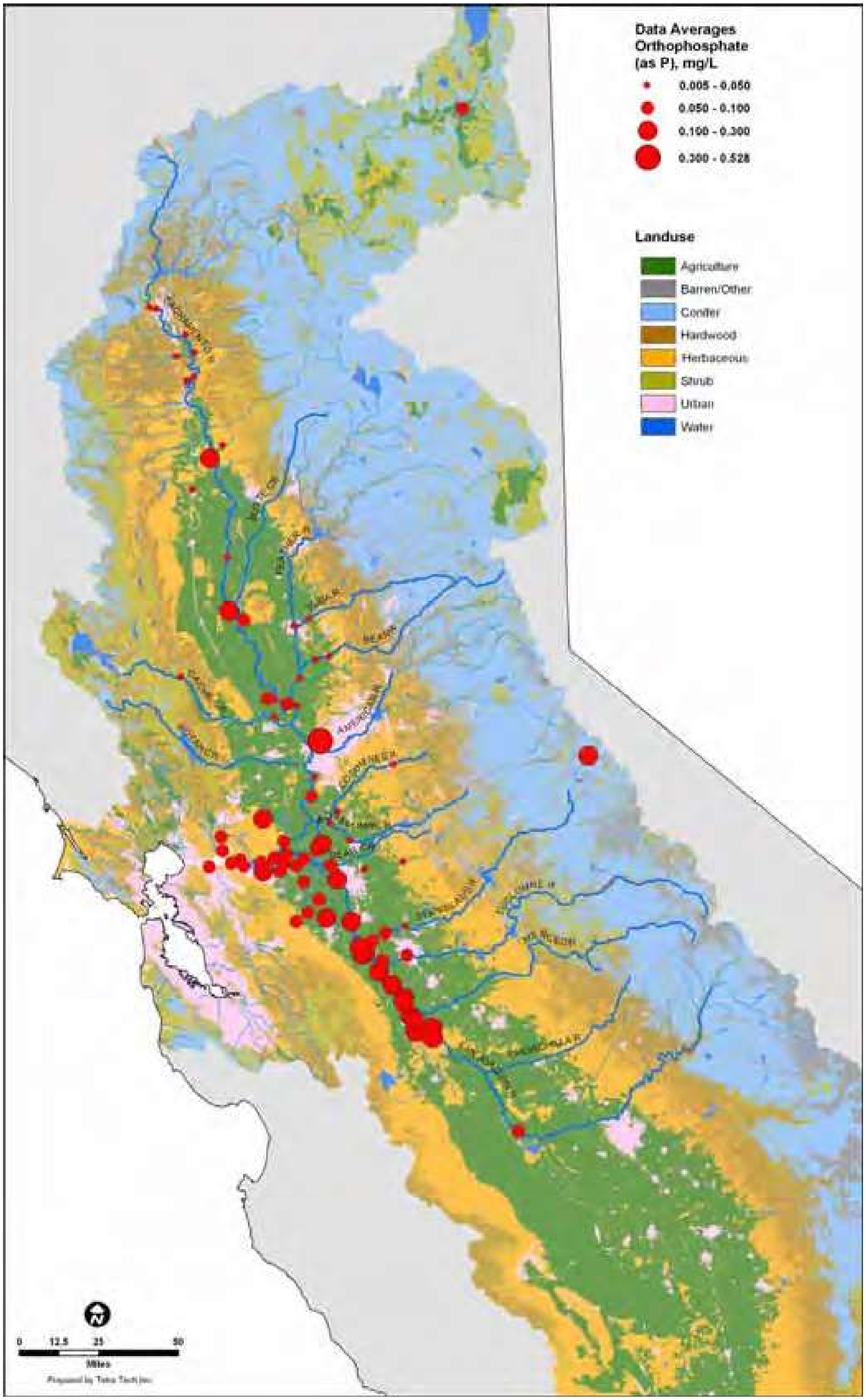


Figure 3-20. Orthophosphate-P concentrations in the Central Valley and Delta.

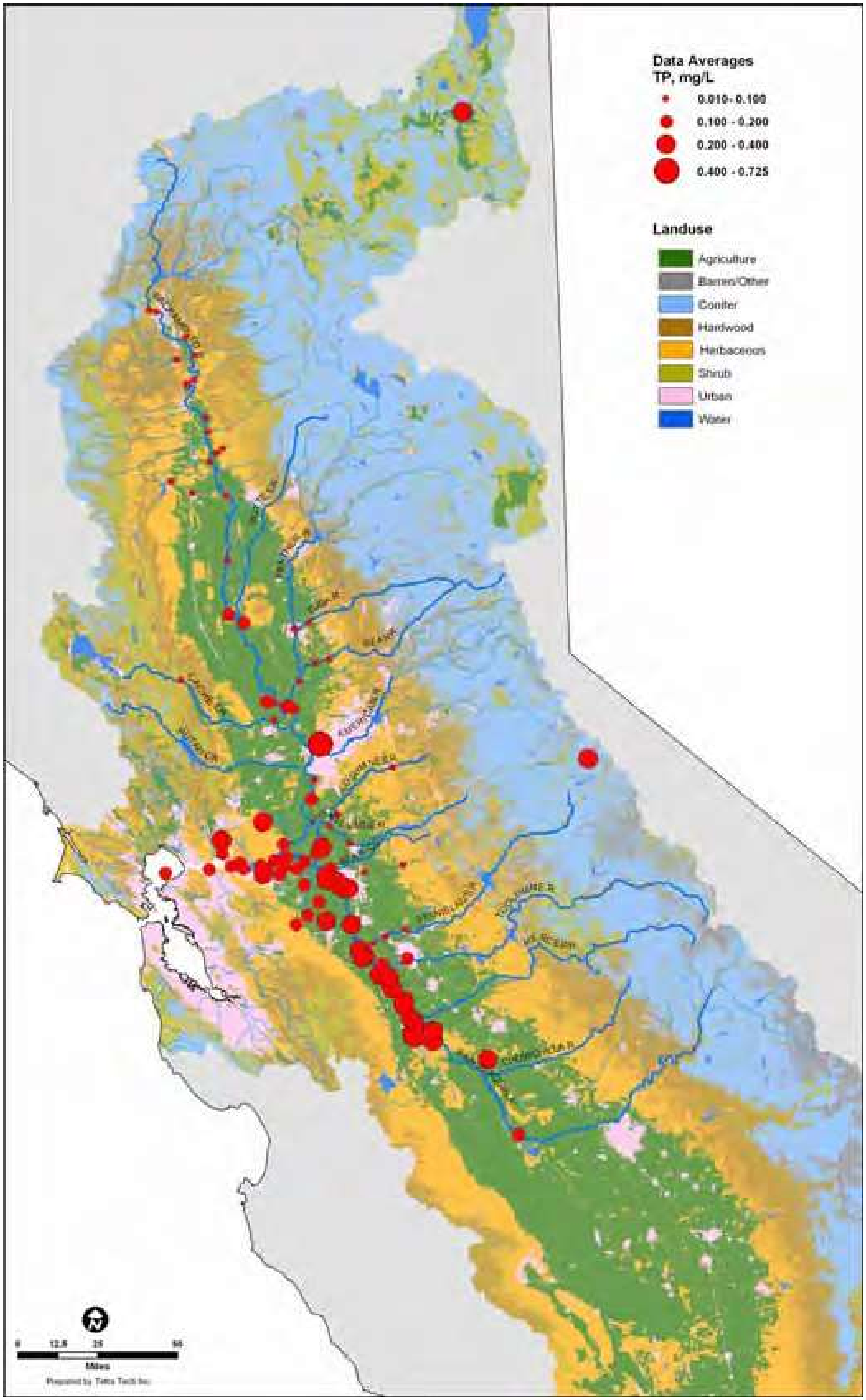


Figure 3-21. TP concentrations in the Central Valley and Delta.

Figures 3-22 and 3-23 illustrate the ratios of NO3-N and ammonia-N, respectively, to TN where simultaneous measurements were available. Figure 3-22 shows that NO3-N represents a large portion of TN over the range of data. Figure 3-23 illustrates that ammonia-N represents a much smaller portion of total nitrogen, though the ratio varies significantly. Figure 3-24 illustrates the ratio of orthophosphate-P to TP where contemporaneous measurements were available. Here the ratio of orthophosphate-P to TP varies even more significantly, from a very small fraction to a ratio of one (where orthophosphate equals TP).

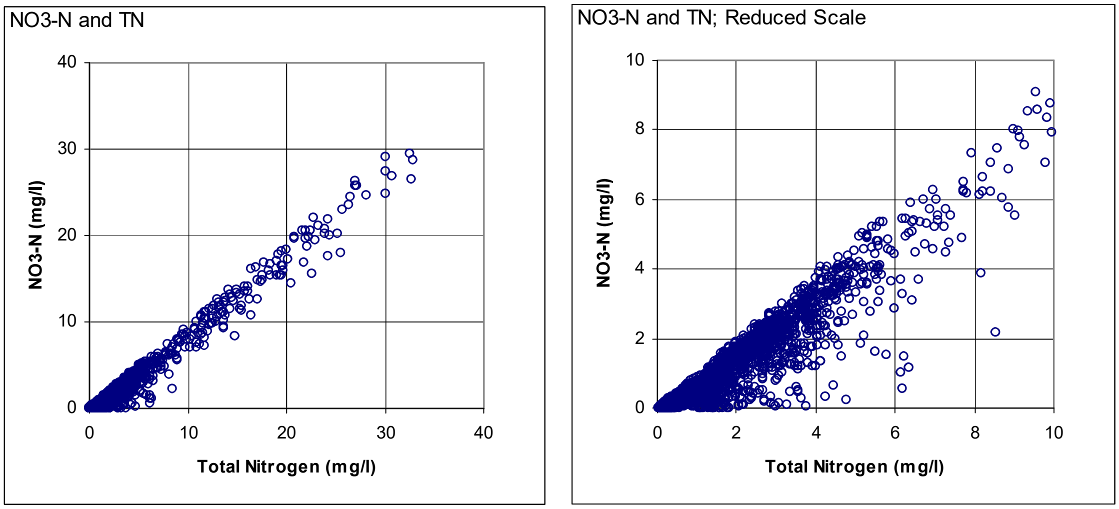


Figure 3-22. NO3-N and TN at all stations in the database where contemporaneous measurements were available.

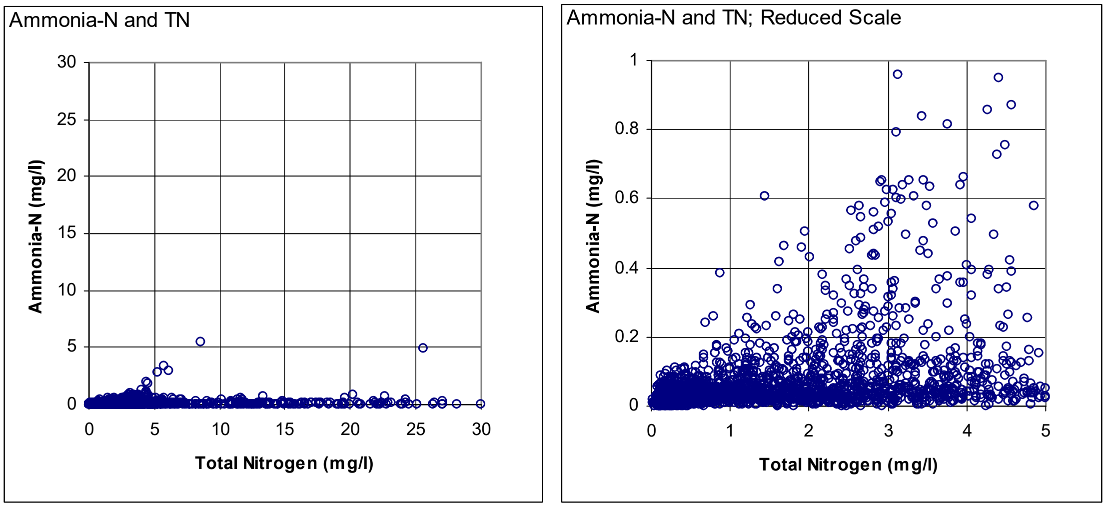


Figure 3-23. Ammonia-N and TN at all stations in the database where contemporaneous measurements were available.

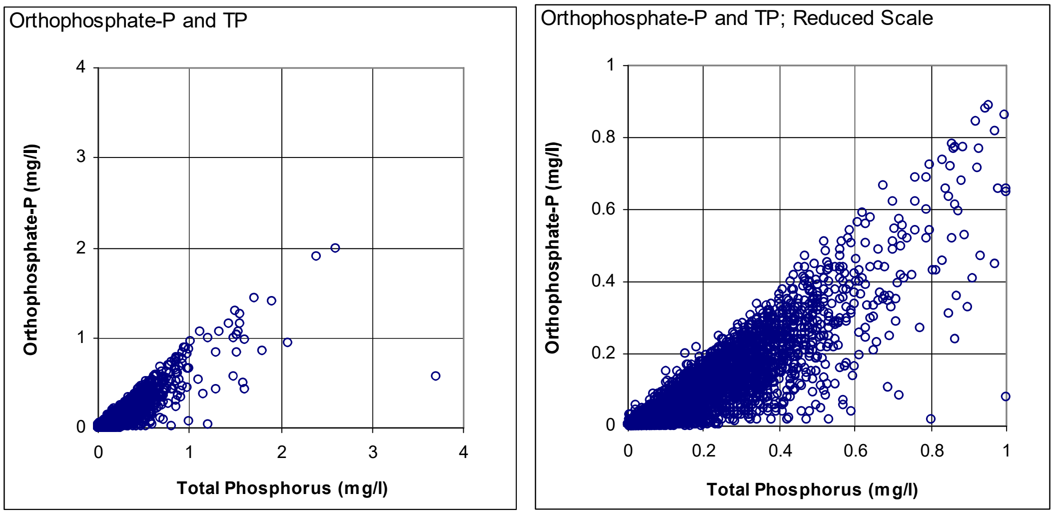


Figure 3-24. Orthophosphate-P and TP at all stations in the database where contemporaneous measurements were available.

Trends along the main stem of the two major rivers were examined through box plots. Figures 3-25 to 3-27 show the NO3+NO2-N, TKN, and TP concentrations, respectively, by station moving upstream to downstream for the Sacramento and San Joaquin Rivers. An interesting and contrasting pattern emerges. Sacramento River (Figures 3-25a, 3-26a, and 3-27a) concentrations for all three species increase with flow downstream, though the pattern is less dominant for TKN. TP is notable for its very low concentrations at the upstream stations that become much higher downstream due to the influences of agriculture, urban runoff, and wastewater sources. San Joaquin River concentrations for NO3+NO2-N (Figure 3-25b) first increase then decrease downstream of Crows Landing. Immediately downstream of Sack Dam, the river is dominated by agricultural drainage which is diluted by flows from other sources with lower concentrations as the river flows downstream, principally the tributaries on the east side of the valley. For TKN and TP (Figures 3-26b and 3-27b), trends are not pronounced in the main stem of the San Joaquin River but dilution is evident in the Delta itself. The upstream concentrations start out high compared to the Sacramento upstream stations due to the influence of agriculture. As previously shown, these figures also illustrate that nutrient species concentrations are generally higher in the San Joaquin River Basin than in the Sacramento River Basin.

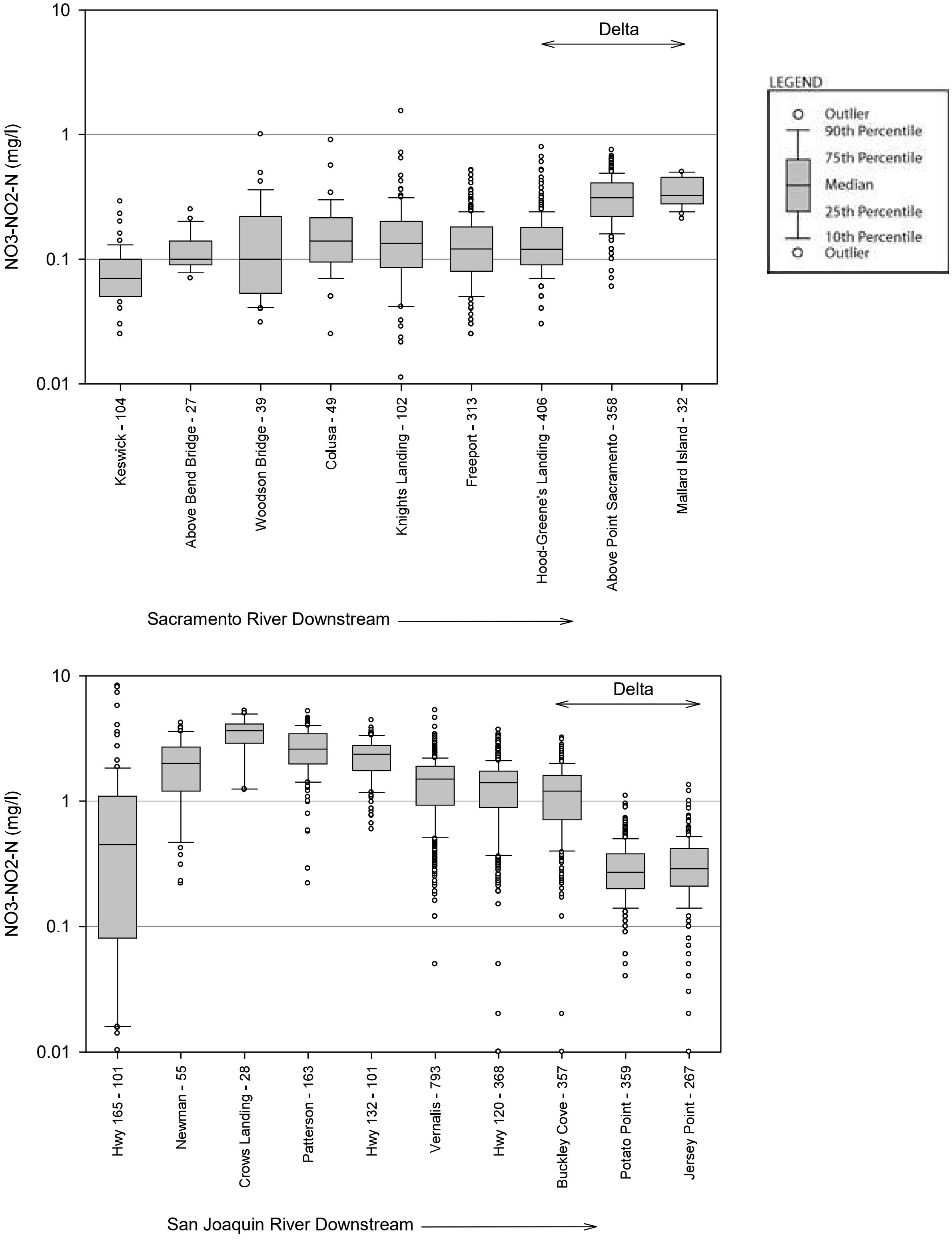


Figure 3-25. NO3+NO2-N at various locations in the Sacramento and San Joaquin Rivers. The number of data points is shown after each station name.

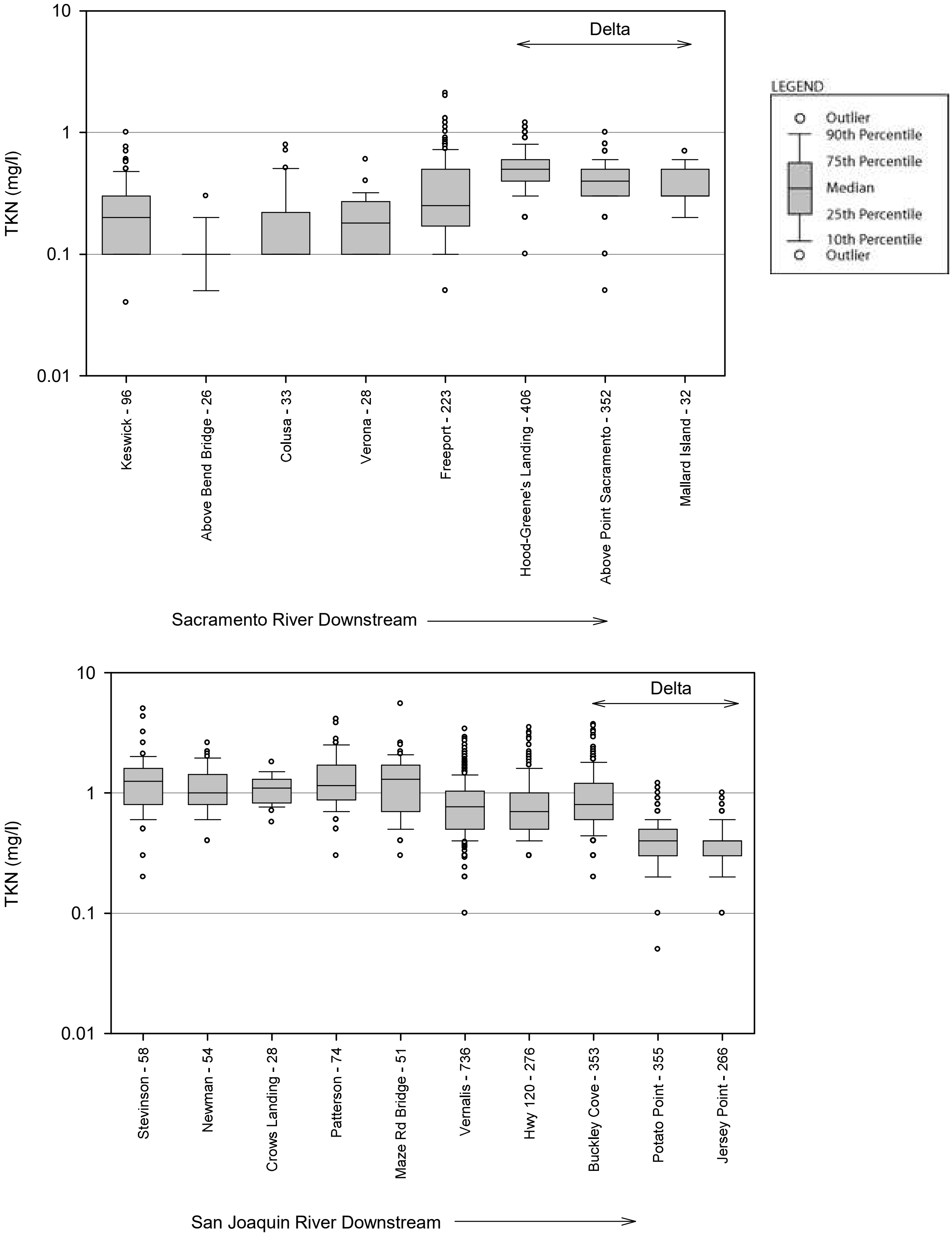


Figure 3-26. TKN at various locations in the Sacramento and San Joaquin Rivers. The number of data points is shown after each station name.

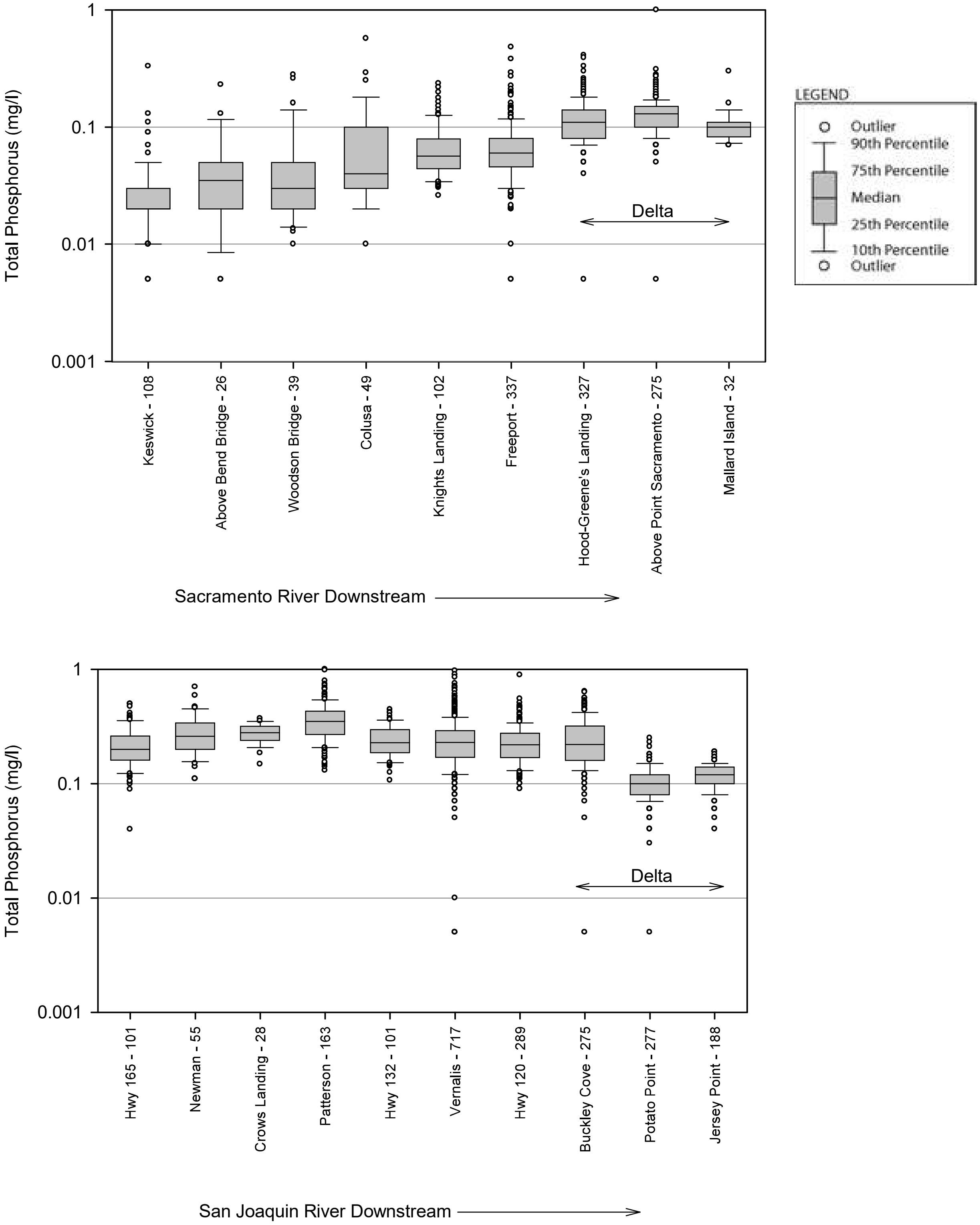


Figure 3-27. TP at various locations in the Sacramento and San Joaquin Rivers. The number of data points is shown after each station name.

Seasonal patterns in concentration can also be explored through box plots as shown in Figures 3-28 and 3-29 for TN and TP, respectively. In each of the figures, three plots display concentrations at locations moving downstream for each of the Sacramento and San Joaquin Rivers. In general, TN displays greater inter-seasonal variation for the Sacramento and San Joaquin Rivers than TP. In the Sacramento basin, the highest concentrations for TN occur in the wet months, and are as much as twice as high during the wet months compared to the dry months (Figure 3-28). In the San Joaquin River, although TN concentrations are much higher than in the Sacramento River, there appears to be less inter-seasonal variation, with the highest concentrations being observed during the months with significant return flows from irrigation. TP concentration values show minimal trends by month for either river, with little discernible influence due to wet weather flows or to irrigation return flows (Figure 3-29).

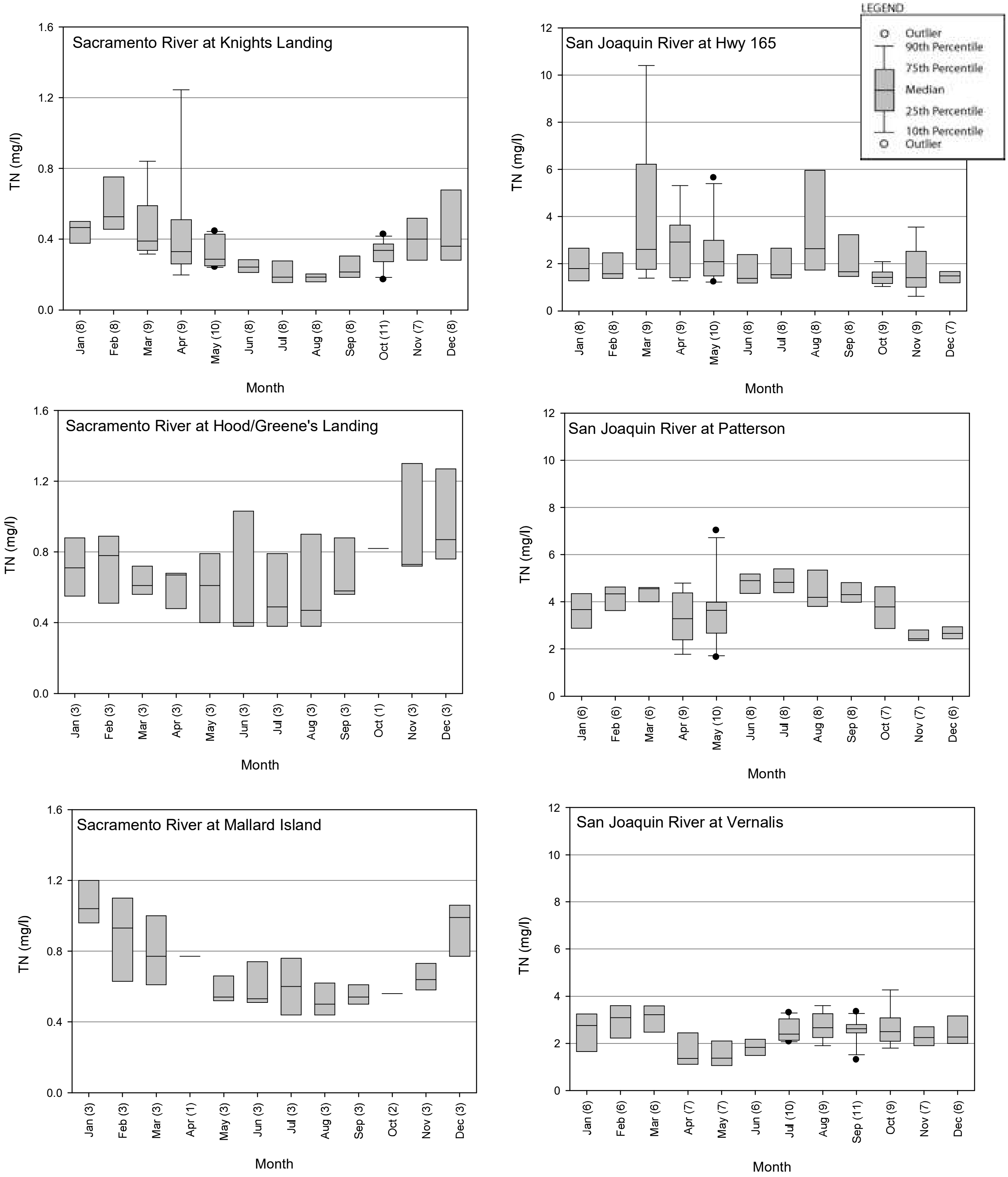


Figure 3-28. Temporal variation in TN concentrations at key locations in the Sacramento and San Joaquin Rivers. NO3+NO2-N and TKN are summed to obtain TN for Sacramento at Hood/Greene's and Mallard Island. Note also that the scale of the data is consistent within each river but different between the two rivers. The number of data points is shown after each month.

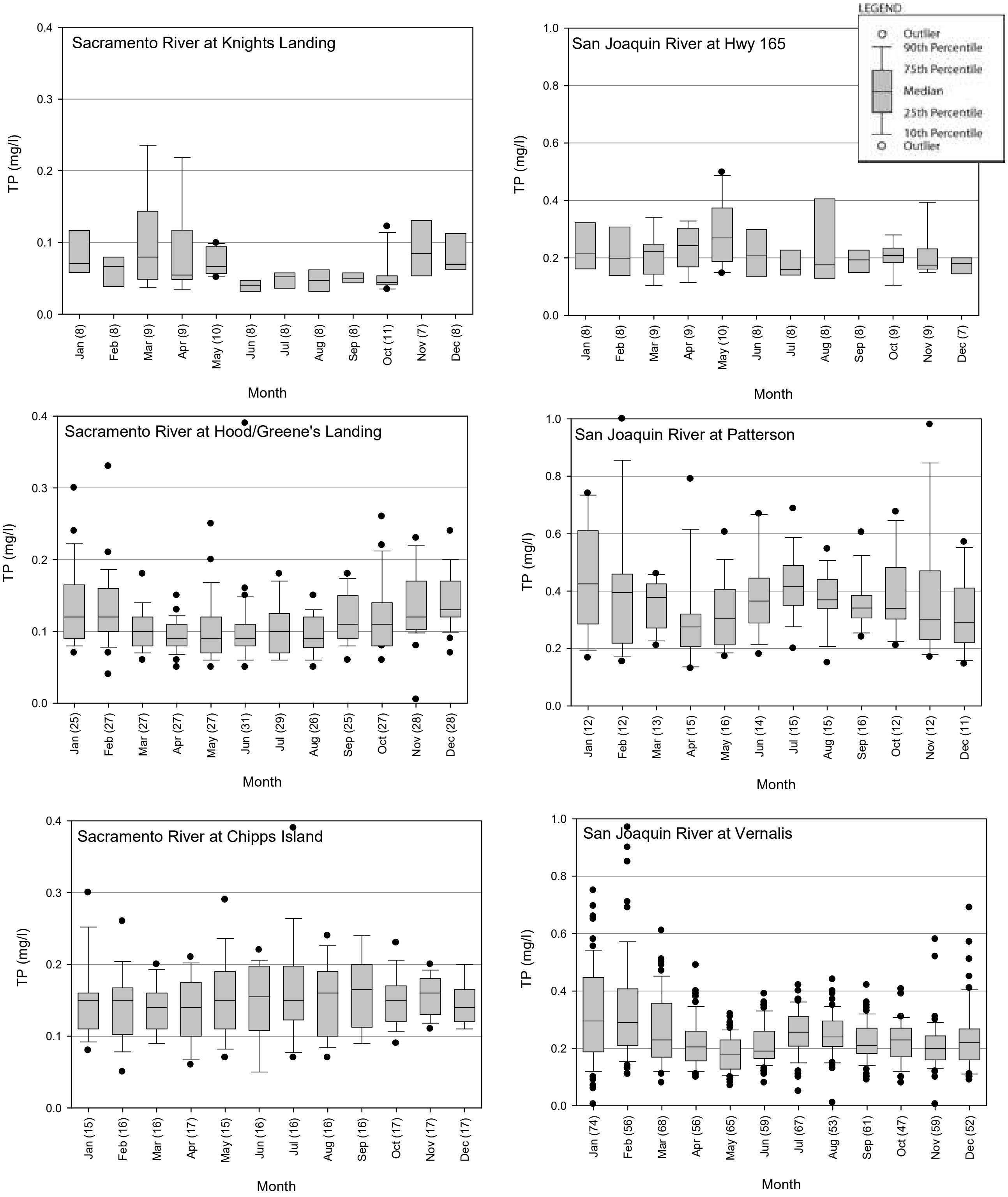


Figure 3-29. Temporal variation in TP concentrations at key locations in Sacramento and San Joaquin Rivers. Note that the scale of the data is consistent within each river but different between the two rivers. The number of data points is shown after each month.

3.2 FLOW DATA USED

In addition to the concentration data in the database discussed above, flow data are used in combination with concentration data to estimate loads. The USGS has an extensive network of flow monitoring stations throughout California (Figure 3-30). Daily stream discharge data were obtained from the USGS from http://nwis.waterdata.usgs.gov/usa/nwis/discharge at selected locations for which loads were estimated. These locations primarily corresponded to the outflow locations of the major tributaries of the Sacramento and San Joaquin Rivers. A detailed evaluation of the flow data is presented in Appendix B. Additional flow data for the Delta region (including outflows in municipal/industrial intakes) were obtained from a computer model called DAYFLOW (supported by California Department of Water Resources, and available electronically from http://www.iep.ca.gov/dayflow/index.html). Load estimates using the USGS and DAYFLOW data are presented in Chapters 4 and 5.

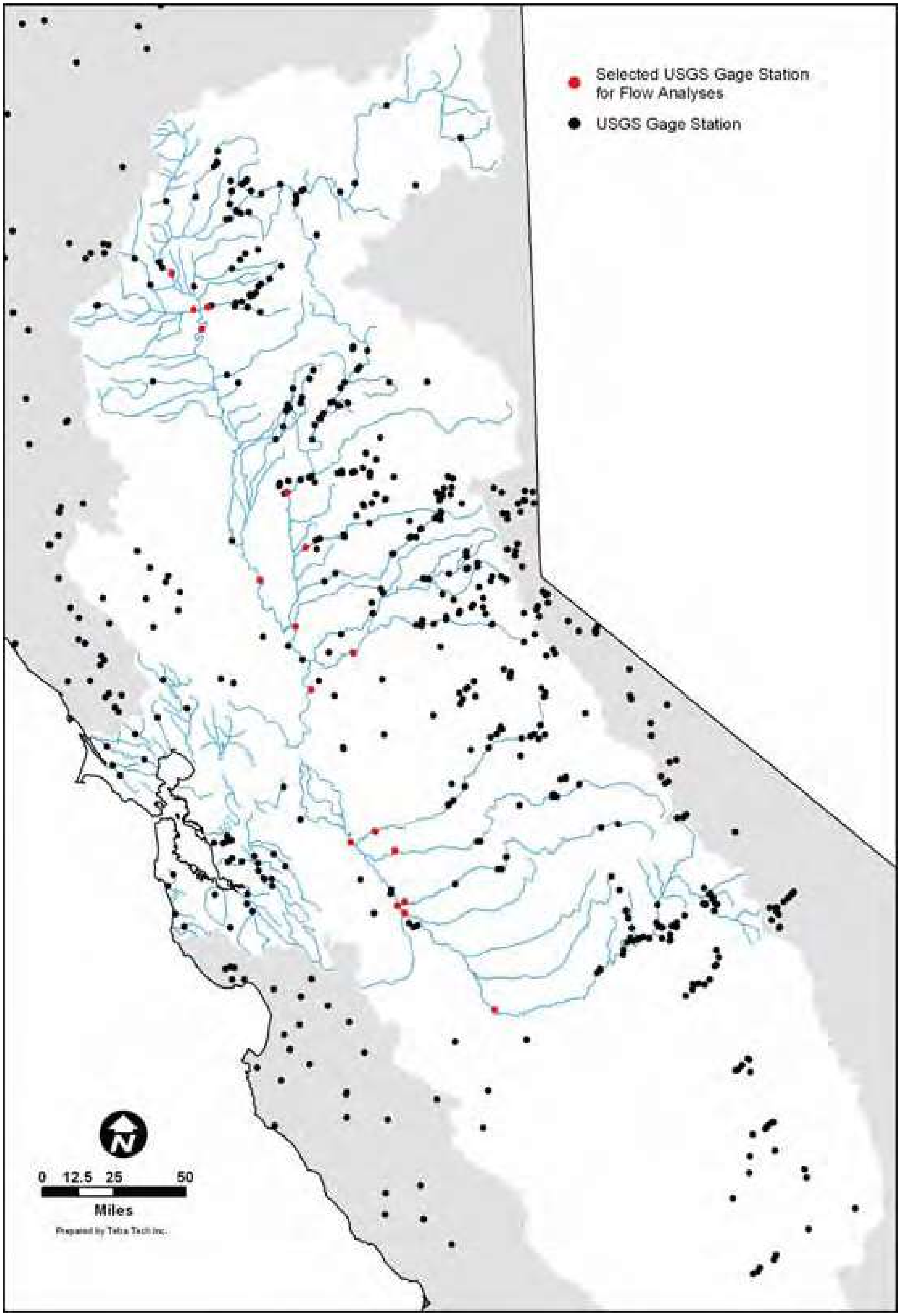


Figure 3-30. Stations with continuous flow records available through the USGS (on the internet at http://nwis.waterdata.usgs.gov/usa/nwis/discharge). Flow records for different stations exist over different time periods.

3.3 MAJOR FINDINGS

The nutrient data in the database, compiled by the Central Valley Drinking Water Policy Workgroup, consisted of measurements of NO3+NO2-N, ammonia-N, TKN, TN, orthophosphate-P and TP. Few stations reported all of these parameters. TN data were the most limited in number. Flow data were not part of the database and were obtained from other publicly available sources.

The greatest density of stations was near the Delta, with relatively limited sampling in the upper portions of the watershed. There was very little information on nutrient concentrations in reservoirs, although reservoirs and their upstream watersheds together comprise a large portion of the overall watershed area.

Box plots provided a quick summary of the available data, and showed clearly the elevated TN and TP concentrations in the San Joaquin River compared to the Sacramento River. Where nutrient species data are available, much of the nitrogen is present as NO3-N. Orthophosphate varies from a small percentage of total phosphorus to almost all of it. Data plotted by month at key locations in the Sacramento and San Joaquin Rivers show inter-seasonal variation for TN, but not for TP. The higher TN concentrations are observed during the wet months in the Sacramento River and in the dry months in the San Joaquin River.

CHAPTER 4.0
LOADS TRANSPORTED FROM SACRAMENTO AND SAN JOAQUIN RIVER BASINS

Estimation of transported loads of nutrients within the Central Valley provides a preliminary understanding of the major tributary sources during different seasons and during wet and dry years. The tributary sources mix with other Delta sources, and undergo various transformation reactions that are reflected in the observed concentrations at Delta drinking water intakes (further discussed in Chapter 5). The information on tributary nutrient concentrations and loads can be used to evaluate cost-effective options for reducing nutrient concentrations at the Delta intakes. Information on tributary nutrient loads at various locations in the Sacramento and San Joaquin basins can be used to evaluate options for improving nutrient concentrations at water intakes upstream of the Delta. This chapter presents the results of calculations to estimate loads at various locations in the Central Valley, using nutrient species concentration data summarized in Chapter 3, and using flow data from USGS stations near the concentration monitoring stations.

Evaluation of load at a point in a stream involves estimation of loads transported in-stream and also involves estimation of the watershed contributions. The basic approach to calculating loads at a point in a stream is simple: daily flow multiplied by concentration can provide an estimate of daily flux, which summed over a year or a season, provides an estimate of the transported load. In general, flow data are available in much greater abundance than chemical concentration data, and the common approach is to estimate concentrations for the days during which there are no measured concentration values. This is done by developing a correlation between flows and concentrations, and can include variables for time (Crawford, 1991; Cohn et al., 1992; Haggard et al., 2003; Saleh et al., 2003). Previous attempts to relate concentration data to flow data in the Central Valley and Delta showed little correlation between the two variables (Tetra Tech, 2006, Conceptual Model for

Organic Carbon in the Central Valley). One possible reason is that the Central Valley and Delta system is a highly managed system with flows controlled by major reservoirs on most rivers. Thus, the method used for this study was to multiply average monthly concentration data by average monthly flows to obtain monthly loads, which were then summed to obtain either seasonal or annual loads. As described later in this chapter, the amount of concentration data varied from location to location, so confidence in the load estimates also varies.

Additionally, a second set of analyses was performed to estimate watershed loads. The watershed corresponding to any location in a stream is typically comprised of many different land uses (e.g., forested land, urban land, agriculture, etc.) and a common approach to estimate the watershed load is to attribute a chemical export rate (measured in units of mass per unit area per unit time) for each type of land use (Boyer et al., 2000; Wetzel, 2001). The total load contribution from the watershed can be estimated as the contribution of the individual land uses weighted by their export rates. This general approach has been employed to develop a summary picture of nutrient loads in the Central Valley. As discussed later in this chapter, there were limited data on export rates from different land uses so these load estimates are considered preliminary in nature.

The following sections describe the division of the Central Valley into a set of smaller subwatersheds, a summary of water flows corresponding to this division, the estimation of transported loads in streams at key locations throughout the Central Valley, estimation of export rates from key land uses, and the comparison of watershed loads with stream transported loads.

4.1 SUBWATERSHEDS

The Central Valley was divided into 22 subwatersheds to represent the major tributaries and the major reaches of the Sacramento and San Joaquin Rivers (Figure 4-1). The subwatersheds were delineated based on the availability of flow and concentration data as well as natural watershed boundaries. The outflow points of these subwatersheds were used to compute loads. The division of the 43,300 square mile Central Valley region into these subwatersheds allows for an improved spatial resolution of the sources of loads to a scenario in which the Sacramento and San Joaquin Rivers were treated as single watersheds. Although a finer resolution is possible, i.e., by consideration of still smaller tributaries and smaller subwatersheds, the existing division shown in Figure 4-1 was considered appropriate for a conceptual model, and was the smallest scale supported by available data. The watershed delineations shown in Figure 4-1 were performed using Geographic Information System (GIS) software (ArcGIS 8, ESRI, Redlands, California).

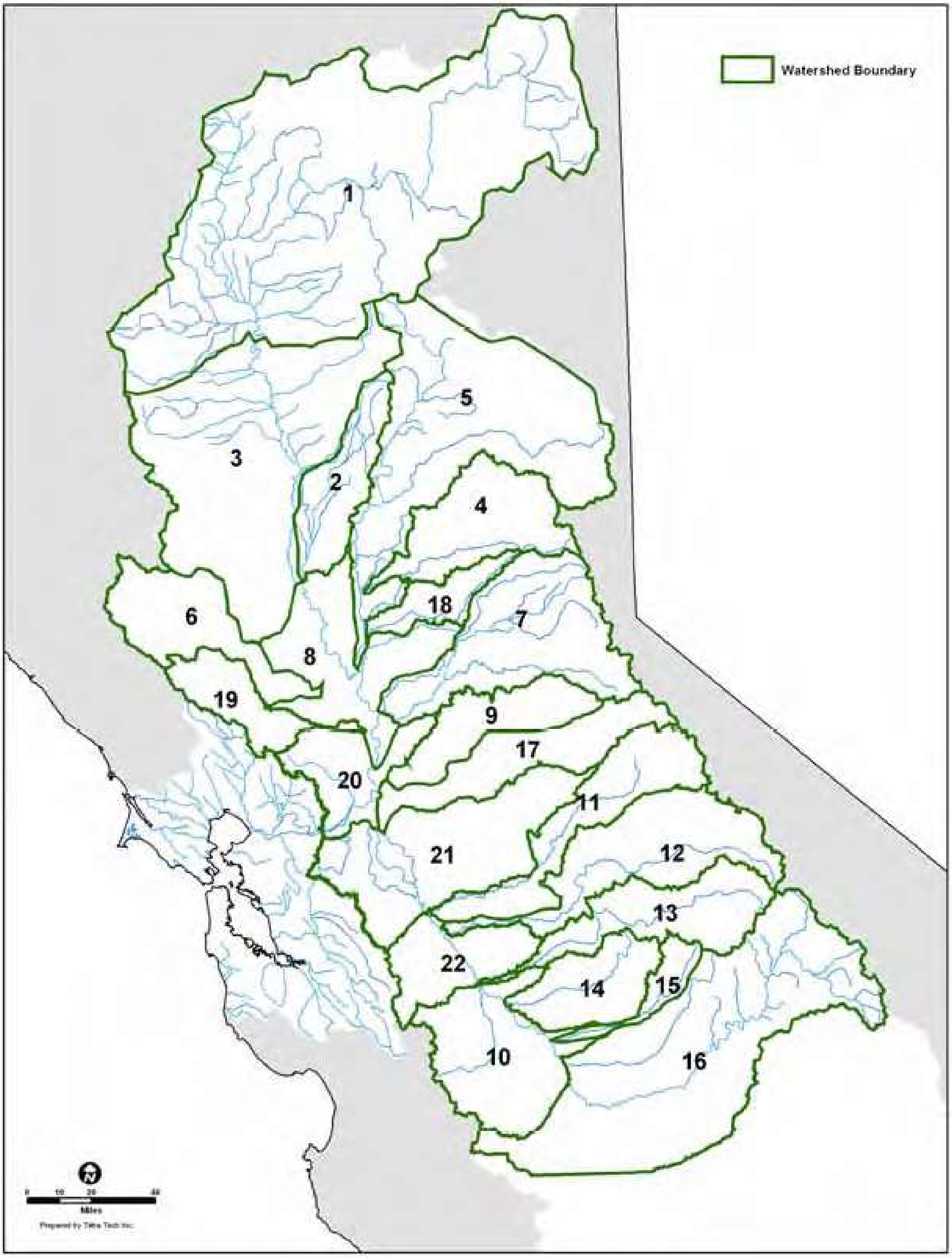


Figure 4-1. Sub-watersheds associated with principal tributaries.

Another approach to the watershed delineation would be to consider only the portion of the Central Valley below the reservoirs, and consider the reservoirs as defining the boundary of the region of interest. This approach has the benefit of implicitly defining reservoir loads as a background source, with other added downstream loads considered to be anthropogenic. However, because there are limited data on the concentrations of nutrients released from the reservoirs, this approach was not used in this study. The discussion of loads that follows in this chapter is thus based on the watersheds in Figure 4-1, although future refinements to this conceptual model could consider the reservoirs to be upstream boundaries to the system.

The land use corresponding to each subwatershed was estimated using a detailed GIS-based year-2002 land use map of California (obtained from http://gis.ca.gov/). The land use map was developed by the California Department of Forestry and Fire Protection Fire and Resource Assessment Program (CDF FRAP) by compiling the best available land cover data into a single data layer. Typically the most current and detailed data were collected for various regions of the state or for unique mapping efforts (farmland, wetlands, riparian vegetation). A view of the land uses in the Central Valley is shown in Figure 4-2. The percent of each subwatershed area by land use is summarized in Table 4-1.

Figures 4-3 and 4-4 illustrate schematics of the Central Valley watershed showing average TN and average TP concentrations, respectively, whose magnitude is indicated by arrow size. On these and subsequent arrow diagrams in this chapter, arrow widths are presented on a continuous scale, examples of which are presented in the legend. Thus, an arrow width between two widths in the legend signifies a data value between the two legend data values. Where data are not available for TN or TP, substitute constituents, such as NO3+NO2-N for TN, are shown as indicated on the figures. As discussed in Chapter 3, the figure illustrates that nutrient concentrations are higher in the San Joaquin River Basin than in the Sacramento River Basin.

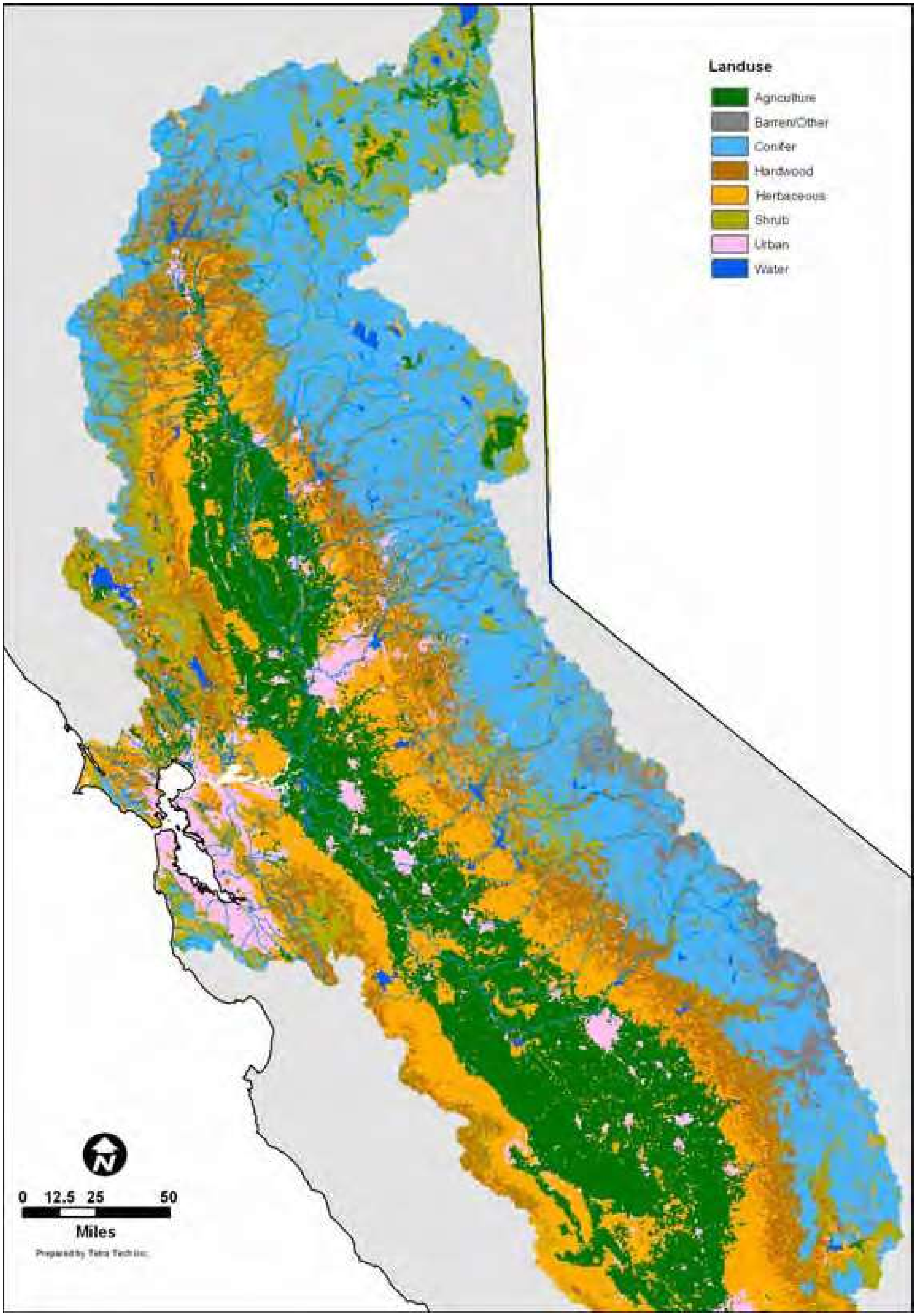


Figure 4-2. Land use in the Central Valley (2002). Data obtained from http://gis.ca.gov/.

Table 4-1.
Percentage of land use in different categories for each subwatershed. Land use data of California obtained from http://gis.ca.gov/.

ID[1]	Watershed Name	Shrub	Agriculture	Herbaceous	Hardwood	Barren	Conifer	Water	Urban
1	Sacramento River above Bend Bridge	22.4%	4.0%	4.8%	15.4%	1.1%	49.8%	1.5%	1.0%
2	Butte Creek	3.2%	41.1%	16.4%	12.3%	0.2%	21.7%	1.6%	3.5%
3	Sacramento River at Colusa	12.4%	23.1%	28.0%	19.2%	0.5%	14.2%	0.9%	1.7%
4	Yuba River	5.7%	1.3%	3.4%	16.1%	3.4%	67.1%	1.8%	1.2%
5	Feather River	9.8%	9.1%	6.3%	7.8%	0.6%	61.9%	2.8%	1.7%
6	Cache Creek	35.0%	11.4%	10.3%	24.1%	0.4%	10.5%	6.0%	2.3%
7	American River	8.3%	0.8%	5.7%	15.1%	3.1%	54.4%	2.0%	10.6%
8	Sacramento River at Hood/Greene's Landing	0.7%	63.7%	17.5%	8.1%	0.0%	0.2%	1.1%	8.7%
9	Cosumnes River	4.0%	12.0%	29.5%	22.0%	0.1%	28.8%	0.5%	3.0%
10	San Joaquin River at Newman	1.6%	44.1%	42.6%	7.8%	0.0%	0.0%	2.3%	1.7%
11	Stanislaus River	8.6%	11.9%	14.5%	11.1%	6.7%	41.1%	2.4%	3.5%
12	Tuolumne River	10.3%	3.8%	11.5%	13.2%	10.2%	46.7%	2.5%	1.8%
13	Merced River	14.7%	6.7%	11.6%	15.2%	5.8%	44.6%	1.1%	0.4%
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	3.9%	31.5%	43.7%	16.5%	0.0%	0.5%	0.3%	3.7%
15	Chowchilla River	6.9%	16.6%	22.9%	42.7%	0.0%	9.6%	0.3%	1.0%
16	San Joaquin River at Sack Dam	2.9%	35.1%	17.9%	10.5%	6.2%	22.0%	1.2%	4.2%
17	Mokelumne River	5.9%	16.0%	15.3%	16.3%	3.5%	38.7%	2.2%	2.1%
18	Bear River	1.8%	13.6%	18.6%	33.0%	0.6%	26.1%	1.3%	4.9%
19	Putah Creek	30.0%	9.6%	13.2%	31.9%	0.2%	7.9%	5.1%	2.0%
20	Delta North	1.0%	58.0%	28.3%	2.2%	0.1%	0.0%	2.1%	8.3%
21	Delta South	3.9%	40.0%	29.6%	10.6%	0.1%	6.5%	1.9%	7.4%
22	San Joaquin River at Vernalis	9.6%	51.9%	21.9%	11.9%	0.0%	0.0%	0.1%	4.6%

[1] Refer to Figure 4-1 for the location of subwatersheds.

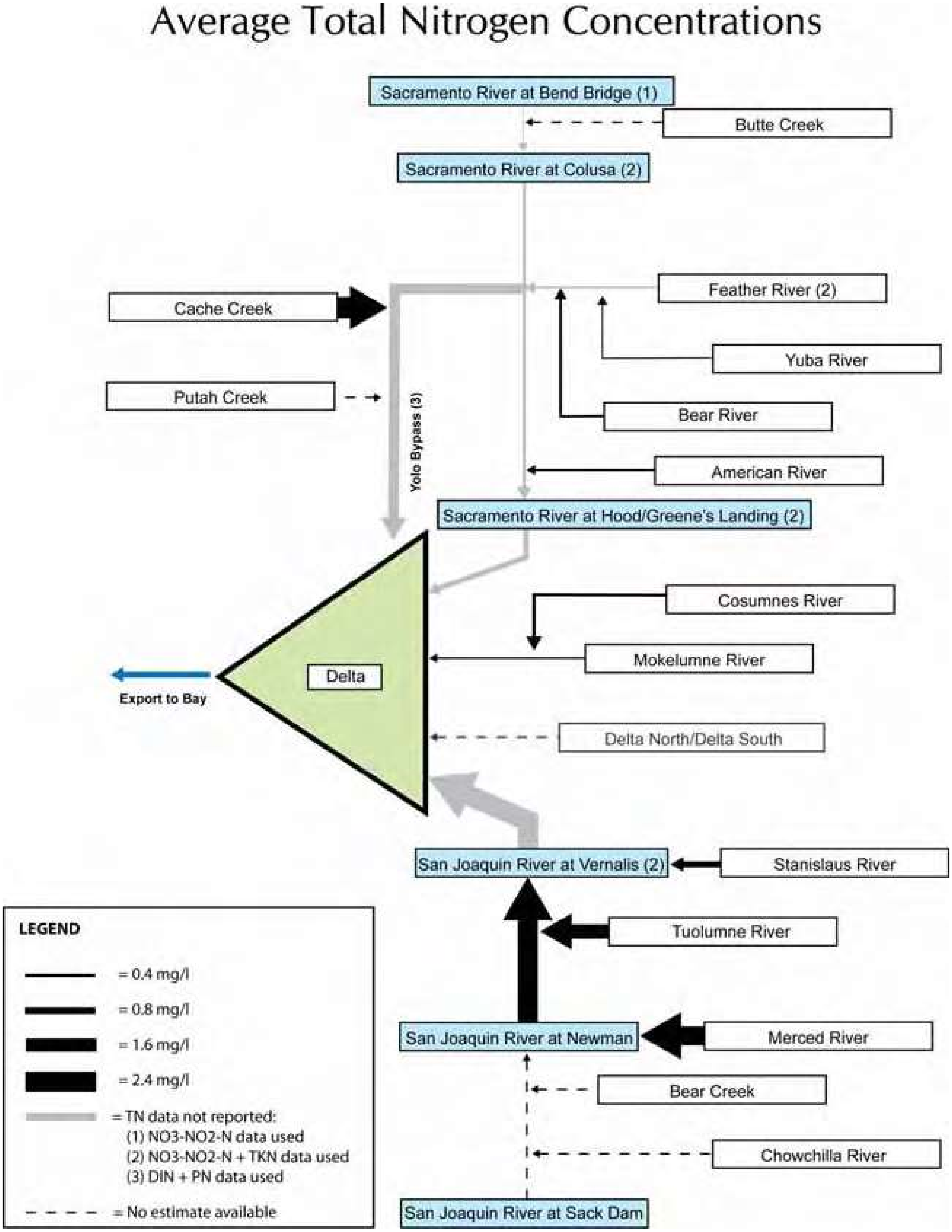


Figure 4-3. Annual average TN concentrations in the sub-watersheds. Other constituents substituted for TN where noted. More detailed temporal data (i.e., monthly) presented below.

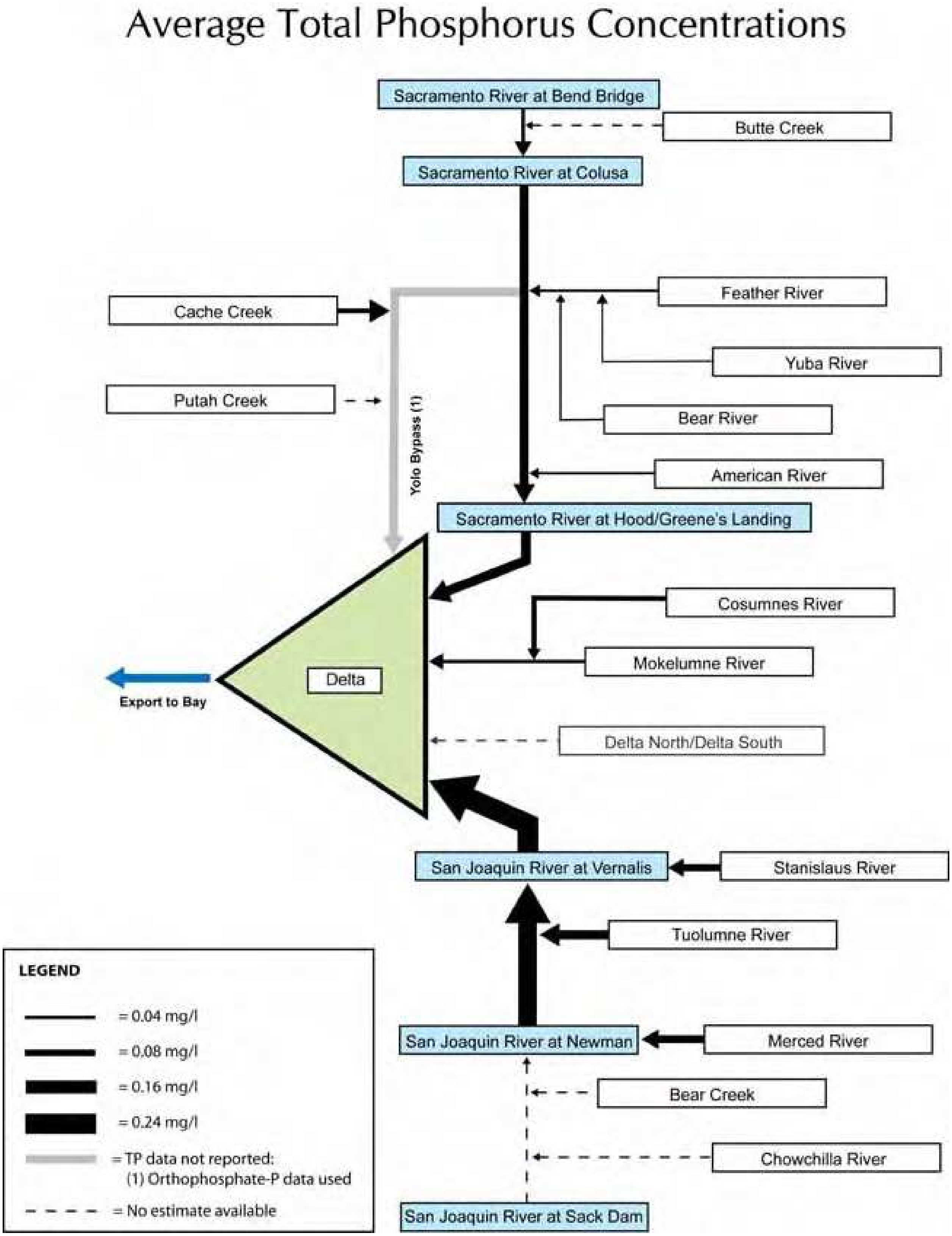


Figure 4-4. Annual average TP concentrations in the sub-watersheds. Other constituents substituted for TP where noted. More detailed temporal data (i.e., monthly) presented below.

4.2 WATER FLOWS IN THE CENTRAL VALLEY

Because loads in streams are a product of flow and concentration, and flows can vary in a given stream by orders of magnitude during different seasons of the year, estimated loads are a strong function of flow. As a first step in the evaluation of nutrient loads, daily flow values were obtained from nearby USGS stations at locations corresponding to the subwatersheds identified in Figure 4-1. Table 4-2 shows the USGS stations (names and IDs) that correspond with the stations in the database developed for this project. Annual and seasonal flows were calculated using these data. In several subwatersheds, there are no flow and/or concentration data. In these cases, nutrient loads were estimated using watershed export rates described below.

Detailed descriptions of the flows at all locations that were used for this work are provided in Appendix B. This includes classification of years as wet or dry, and plots of flows in the wet and dry seasons of wet and dry years. Data from water year 1980 and beyond were used to reflect land use conditions that are reasonably representative of current conditions. Water years classified by the California Department of Water Resources as below normal, dry, or critical, are termed dry, and water years termed above normal or wet are termed wet. The wet season is defined as October 1 to April 30 and the dry season is defined as May 1 to September 30. Summary flow information is provided graphically on a schematic of the Central Valley watershed below. Flows in the dry and wet season of a typical dry year (2002) are shown in Figure 4-5, and flows in the dry and wet season of a typical wet year (2003) are shown in Figure 4-6. Both figures use the same linear scale to represent flows and can be used to compare values across seasons and years. The Sacramento River flows are substantially higher than the San Joaquin River flows, with wet season flows exceeding dry season flows.

Table 4-2.
Subdivision of watersheds in the Central Valley, nearby stations with concentration data in the Central Valley Drinking Water Policy Workgroup database, and USGS stations with continuous flow data

ID	Watershed Name	Area (km^2)	Area (mi^2)	Station Name in Drinking Water Database	Nearest USGS Gauge Station[1]	Name of USGS Gage Station
1	Sacramento River above Bend Bridge	23,145	8,934	Sacramento River above Bend Bridge	11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA
2	Butte Creek	2,402	927	--	11390000	BUTTE C NR CHICO CA
3	Sacramento River at Colusa	11,261	4,347	Sacramento River at Colusa	11389500	SACRAMENTO R A COLUSA CA
4	Yuba River	3,502	1,352	Yuba River at Simpson Lane	11421000	YUBA R NR MARYSVILLE CA
5	Feather River[2]	9,995	3,858	Feather River Near Nicolaus	11425000	FEATHER RIVER NEAR NICOLAUS CA
6	Cache Creek	3,112	1,201	Cache Creek at Hwy 113	11452500	CACHE C A YOLO CA
7	American River	5,528	2,134	American River at Discovery Park	11446500	AMERICAN R A FAIR OAKS CA
8	Sacramento River at Hood/Greene's Landing[3]	4,256	1,643	Sacramento River at Hood Sacramento River at Greene's Landing	11447810	SACRAMENTO R A GREENS LANDING CA
9	Cosumnes River	2,390	922	Cosumnes River at Twin Cities Road	11335000	COSUMNES R A MICHIGAN BAR CA
10	San Joaquin River at Newman	4,170	1,610	San Joaquin River at Highway 165	11274000	SAN JOAQUIN R A NEWMAN CA
11	Stanislaus River	3,478	1,343	Stanislaus River at Caswell Park	11303000	STANISLAUS R A RIPON CA
12	Tuolumne River	4,586	1,770	Tuolumne River at Shiloh	11290000	TUOLUMNE R A MODESTO CA
13	Merced River	3,290	1,270	Merced River at River Road	11272500	MERCED R A STEVINSON
14	Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	2,397	925	--	--	--
15	Chowchilla River	850	328	--	--	--
16	San Joaquin River at Sack Dam	11,667	4,504	--	11254000	SAN JOAQUIN R NR MENDOTA CA
17	Mokelumne River	3,022	1,167	Mokelumne River at New Hope Road	11325500	MOKELUMNE R A WOODBRIDGE CA
18	Bear River	1,229	475	Bear River at Forty Mile Road	11424000	BEAR R NR WHEATLAND CA
19	Putah Creek	1,795	693	--	11454210	PUTAH SOUTH CN NR WINTERS CA
20	Delta North	2,148	829	--	--	--
21	Delta South	5,730	2,212	--	--	--
22	San Joaquin River at Vernalis	2,344	905	San Joaquin River at Vernalis	11303500	SAN JOAQUIN R NR VERNALIS CA
	Total Watershed Area	**112,297**	**43,347**			

[1] Flow data USGS website (http://nwis.waterdata.usgs.gov/usa/nwis/discharge), unless otherwise noted.
[2] Flow data from Saleh et al., 2003.
[3] Flow data from DWR's DAYFLOW model.

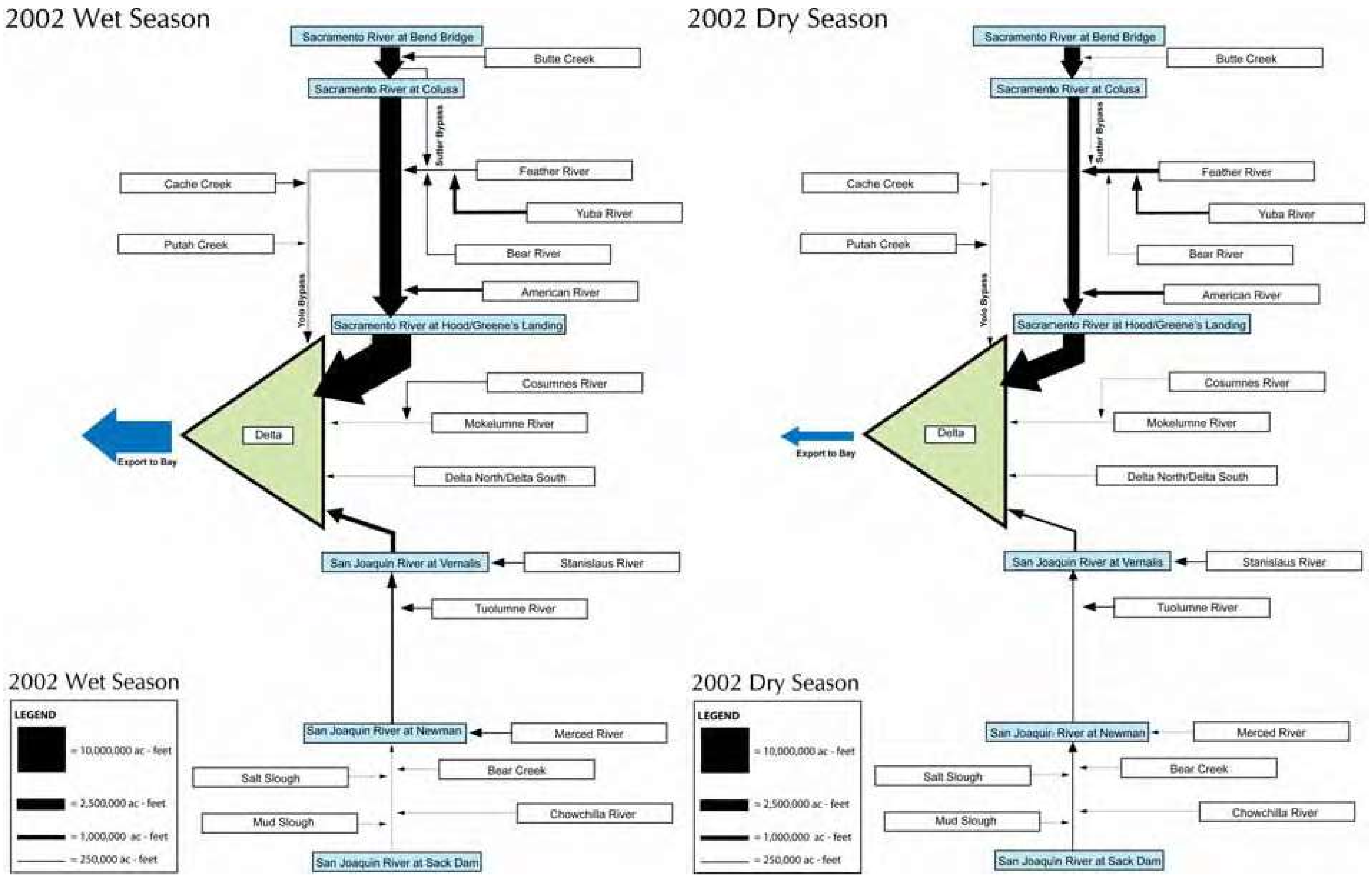


Figure 4-5. Flows in the dry and wet season of 2002 (a dry year) on a schematic representation of the San Joaquin-Sacramento River systems.

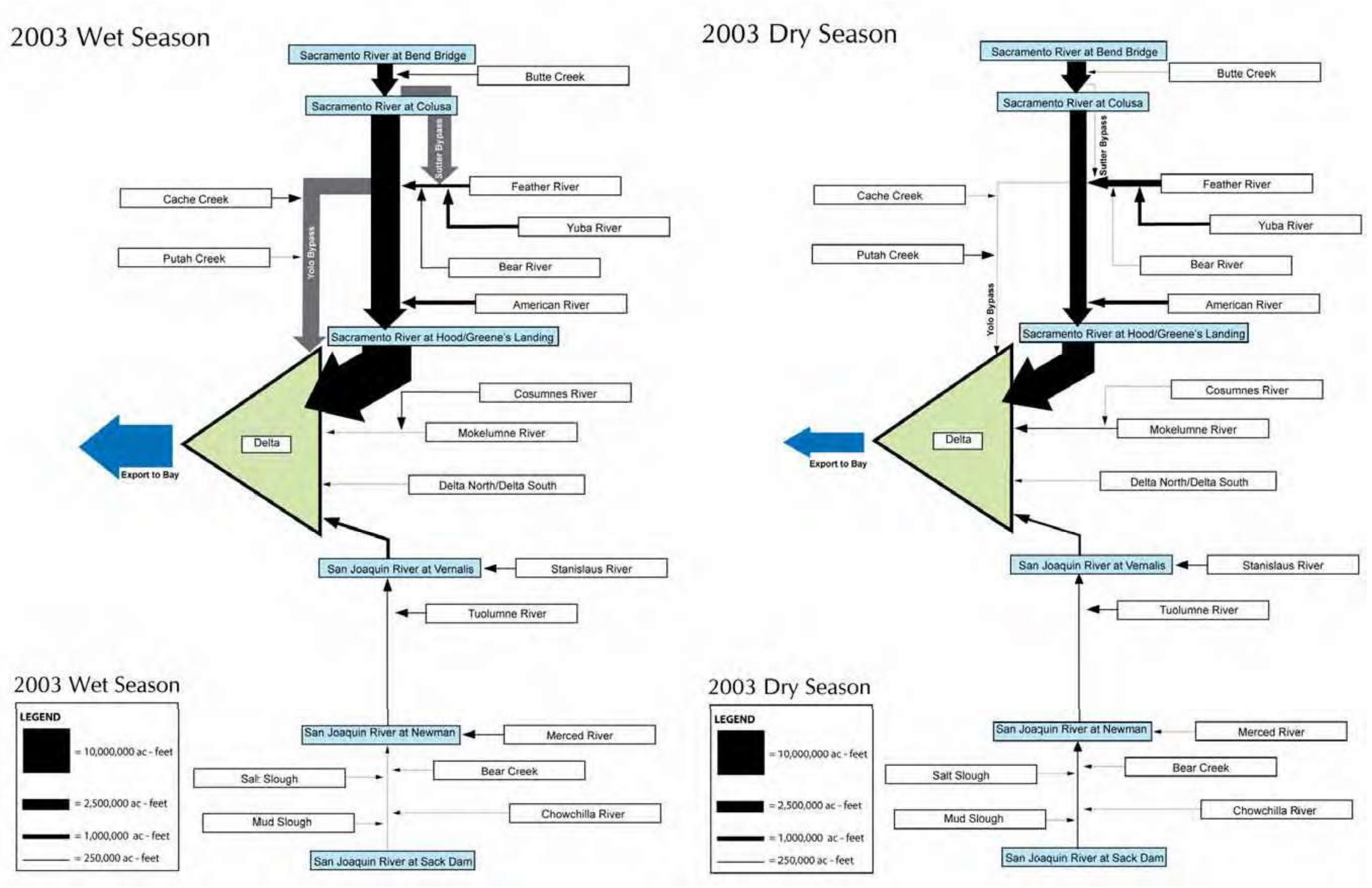


Figure 4-6. Flows in the dry and wet season of 2003 (a wet year) on a schematic representation of the San Joaquin-Sacramento River systems.

4.3 ESTIMATION OF TRANSPORTED LOADS IN STREAMS

Nutrient concentration data were limited at most locations whereas continuous records of flow data were often, though not always, available. Nutrient data were especially limited at many upstream locations.

For this study, the average monthly concentration and the average monthly flow were multiplied to get monthly and annual loads, as in Jassby and Cloern (2000). If one or more concentration values were available for a specific month of a given year (i.e., January 1995), the average of data for that month was used. If data were not available for a specific month and year but were available for the same month of any year, then the average of that data was used (i.e., the average of all January values). If there were no data at all for a given month, then an estimate was made using data for months before and after it (i.e., if there were no January data, then the average of December and February data was used). When no TN data were reported, either NO3+NO2-N, NO3+NO2-N + TKN, or dissolved inorganic nitrogen plus particulate nitrogen (DIN + PN; Yolo Bypass only) were used to approximate TN. When no TP data were reported, orthophosphate-P was used to approximate TP (Yolo Bypass only). Due to the limitations in the data, the load estimates for a number of locations are considered preliminary. The limited concentration data introduced a fair amount of uncertainty into the analysis due to the following factors:

- Grab sample data collected monthly or less frequently do not adequately characterize nutrient concentrations, particularly during the wet season.
- The assumption that data from a month in one year could be used to estimate concentrations for the same month in another year assumes that there is not year-to-year variability in the data. Based on intensive monitoring in the Sacramento River at Hood, variability is seen in the data (as presented in Chapter 5, Figures 5-7 and 5-8).
- For months for which there are no data, averages of the prior and next month were used. This assumes more consistency in the concentration data than actually exists, based on the intensive monitoring.

Monthly TN and TP loads were estimated using the entire record of daily flow data at selected stations, and the average monthly concentration values generated as described previously. The monthly loads were used to calculate seasonal and annual loads at the outflow points of the subwatersheds shown in Figure 4-1. Loads were estimated for all but seven subwatersheds where no concentration data were available: the Bear, Owens, Mariposa, and Deadmans Creeks (defined as one composite subwatershed in Figure 4-1), Chowchilla River, Putah Creek, Butte Creek, San Joaquin River at Sack Dam, and the Delta North and Delta South subwatersheds. Figures 4-7 to 4-21 present the average monthly nutrient concentrations (including data count), the daily discharge, and the wet and dry season nutrient loads by water year for outlet points of the subwatersheds. Where either TN or TP data were not available, the substitute nutrient constituent used for the load calculation is noted on the figure. These figures illustrate the extent of available data and the time period of record. Data from water year 1980 and beyond were used to reflect land use conditions that are reasonably representative of current conditions. For ease of comparison across stations, the time scale in all figures extends from 1980 to 2005. For the stations on the main stems of the Sacramento and San Joaquin Rivers, particularly stations near the Delta, both flow and concentration data are collected at a reasonable frequency. Stations on the tributaries have more limited concentration data. Most stations have enough flow data to allow estimation of loads for at least 10 years between 1980 and 2005 except for the Feather River, Mokelumne River, and Merced River.

Exports of nutrients from the Yolo Bypass and from the Delta to San Francisco Bay were also computed. Flows were obtained from the DAYFLOW model discussed in greater detail in Chapter 5. Due to lack of data from any previously discussed source, concentration data for the Yolo Bypass was obtained from Schemel et al., 2002. MWQI concentration data for Mallard Island were used for Delta outflow calculations and were downloaded from the internet at http://wdl.water.ca.gov/wq-gst/. Like the tributary stations, monthly averages of the flows and nutrient concentrations were calculated, and used to estimate monthly, and then seasonal and annual loads (Figures 4-22 and 4-23 for the Yolo Bypass and Delta outflows, respectively).

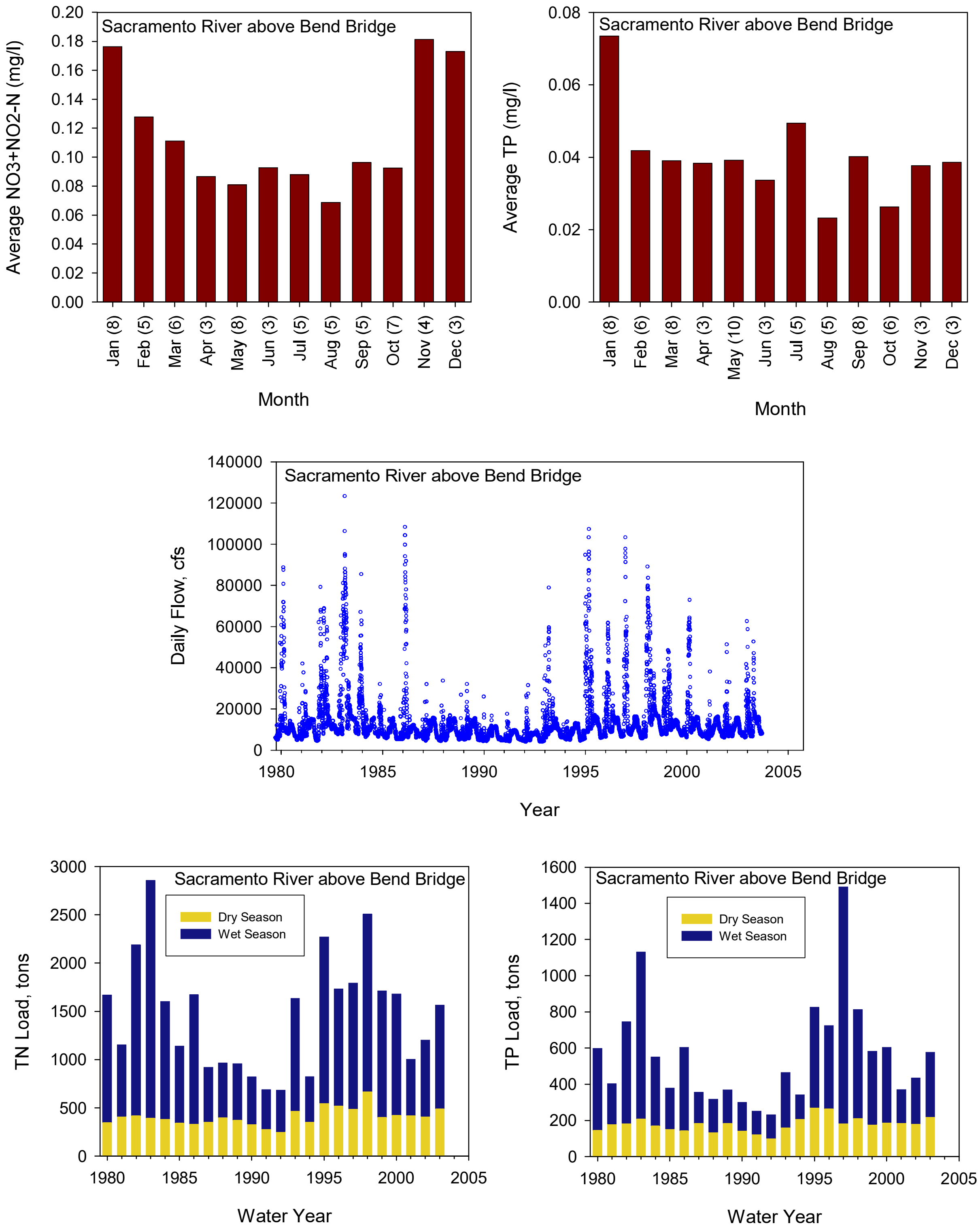


Figure 4-7. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River above Bend Bridge.

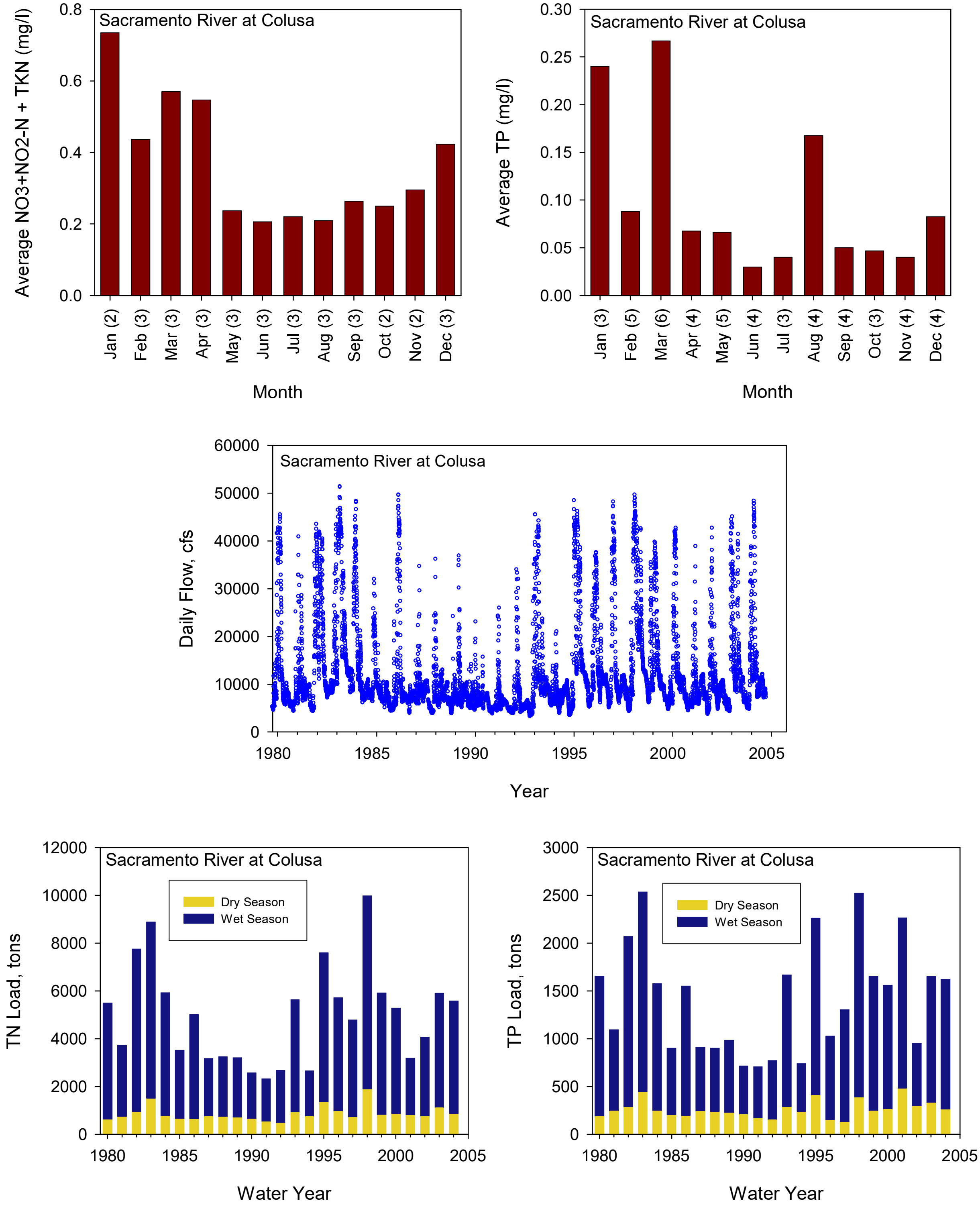


Figure 4-8. **Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River at Colusa.**

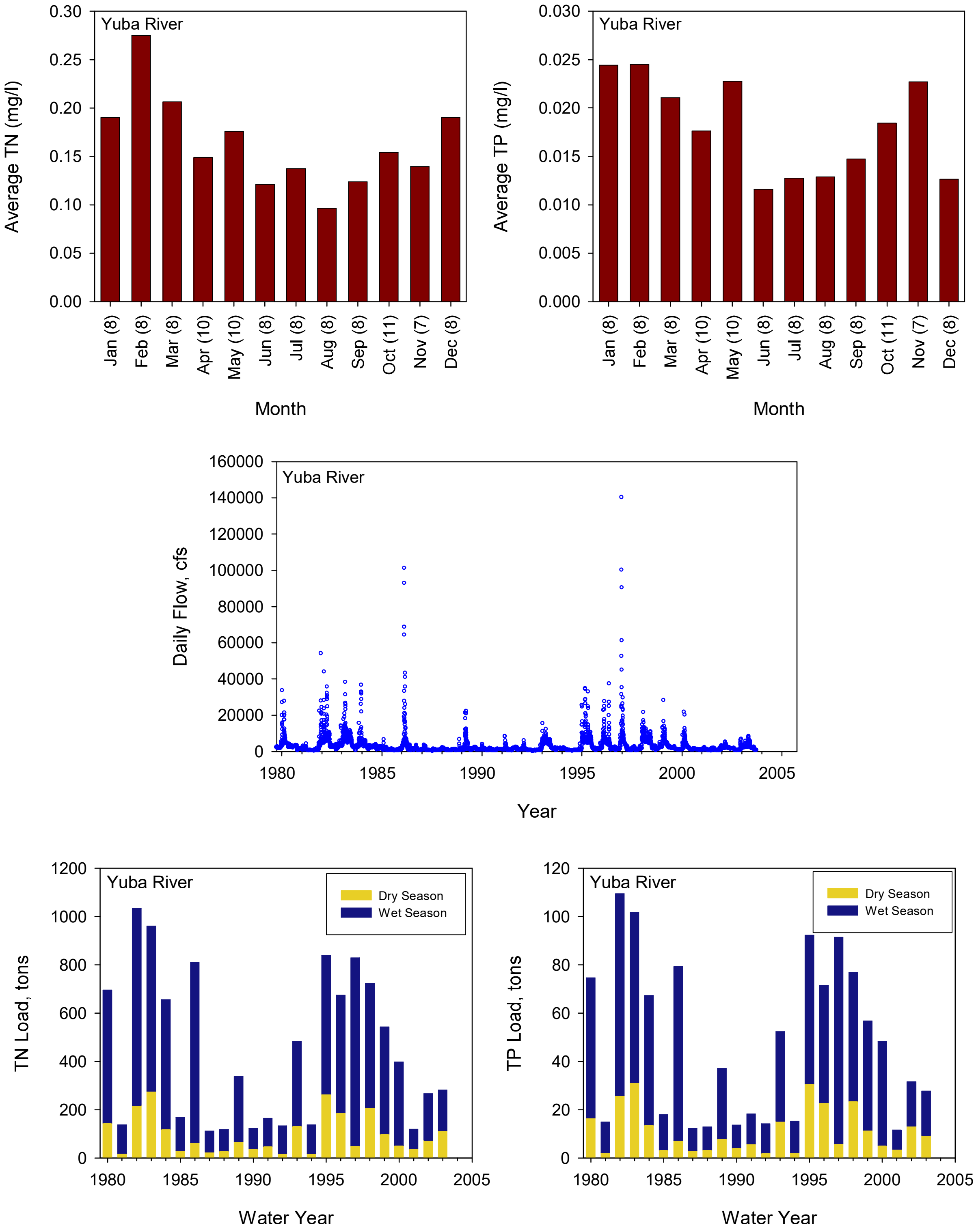


Figure 4-9. **Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Yuba River.**

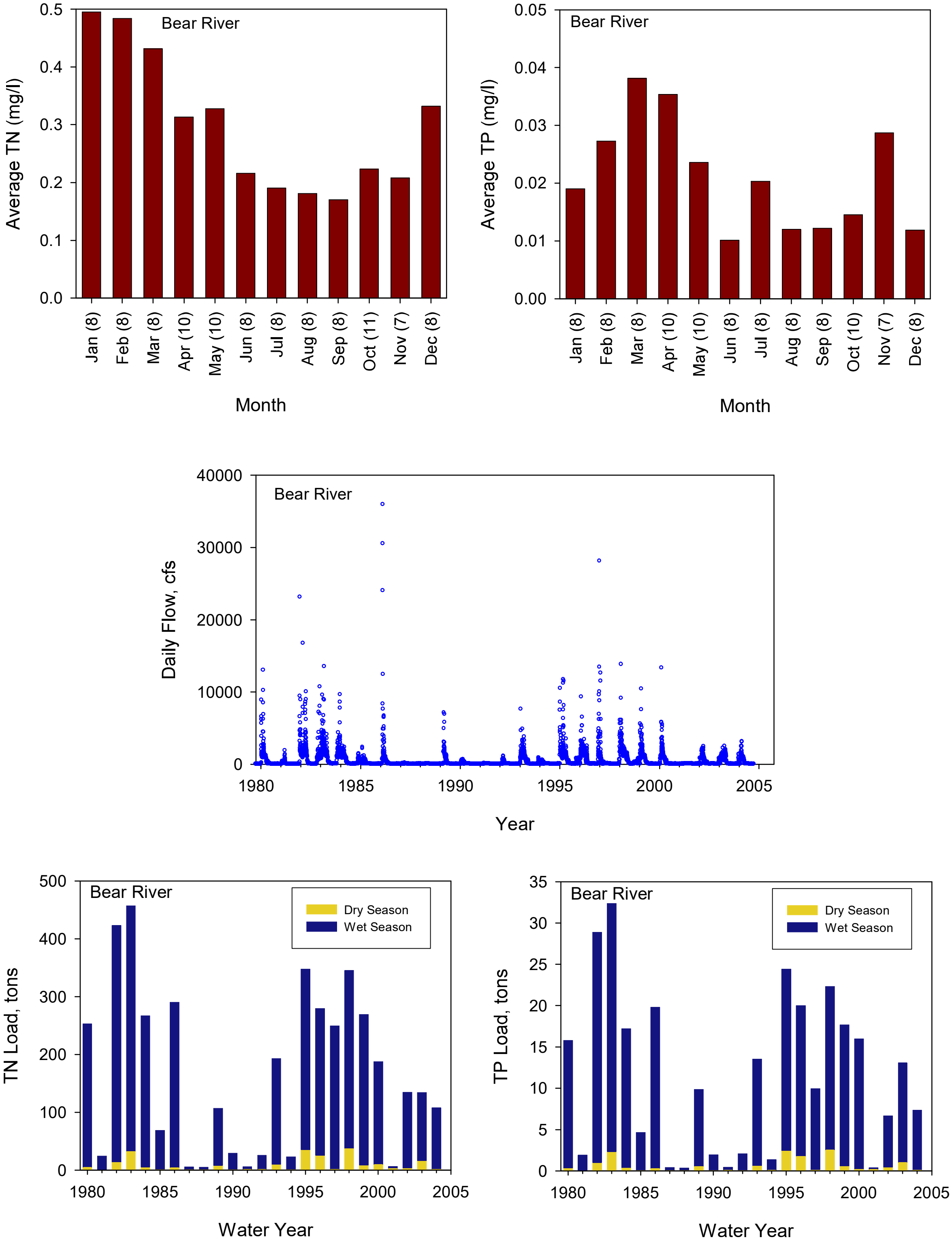


Figure 4-10. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Bear River.

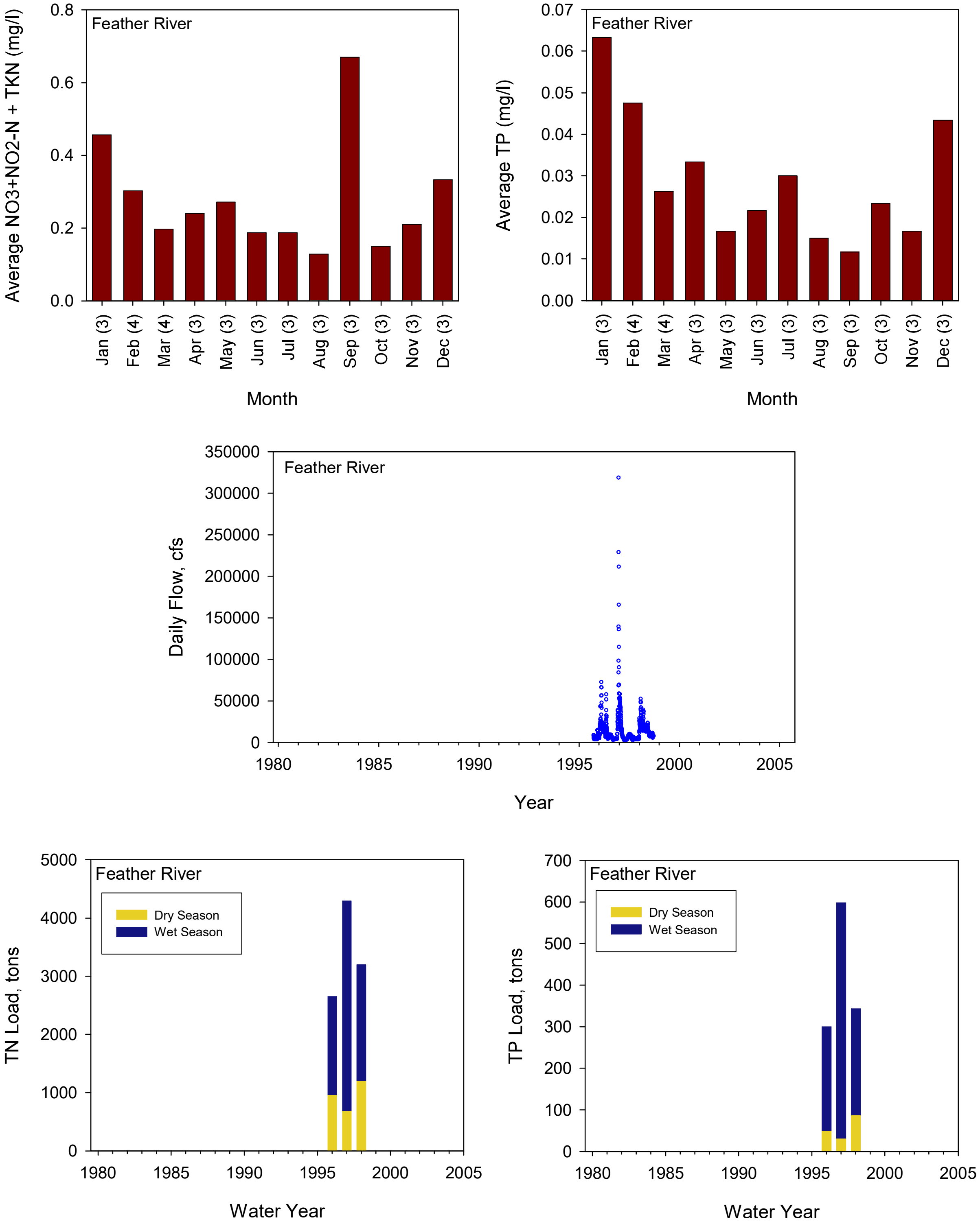


Figure 4-11. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Feather River.

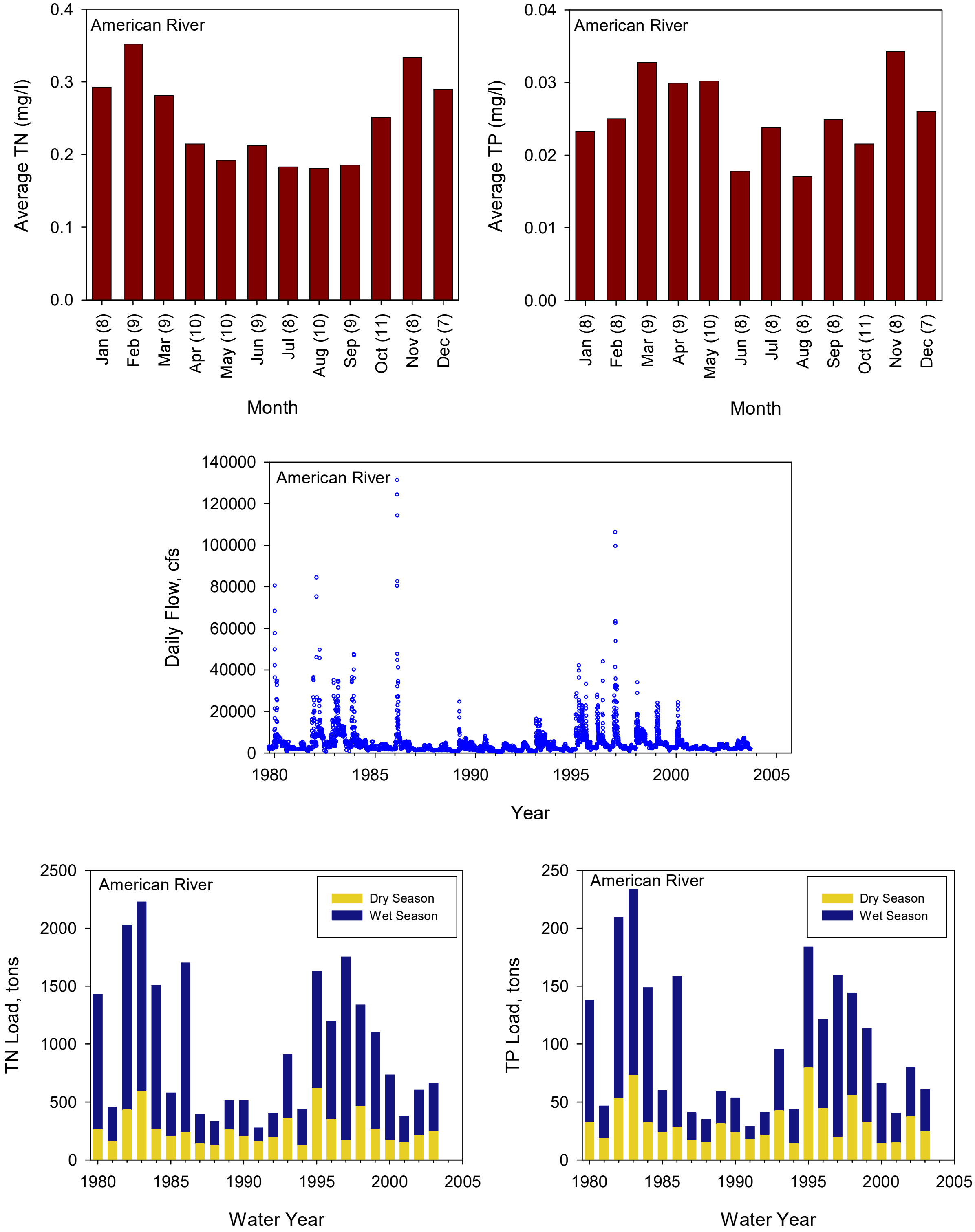


Figure 4-12. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the American River.

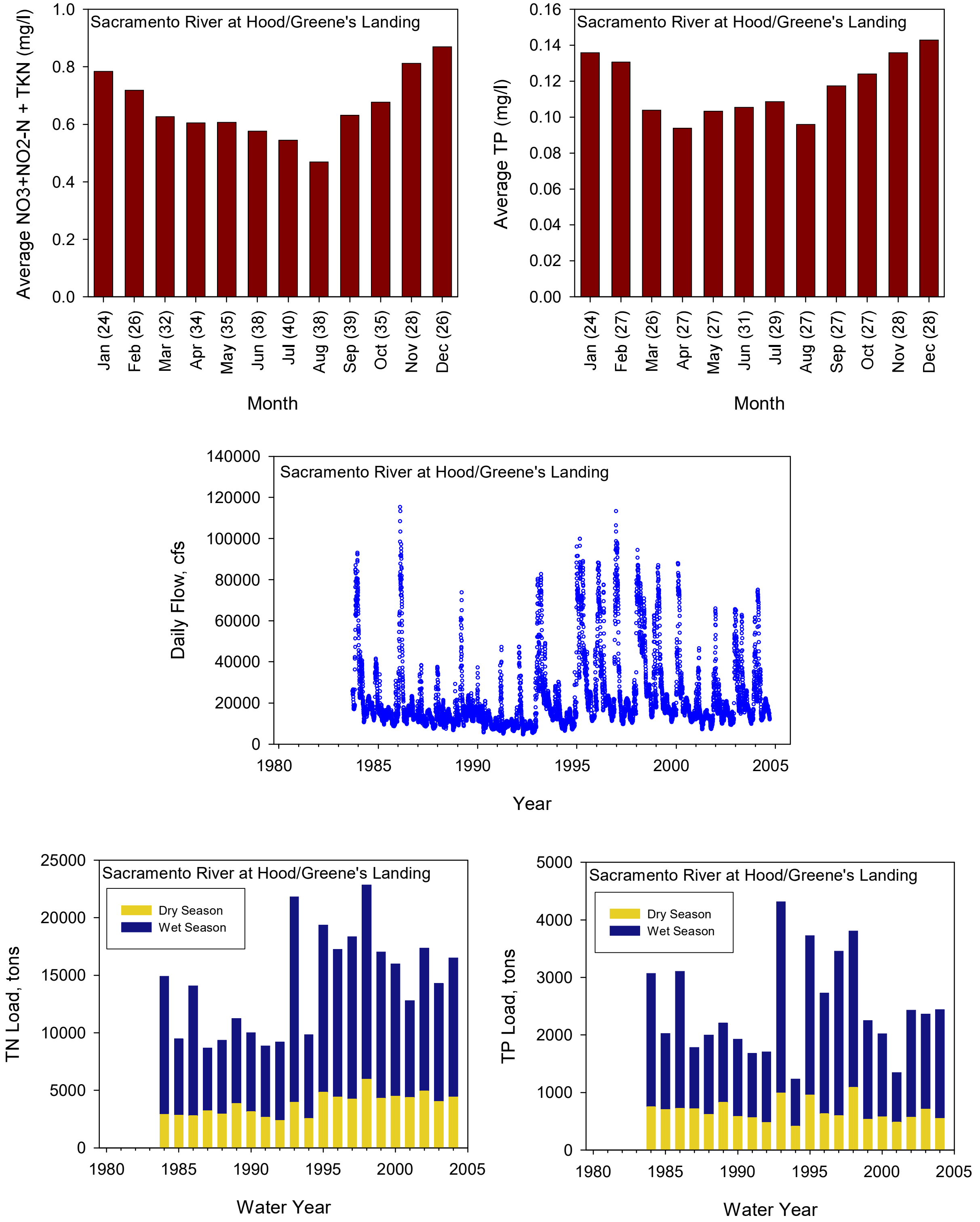


Figure 4-13. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Sacramento River at Hood/Greene's Landing.

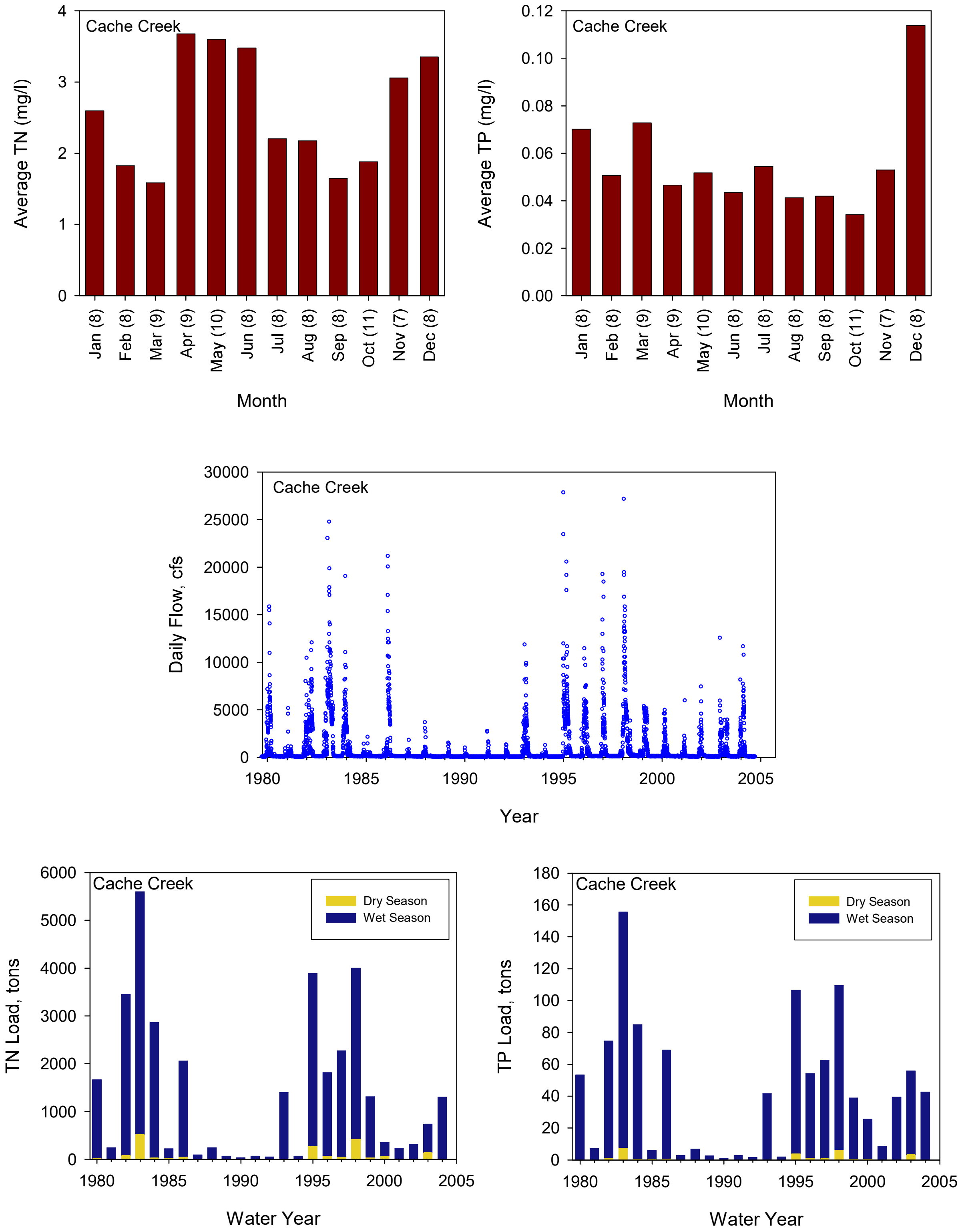


Figure 4-14. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Cache Creek.

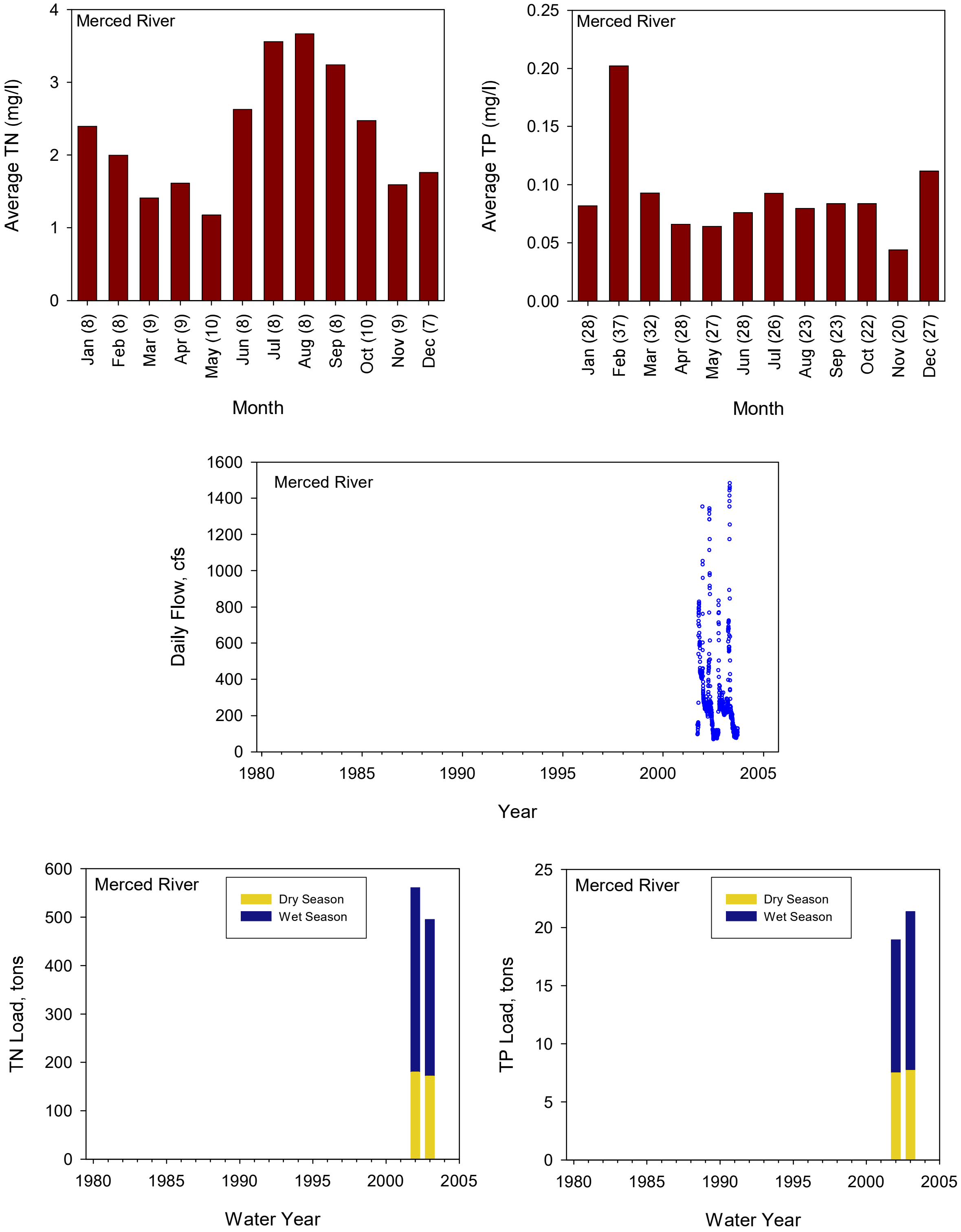


Figure 4-15. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Merced River.

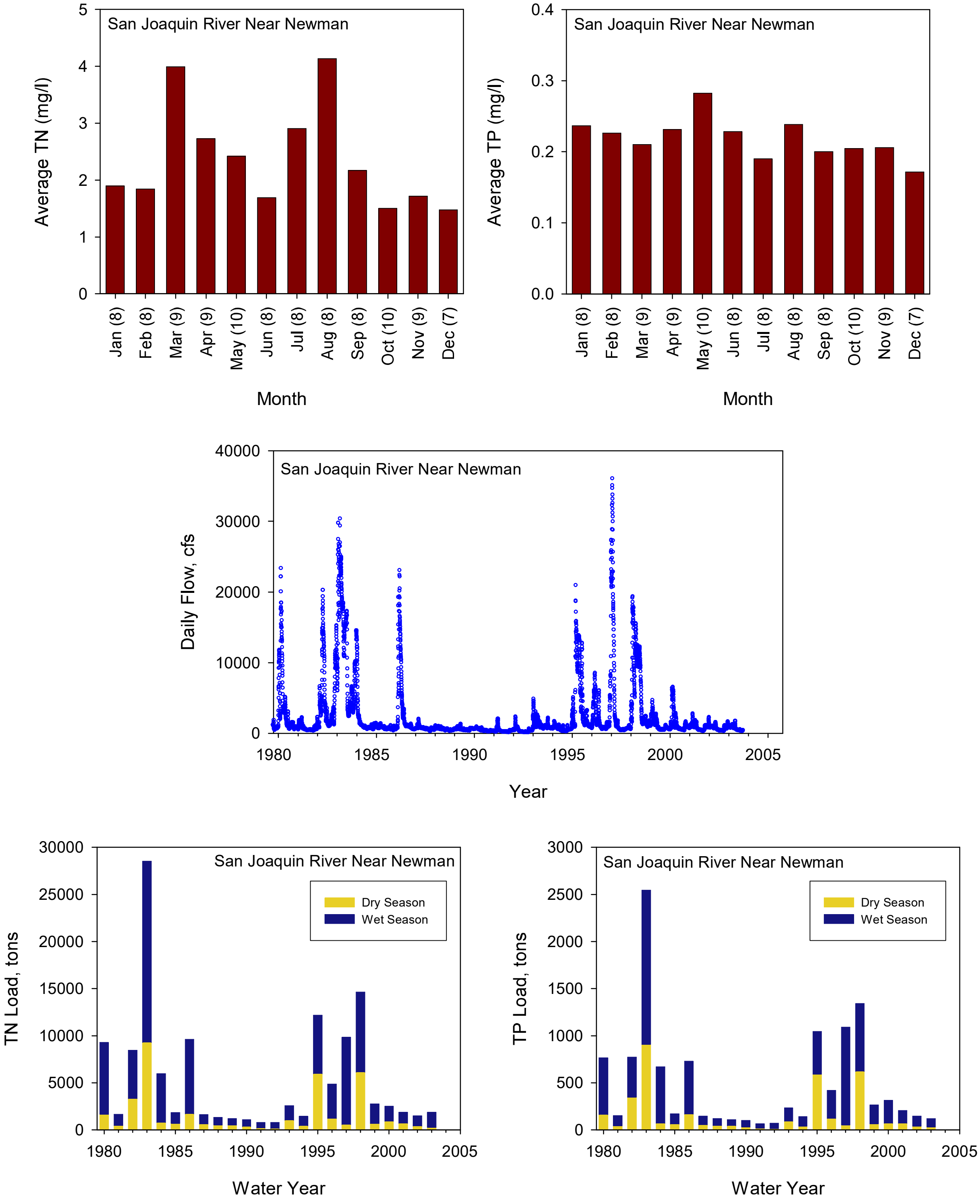


Figure 4-16. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the San Joaquin River at Newman.

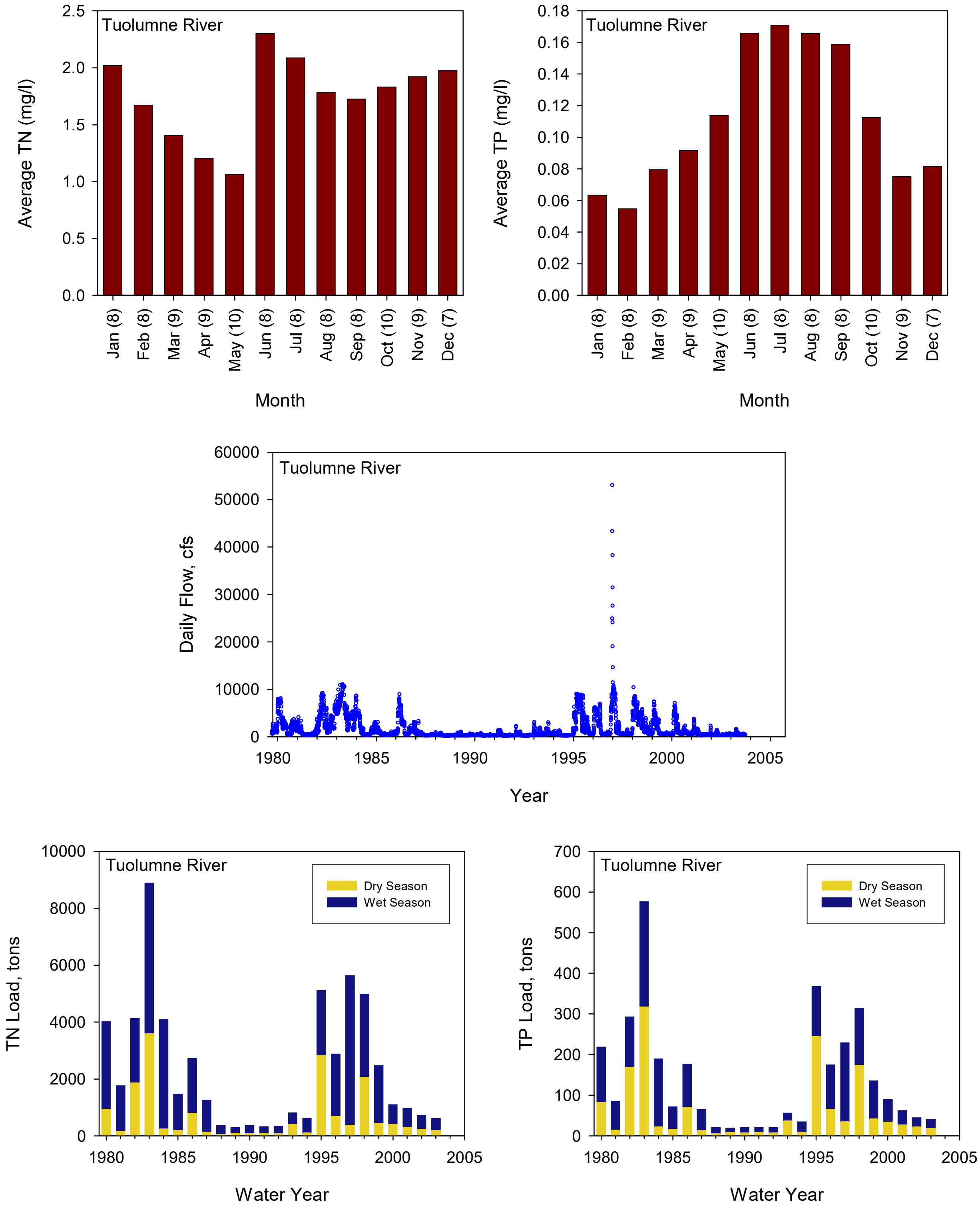


Figure 4-17. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Tuolumne River.

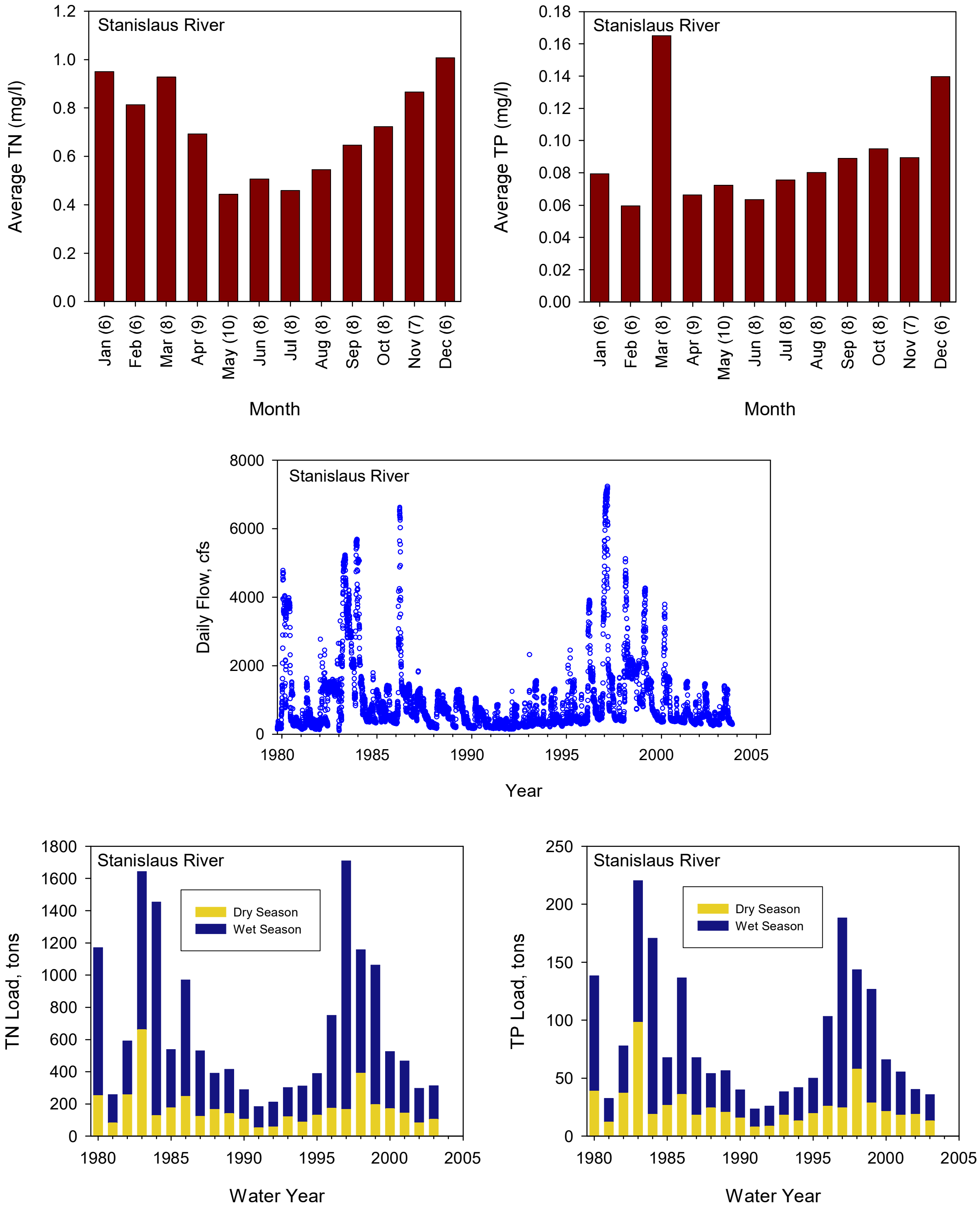


Figure 4-18. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Stanislaus River.

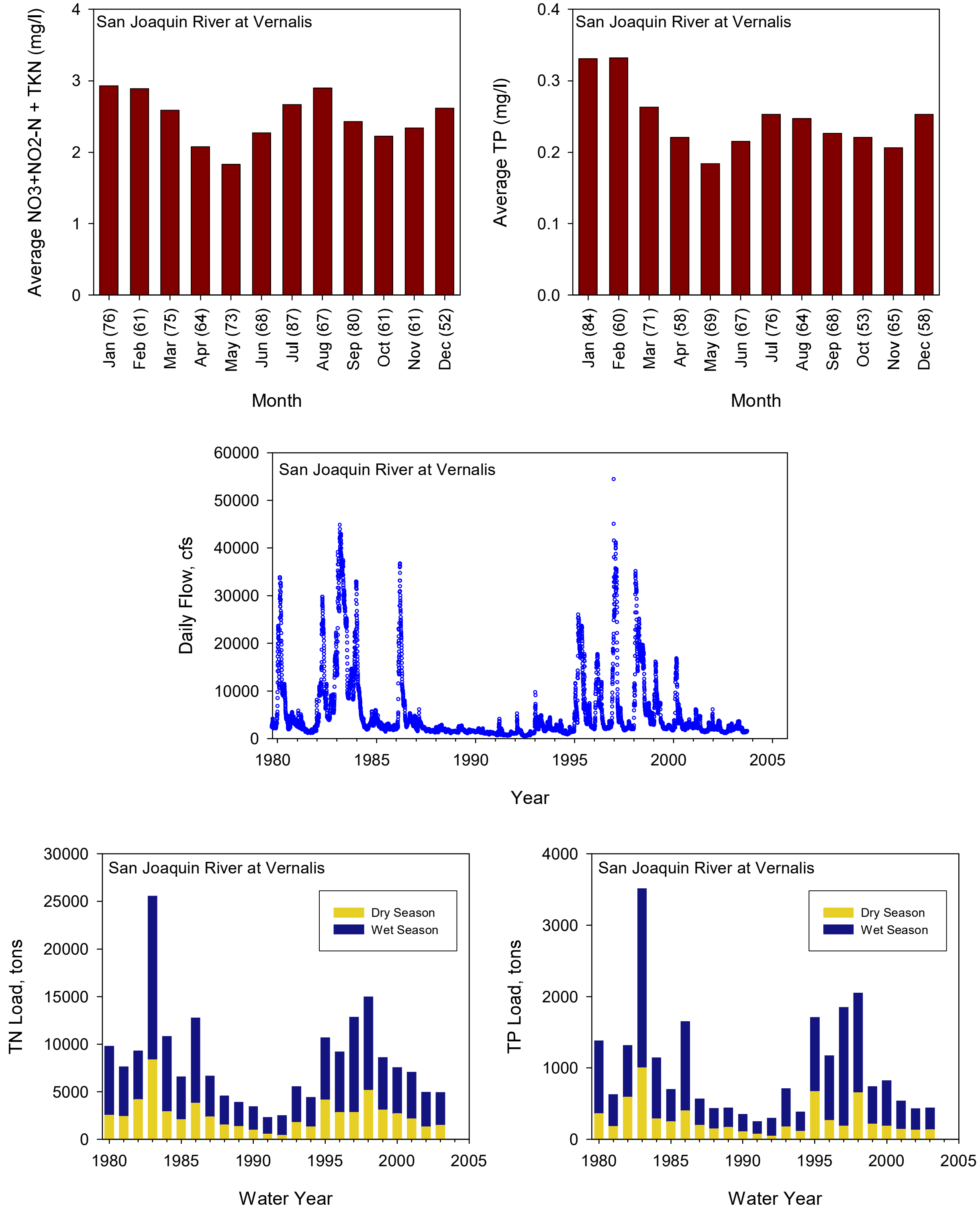


Figure 4-19. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for San Joaquin River at Vernalis.

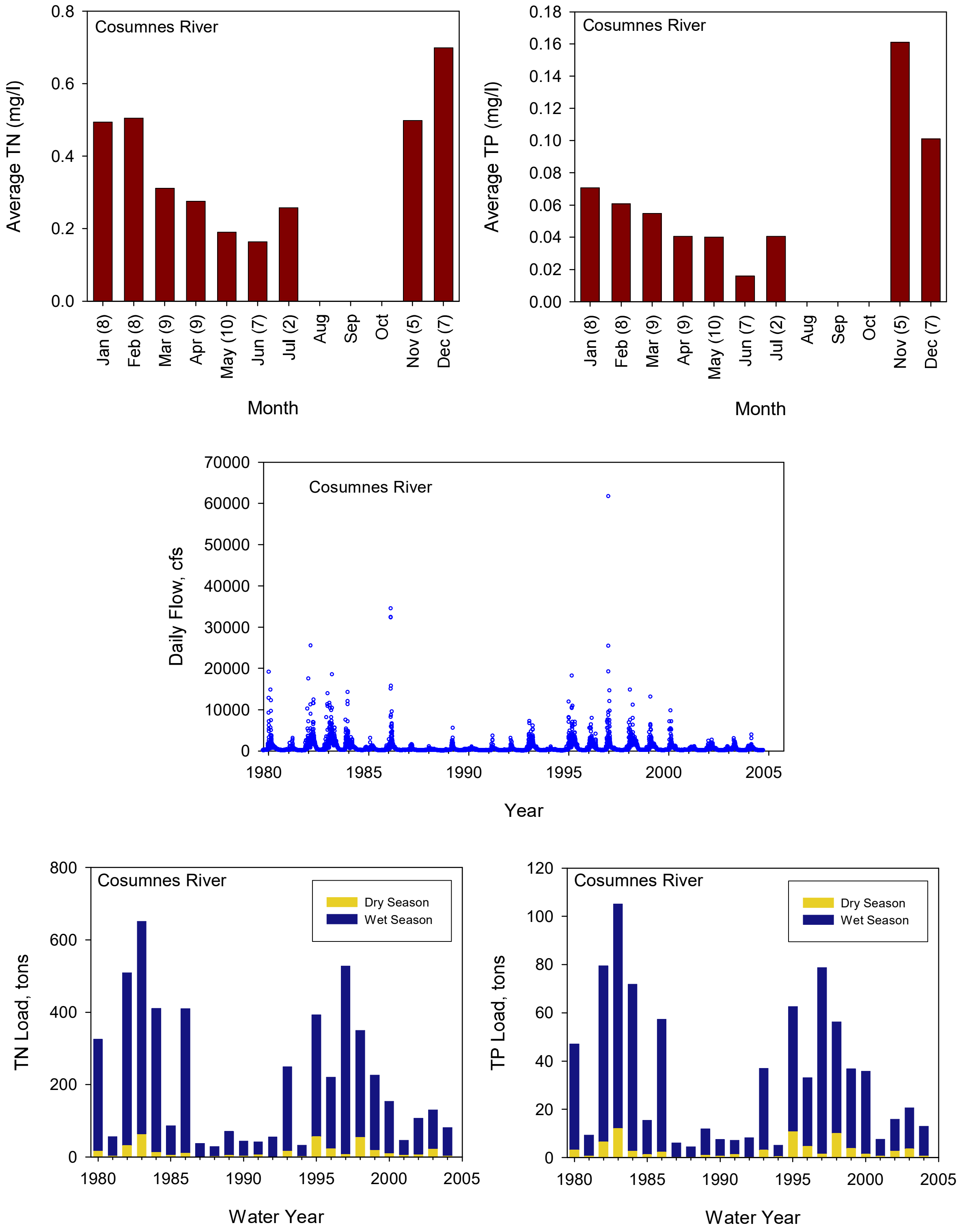


Figure 4-20. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Cosumnes River.

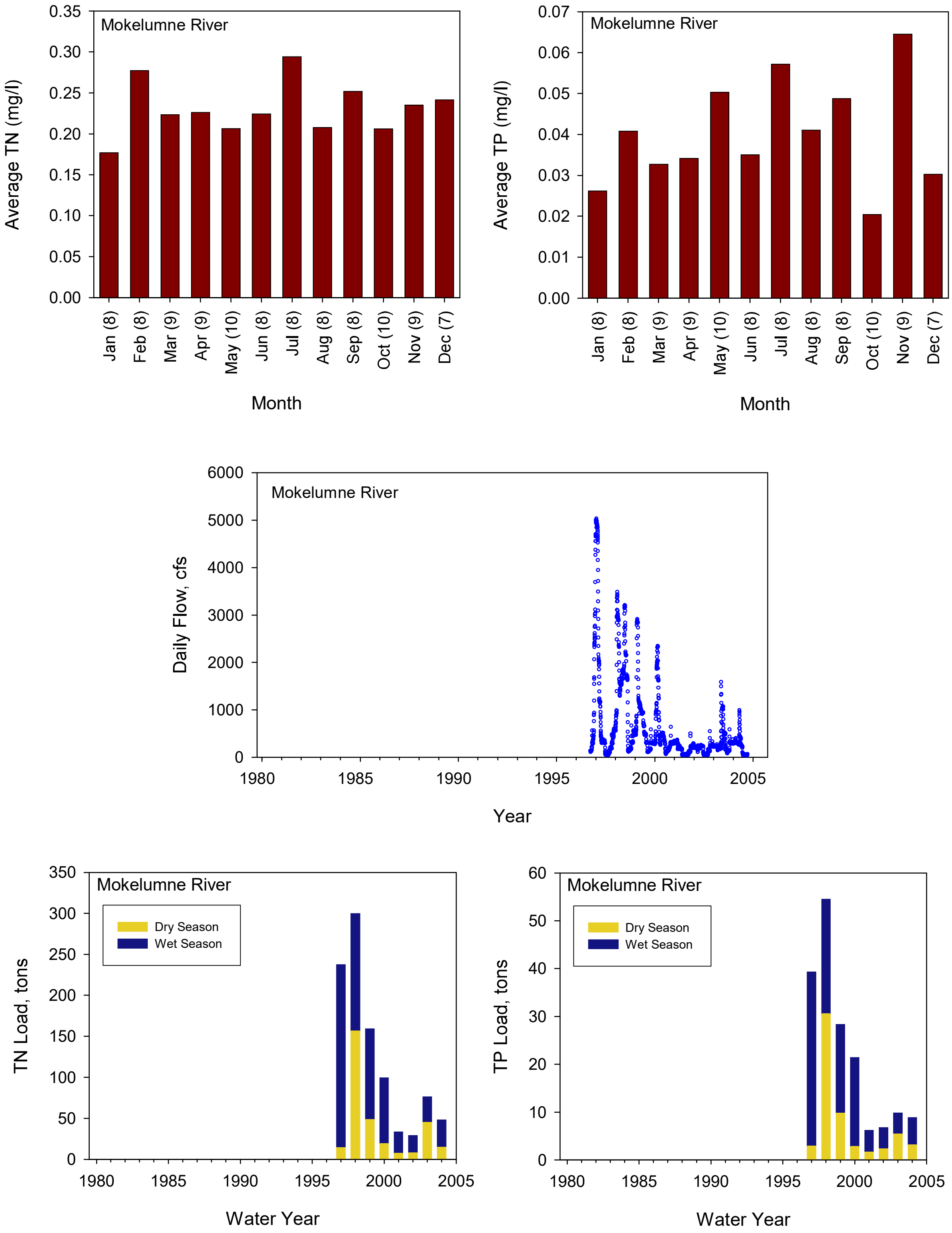


Figure 4-21. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Mokelumne River.

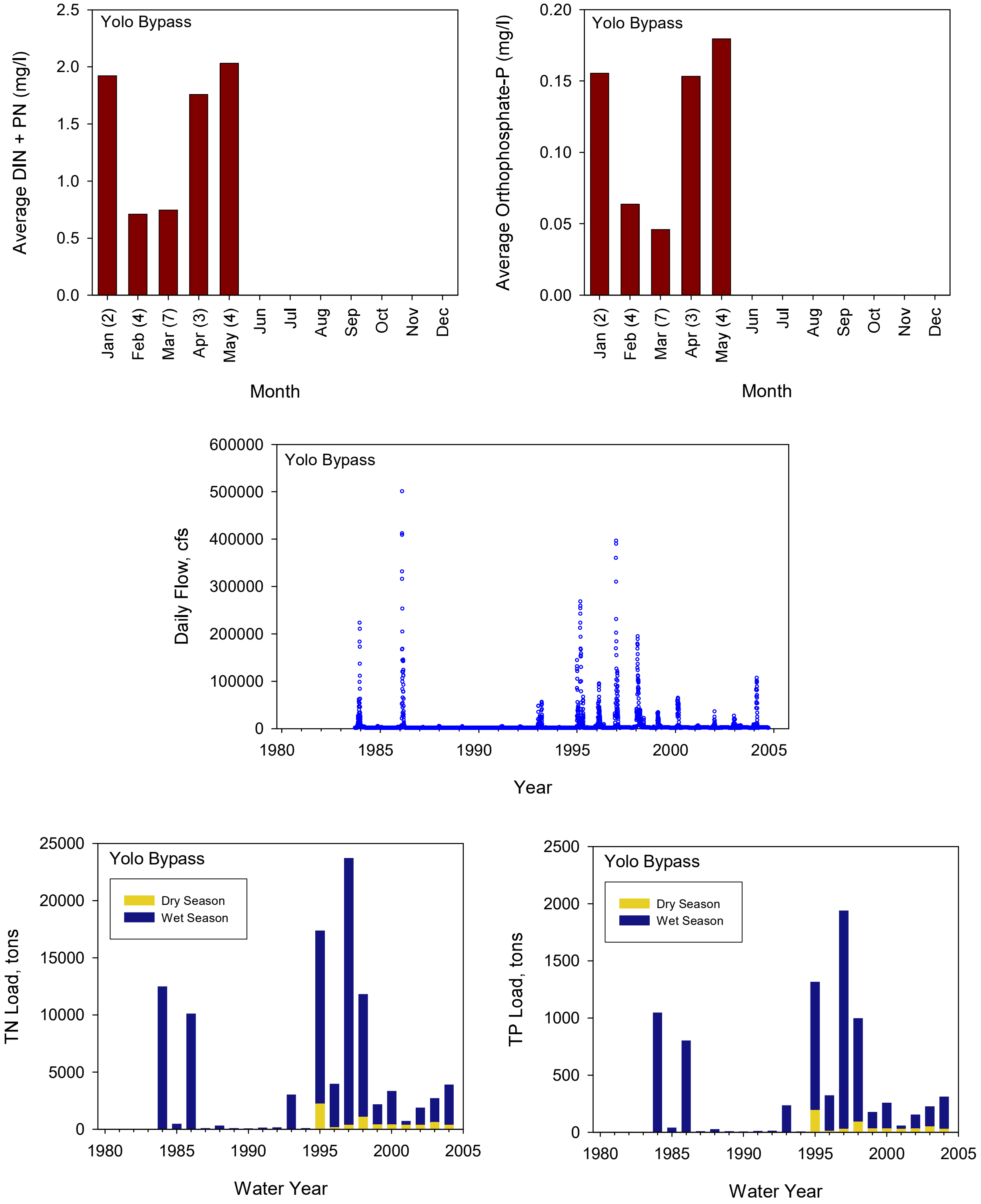


Figure 4-22. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Yolo Bypass.

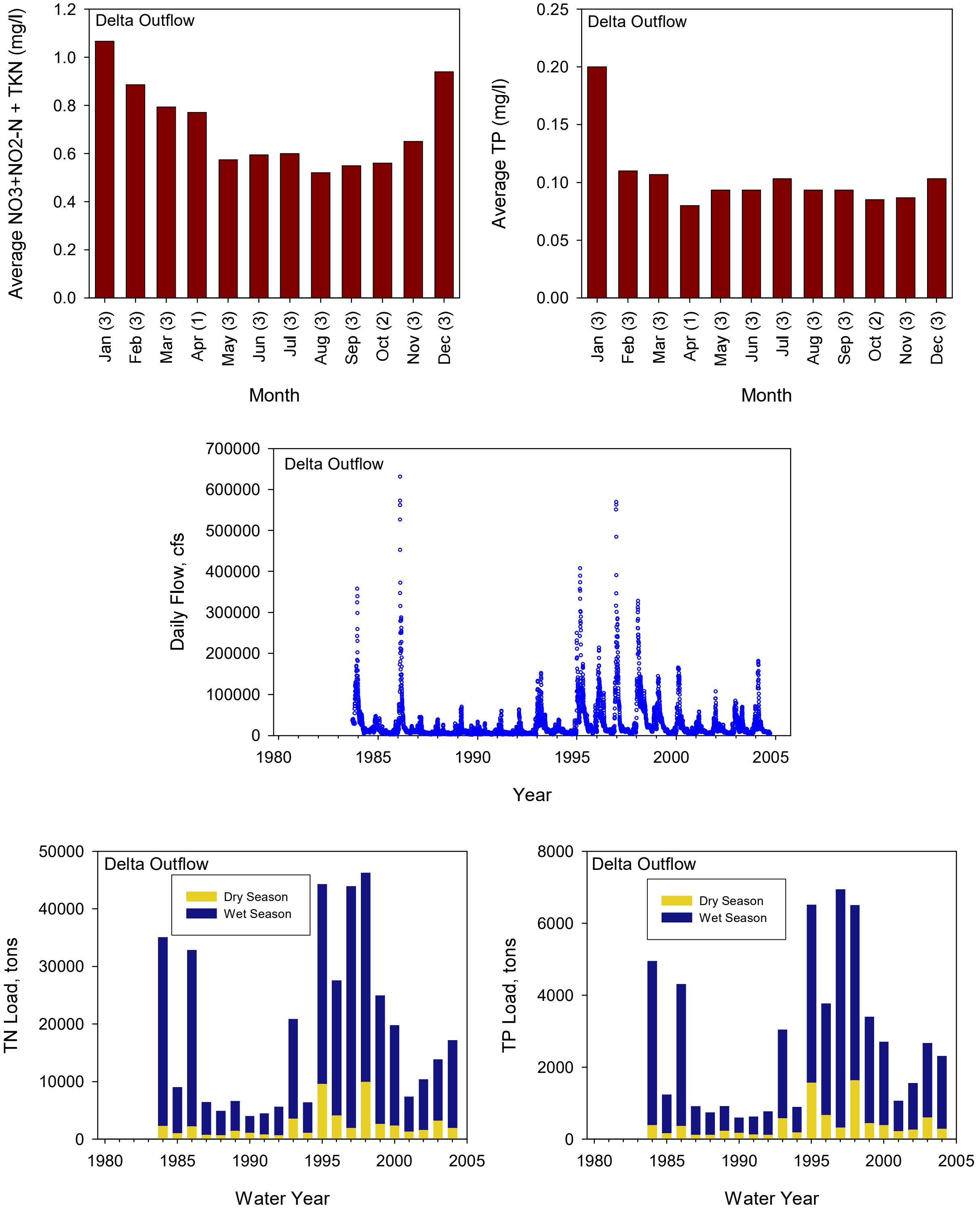


Figure 4-23. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Delta outflows. MWQI concentration data for Mallard Island were used and downloaded from the internet at http://wdl.water.ca.gov/wq-gst/.

The loads calculated for the key subwatersheds are summarized in Table 4-3 and Table 4-4 for the dry and wet season of wet and dry years for TN and TP, respectively. Loads of TN and TP during wet years are shown graphically in Figures 4-24 and 4-25, respectively. The graphical representation uses arrow thicknesses to scale loads, and can be used to compare across locations. The loads closely follow the pattern for flows shown in Figure 4-5, with the Sacramento River being the dominant source. This is true even though concentrations in the San Joaquin River are generally much higher than in the Sacramento River (Chapter 3). Wet season tributary loads and Delta exports can be several times higher than the dry season loads. Similarly, wet year tributary loads and Delta exports can be several times higher than the dry year loads.

Estimated loads from this study compare favorably with loads estimated in previous studies, as shown in Table 4-5 and 4-6 for TN and TP, respectively, with the exception of TN agreement in the Sacramento River with Saleh et al. (2003). At the Sacramento River (either Freeport or Greene's Landing), loads from Woodard (2000) for wet and dry years are within 25% of the estimates from this study for both TN and TP. Loads from Saleh et al. (2003) are within 20% of the estimates from this study for TP. At the San Joaquin River at Vernalis, loads from Woodard (2000) and from Saleh et al. (2003) for wet and dry years are within 20% of the estimates from this study for both TN and TP. Loads from Kratzer et al. (2004) for the San Joaquin River at Vernalis (all years) are between wet and dry year estimates from this study for both TN and TP.

Table 4-3.
Total nitrogen loads transported at locations corresponding to the outflow points of the subwatersheds in Table 4-1.

			Dry Years (tons)			Wet Years (tons)			Export Rates (tons/km^2)	
ID	**Watershed Name**	**Upstream Area (km^2)**	Dry Season	Wet Season	Total	Dry Season	Wet Season	Total	Dry year	Wet Year
1	Sacramento River above Bend Bridge	23,144	360	580	940	456	1,457	1,913	0.041	0.083
2	Butte Creek	2,402	-	-	-	-	-	-	-	-
3	Sacramento River at Colusa	36,807	709	2,615	3,323	1,018	5,429	6,447	0.090	0.18
4	Yuba River	3,502	37	129	166	149	538	687	0.047	0.20
5	Feather River	9,994	-	-	-	953	2,424	3,378	-	0.34
6	Cache Creek	3,112	8.7	234	243	144	2,271	2,414	0.078	0.78
7	American River	5,528	181	262	442	346	1,054	1,400	0.080	0.25
8	Sacramento River at Hood/Greene's	61,316	3,442	7,750	11,193	4,241	13,342	17,583	0.18	0.29
9	Cosumnes River	2,390	4.7	52	57	28	322	350	0.024	0.15
10	San Joaquin River at Newman	19,085	446	965	1,411	2,776	6,475	9,251	0.074	0.48
11	Stanislaus River	3,478	114	236	350	245	732	976	0.10	0.28
12	Tuolumne River	4,586	165	594	759	1,241	2,660	3,901	0.17	0.85
13	Merced River	3,289	177	351	528	-	-	-	0.16	-
14	Bear Cr/Owens Cr/Mariposa Cr/ Deadmans Cr	2,397	-	-	-	-	-	-	-	-
15	Chowchilla River	850	-	-	-	-	-	-	-	-
16	San Joaquin River at Sack Dam	11,667	-	-	-	-	-	-	-	-
17	Mokelumne River	3,022	19	27	47	60	138	199	0.015	0.066
18	Bear River	1,229	2.7	42	45	16	268	284	0.037	0.23
19	Putah Creek	1,795	-	-	-	-	-	-	-	-
20	Delta North	2,148	-	-	-	-	-	-	-	-
21	Delta South	5,730	-	-	-	-	-	-	-	-
22	San Joaquin River at Vernalis	32,782	1,555	3,343	4,898	3,748	7,702	11,450	0.15	0.35
-	Yolo Bypass	-	132	565	697	561	8,490	9,051	-	-
-	**Delta Outflow Loads**	-	**1,171**	**6,264**	**7,435**	**4,243**	**26,642**	**30,885**	-	-

Note: Loads for watersheds without data in this table are presented in Table 4-10 and 4-11 for dry and wet years, respectively, as estimated using export rates.

Table 4-4.
Total phosphorus loads transported at locations corresponding to the outflow points of the subwatersheds in Table 4-1.

			Dry Years (tons)			Wet Years (tons)			Export Rates (tons/km^2)	
ID	**Watershed Name**	**Upstream Area (km^2)**	Dry Season	Wet Season	Total	Dry Season	Wet Season	Total	Dry year	Wet Year
1	Sacramento River above Bend Bridge	23,144	163	177	341	196	550	746	0.015	0.032
2	Butte Creek	2,402	-	-	-	-	-	-	-	-
3	Sacramento River at Colusa	36,807	249	796	1,045	276	1,494	1,770	0.028	0.048
4	Yuba River	3,502	4.6	14	18	17	56	73	0.0052	0.021
5	Feather River	9,994	-	-	-	56	357	413	-	0.041
6	Cache Creek	3,112	0.15	10	10	2.3	69	72	0.0033	0.023
7	American River	5,528	22	26	48	41	99	141	0.0087	0.025
8	Sacramento River at Hood/Greene's	61,316	602	1,284	1,886	766	2,316	3,082	0.031	0.050
9	Cosumnes River	2,390	1.0	8.3	9.3	5.2	50	55	0.0039	0.023
10	San Joaquin River at Newman	19,085	41	87	128	272	576	848	0.0067	0.044
11	Stanislaus River	3,478	17	28	45	36	86	122	0.013	0.035
12	Tuolumne River	4,586	15	27	42	109	126	235	0.0092	0.051
13	Merced River	3,289	7.7	12	20	-	-	-	0.0061	-
14	Bear Cr/Owens Cr/Mariposa Cr/ Deadmans Cr	2,397	-	-	-	-	-	-	-	-
15	Chowchilla River	850	-	-	-	-	-	-	-	-
16	San Joaquin River at Sack Dam	11,667	-	-	-	-	-	-	-	-
17	Mokelumne River	3,022	3.3	4.6	7.9	12	24	36	0.0026	0.012
18	Bear River	1,229	0.20	2.9	3.1	1.1	18	19	0.0025	0.016
19	Putah Creek	1,795	-	-	-	-	-	-	-	-
20	Delta North	2,148	-	-	-	-	-	-	-	-
21	Delta South	5,730	-	-	-	-	-	-	-	-
22	San Joaquin River at Vernalis	32,782	148	305	454	425	1,077	1,502	0.014	0.046
-	Yolo Bypass	-	11	45	57	49	681	730	-	-
-	**Delta Outflow Loads**	-	**192**	**857**	**1,049**	**708**	**3,765**	**4,473**	-	-

Note: Loads for watersheds without data in this table are presented in Table 4-12 and 4-13 for dry and wet years, respectively, as estimated using export rates.

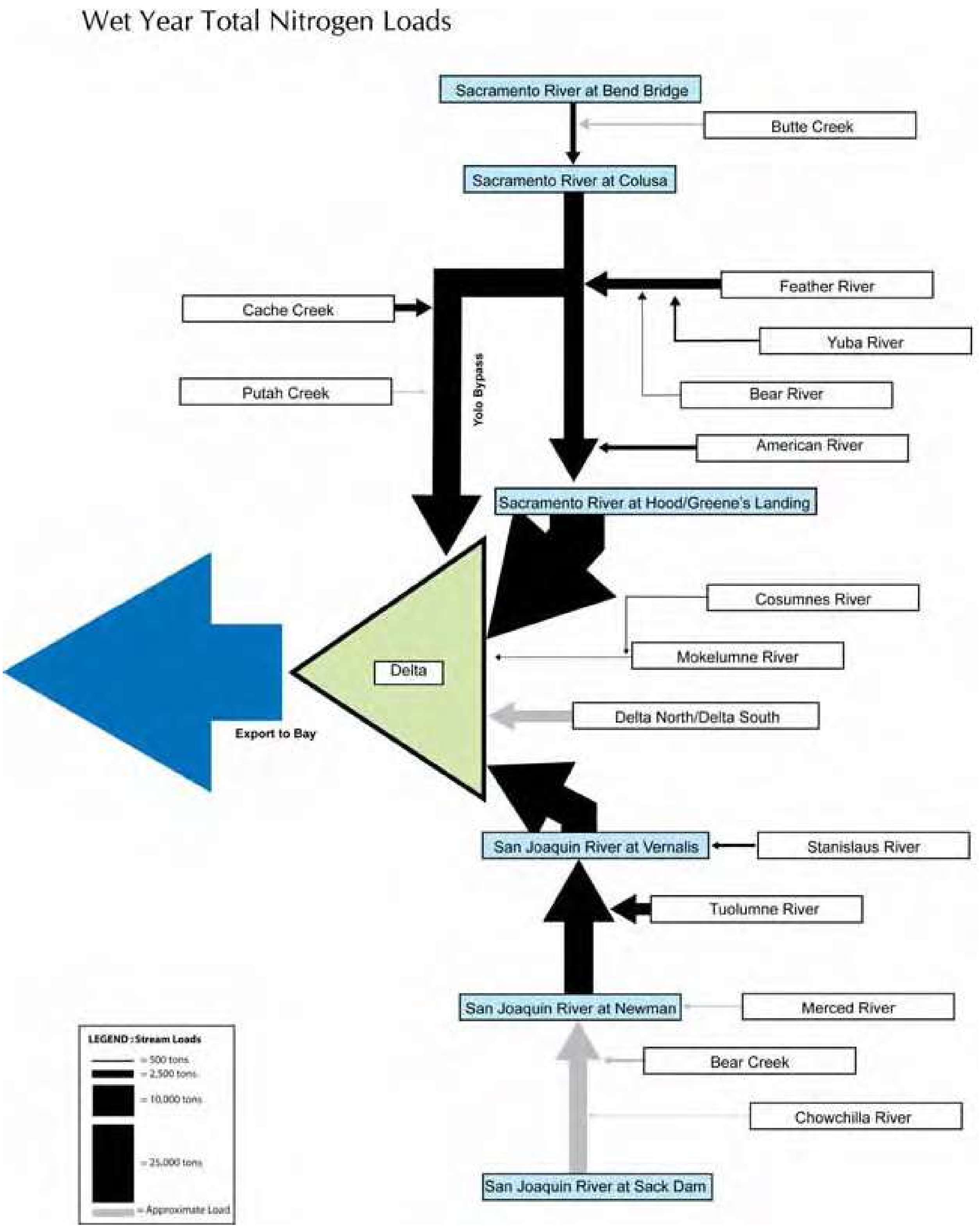


Figure 4-24. TN loads for an average wet year on a schematic representation of the San Joaquin-Sacramento River systems. In-Delta nutrient sources and sinks are presented in Chapter 5.

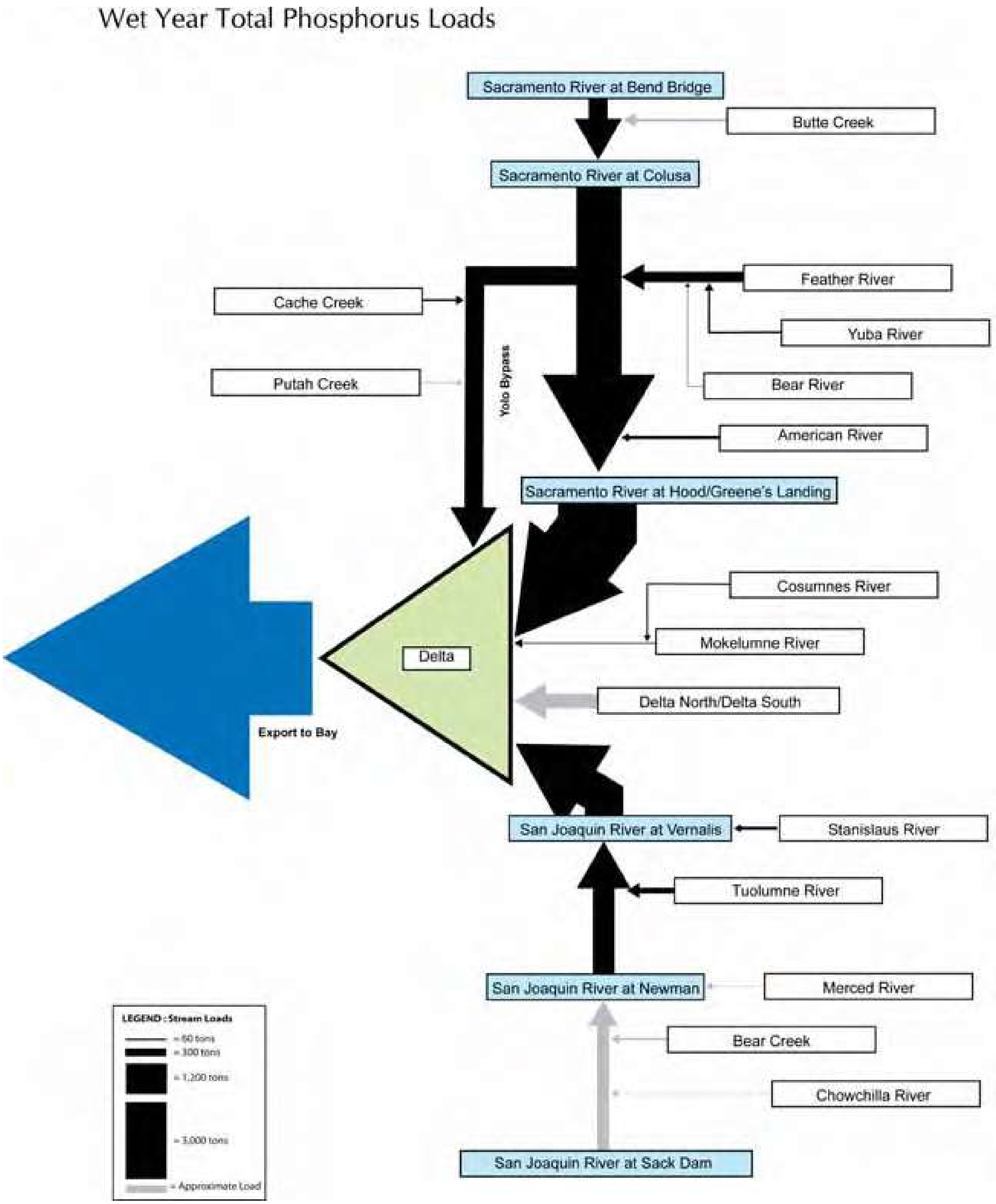


Figure 4-25. TP loads for an average wet year on a schematic representation of the San Joaquin-Sacramento River systems. In-Delta nutrient sources and sinks are presented in Chapter 5.

Table 4-5.
Estimated TN loads from this study compared with other published studies (Saleh et al., 2003; Woodard, 2000, Kratzer et al., 2004).

	This Study (tons)		Saleh et al., 2003; Data from 1980-2000 (tons)		Woodard, 2000; Data from 1980-1999 (tons)		Kratzer et al., 2004; Data from 1972-1999 (tons)
Watershed Name	Dry Years	Wet Years	Dry Years	Wet Years	Dry Years	Wet Years	All Years[2]
Sacramento River at Hood/Greene's Landing	11,193	17,583	4,116[1]	8,848[1]	13,516[1]	21,917[1]	-
San Joaquin River at Vernalis	4,898	11,450	3,843	9,017	4,391	10,923	7,000

[1] Data from Sacramento River at Freeport.

[2] Breakdown between wet and dry years not available.

Table 4-6.
Estimated TP loads from this study compared with other published studies (Saleh et al., 2003; Woodard, 2000, Kratzer et al., 2004).

	This Study (tons)		Saleh et al., 2003; Data from 1980-2000 (tons)		Woodard, 2000; Data from 1980-1999 (tons)		Kratzer et al., 2004; Data from 1972-1999 (tons)
Watershed Name	Dry Years	Wet Years	Dry Years	Wet Years	Dry Years	Wet Years	All Years[2]
Sacramento River at Hood/Greene's Landing	1,886	3,082	1,483[1]	3,358[1]	1,409[1]	3,070[1]	-
San Joaquin River at Vernalis	454	1,502	517	1,536	453	1,213	944

[1] Data from Sacramento River at Freeport.

[2] Breakdown between wet and dry years not available.

4.4 ESTIMATION OF WATERSHED LOADS

Stream loads calculated above can be compared with loads originating in the watershed that include non-point sources (principally different land uses, such as agriculture, urban land, wetlands, and other natural lands), and point sources (principally wastewater treatment, although other sources may be contributors). The sections below discuss the approach used to estimate these contributions. These are preliminary estimates due to the limited data that were available to calculate export rates from individual land uses.

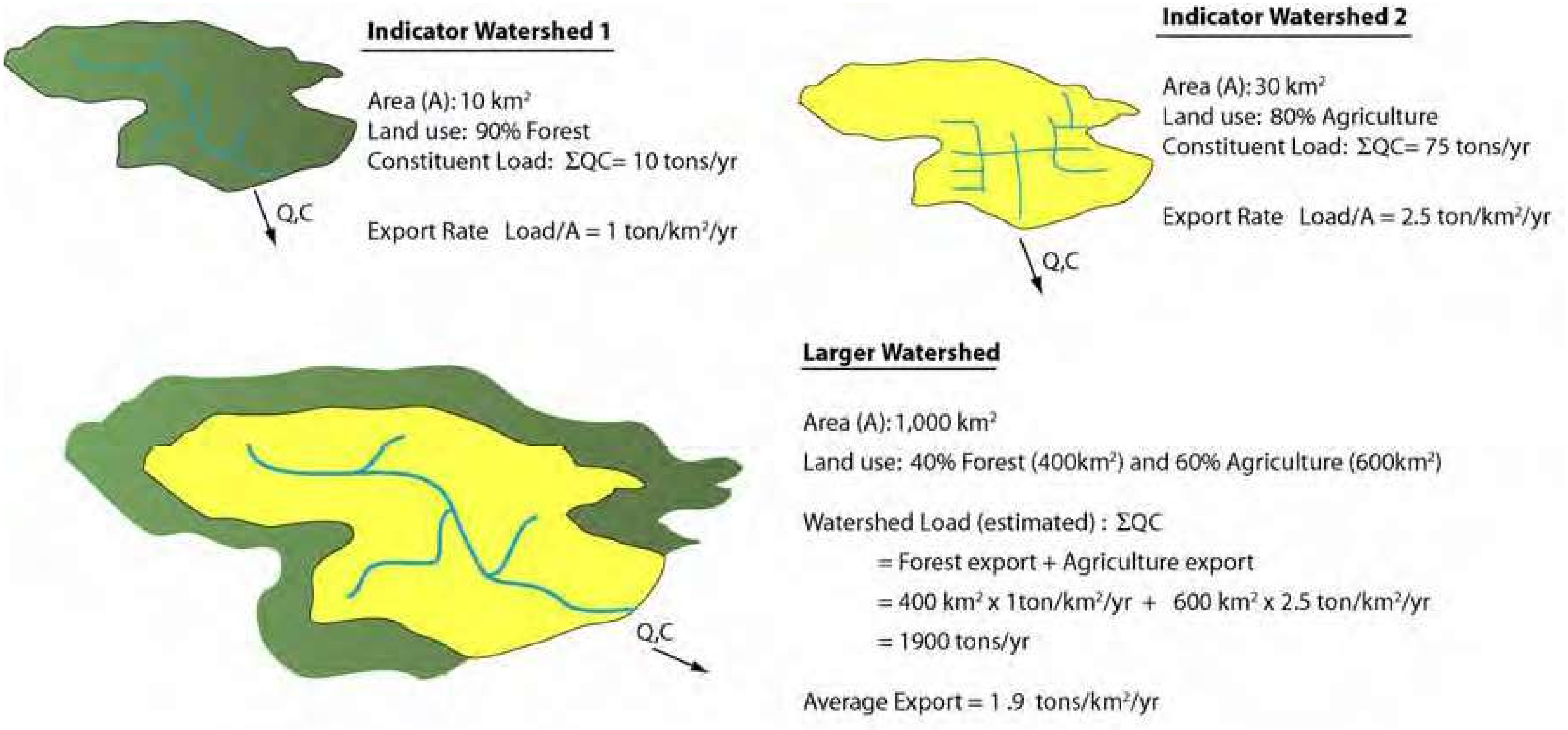
4.4.1 ESTIMATION OF NUTRIENT EXPORT RATES FROM NON-POINT SOURCES

Non-point source contributions of nutrient loads to streams are expressed as mass delivered to the stream per unit area per unit time. The stream outflow represents the load contributions in surface runoff as well as baseflow (i.e., through groundwater). The export rate calculations are similar to the load estimates from streams except that for the rates to be applicable to one type of land use, the watershed in consideration must contain only that land use. Thus, an urban land nitrogen or phosphorus export rate is obtained from a watershed that is entirely urban land, and a background export rate is obtained from a watershed with minimal development. In practice, finding watersheds with only one type of land use is very difficult, although in some instances small indicator watersheds may be found that fit this criterion. Export rates from specific land uses, weighted by the area of that land use in a watershed, can be used to compute the non-point source contribution, as shown schematically in Figure 4-26.

Nitrogen and phosphorus export rates were estimated for urban land and agricultural land, background loads from a mix of forest, shrubland, or rangeland, and from wetlands. Further stratification of land use-based export rates (e.g., by crop type for agricultural land) was not possible given the existing data. This is an area that will benefit greatly through collection of additional data in small indicator watersheds as described in Chapter 6.

The following locations were used to develop preliminary export rates:

- The Colusa Basin Drain was used for estimating agricultural loads in the Sacramento River Basin as shown in Figure 4-27. Although the Colusa Basin Drain watershed includes non-agricultural land, it was the best station based on the existing data.



Indicator Watershed 1

Area (A): 10 km²
Land use: 90% Forest
Constituent Load: ΣQC= 10 tons/yr

Export Rate Load/A = 1 ton/km²/yr

Indicator Watershed 2

Area (A): 30 km²
Land use: 80% Agriculture
Constituent Load: ΣQC= 75 tons/yr

Export Rate Load/A = 2.5 ton/km²/yr

Larger Watershed

Area (A): 1,000 km²

Land use: 40% Forest (400km²) and 60% Agriculture (600km²)

Watershed Load (estimated) : ΣQC
= Forest export + Agriculture export
= 400 km² x 1ton/km²/yr + 600 km² x 2.5 ton/km²/yr
= 1900 tons/yr

Average Export = 1 .9 tons/km²/yr

Figure 4-26. Export rates from specific land uses, weighted by the area of that land use in a watershed, can be used to compute the non-point source contribution for a mixed land use watershed.

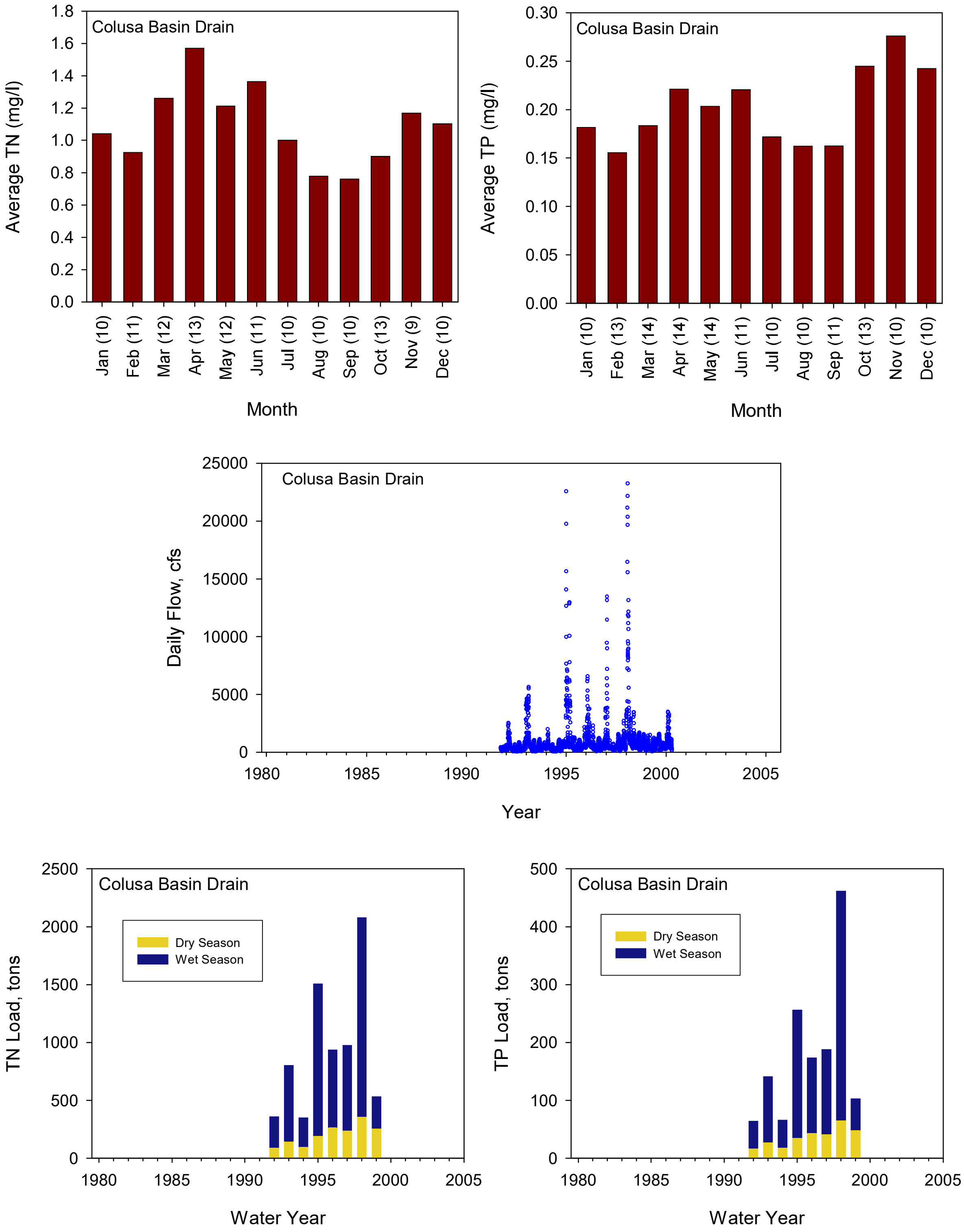


Figure 4-27. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Colusa Basin Drain. These data were used to estimate the nutrient export rate from agriculture in the Sacramento River basin.

- Mud Slough was used for estimating agricultural loads in the San Joaquin River Basin as shown in Figure 4-28. For the Organic Carbon Conceptual Model Report (Tetra Tech, 2006), Harding Drain was used for agricultural loads in the San Joaquin Basin. Nutrient concentrations in the Harding Drain are impacted by effluent received from the City of Turlock wastewater treatment plant, however, and calculated monthly average concentrations were as high as 30 mg/l for TN and 10 mg/l for TP. Mud Slough also has some drawbacks associated with its use as representative of San Joaquin Valley agricultural loads. It contains an atypical mix of tile drainage transported via the San Luis drain and also receives overflow from private duck clubs. Thus, Mud Slough provides only a preliminary estimate of the export rate from agriculture in the San Joaquin Basin.

- Salt Slough was used for estimating wetland loads in the San Joaquin Basin as shown in Figures 4-29.

- The urban runoff export rate for nutrients was estimated using USGS NWIS data collected at Arcade Creek, which is a small, entirely urban, watershed (Figure 4-30). Data collected at the Natomas East Main Drainage Canal (NEMDC) may also be used for estimating urban runoff loads. Although this watershed is rapidly urbanizing, it still contains some agricultural land. The Arcade Creek watershed was considered the best choice for this analysis since it is an entirely urbanized watershed. Other urban runoff data in the Drinking Water Policy Database, from the cities of Sacramento and Stockton, could not be used for load calculations because these data were not accompanied by flow measurements. Figure 4-31 presents NO3-N, TKN, and TP data for the NEMDC and for dry weather and stormwater flows at Sacramento and Stockton. NEMDC data were obtained from the MWQI website for the period 2001 to 2004. The urban runoff data from Sacramento, Stockton, and from the NEMDC were compared to the data collected on Arcade Creek. Note that there is a degree of overlap among these data sources. Arcade Creek is a subwatershed of the NEMDC and both overlap with the Sacramento Stormwater program area. This fact should be taken into consideration when comparing the data. The monthly average concentrations for Arcade Creek ranged from 1 to 2.5 mg/L for TN and 0.2 to 0.5 mg/L for TP. The Sacramento, Stockton, and NEMDC nitrogen data showed some degree of variability with median concentrations of both NO3-N and TKN ranging from approximately 1 mg/l to 2 mg/l, which are comparable to Arcade Creek data. The Sacramento, Stockton, and NEMDC phosphorus data show median values from 0.3 to 0.8 mg/l, slightly higher than the Arcade Creek data.

- For the Sacramento Basin, no station could be clearly identified as a background station with insignificant anthropogenic activity. As a first approximation, the Yuba River watershed was used to estimate background loads (representing forest/rangeland) for the Sacramento River Basin. Of the major tributaries, the Yuba River watershed has the least amount of urban and agricultural land. For background loads representing forest/rangeland in the San Joaquin Basin, Merced River at Happy Isles Bridge near Yosemite was identified as a possible station. This station is part of the Hydrologic Benchmark Network, which is a USGS program that provides long-term measurements of streamflow and water quality in areas that are minimally impacted by human activities (http://ny.cf.er.usgs.gov/hbn/). Flows for this station are higher in the dry season, however, due to snowmelt in late spring. Because this behavior is not reflective of the majority of the basin, this station was not used to calculate an export rate for background loads.

The summary of export rates for various land uses in the Central Valley is presented in Table 4-7. Although it would be preferable to obtain separate export rates for the Sacramento and San Joaquin Basins because of the distinct differences in rainfall, this was not possible with existing data. Rainfall during water years 2002 and 2003 measure at three stations in the Sacramento Valley averaged 23.7 inches and measured at three stations in the San Joaquin Valley averaged 11.7 inches (MWQI, 2005), which is a factor of two difference. Therefore, when a rate from the Sacramento Basin was applied to the San Joaquin Basin (for urban runoff and forest/rangeland), the export rate was divided by two to account for the lower rainfall in the San Joaquin Basin. When a rate from the San Joaquin Basin was applied to the Sacramento Basin (for wetlands), the rate was multiplied by two to account for the higher rainfall in the Sacramento Basin. For agricultural land, separate values were used for the Sacramento and San Joaquin Basins.

In summary, it was not possible to calculate export rates for each type of land use present in the Central Valley and Delta. A limited amount of nutrient data was available from watersheds with one particular type of land use. Significant inherent uncertainty exists in the calculated export rates due to sparse or inadequate data, and in the application of export rates from one basin to another. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

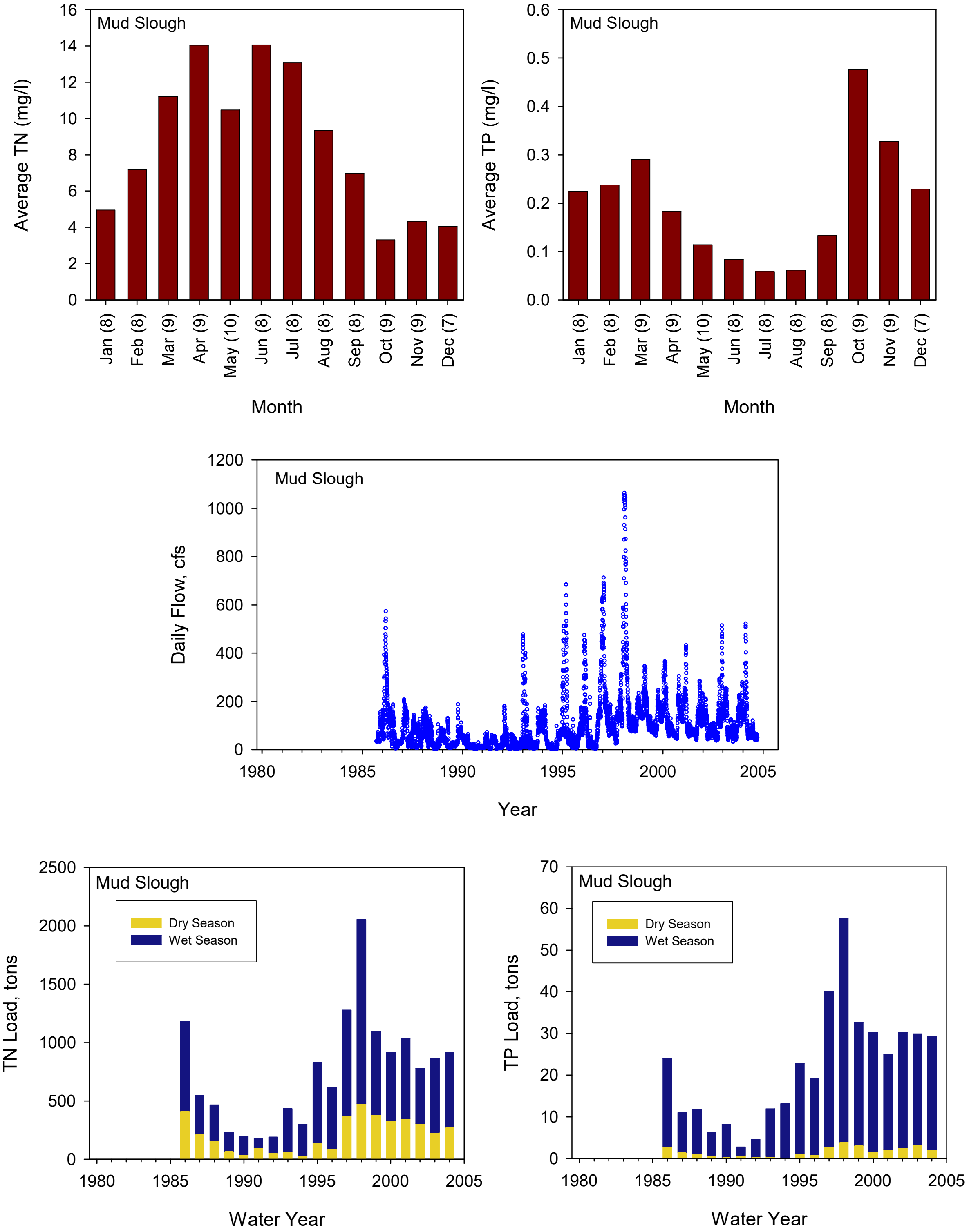


Figure 4-28. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for the Mud Slough. These data were used to estimate the nutrient export rate from agriculture in the San Joaquin River basin.

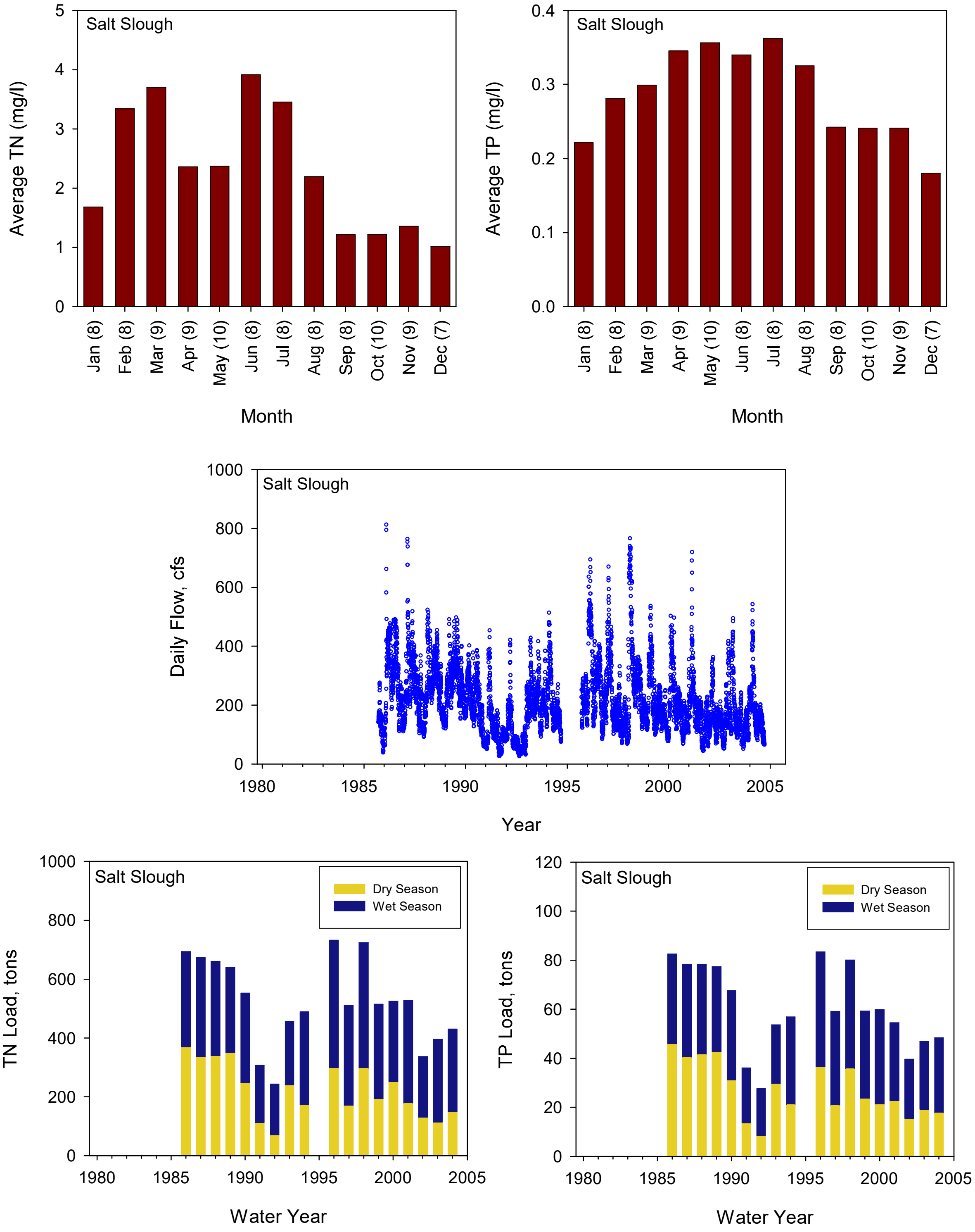


Figure 4-29. **Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Salt Slough. These data were used to estimate the nutrient export rate from wetlands in the San Joaquin River basin.**

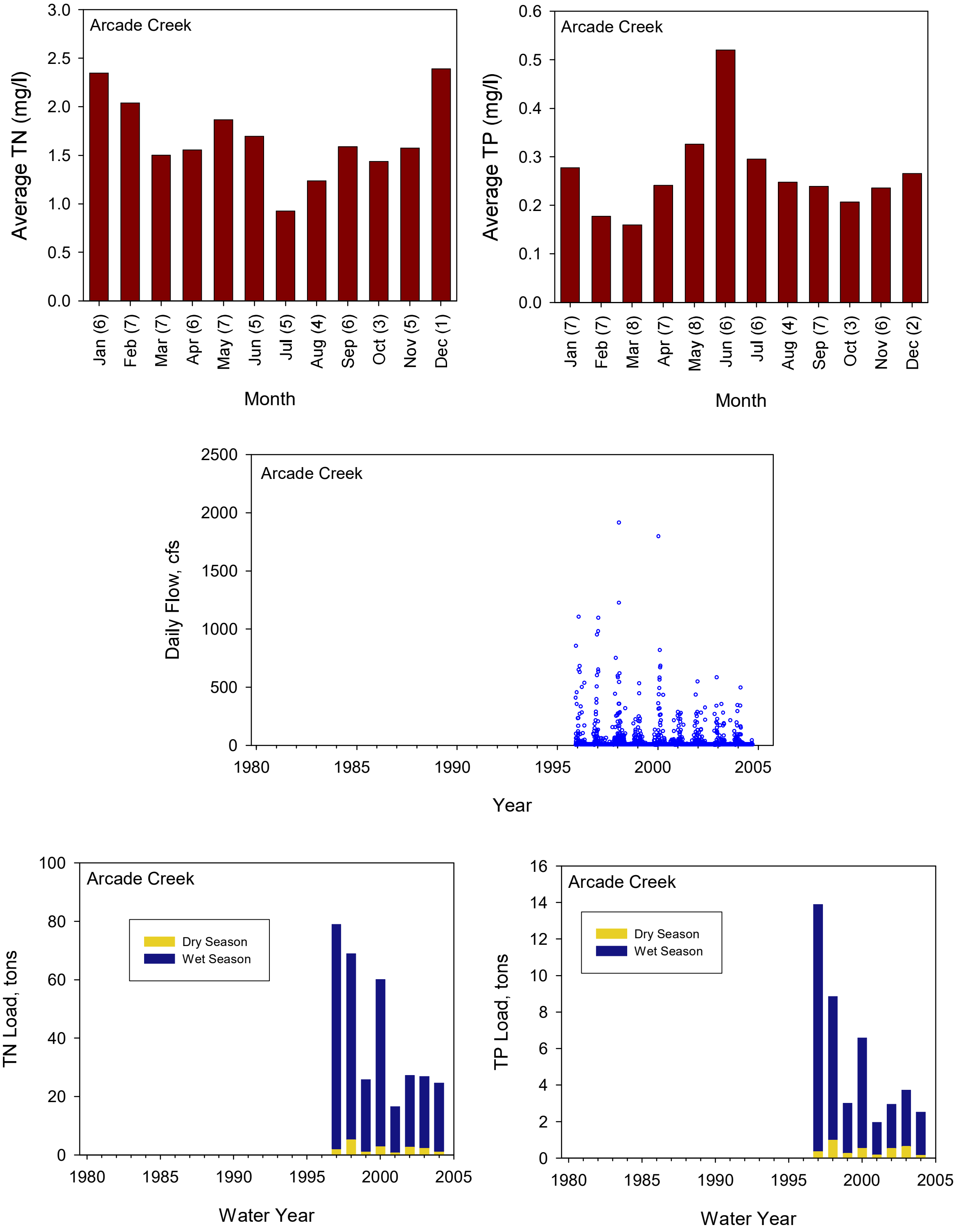


Figure 4-30. Monthly average concentration, daily discharge, and estimated wet and dry season loads by water year for Arcade Creek, used to estimate the urban runoff export rate for nutrients from the Sacramento River basin.

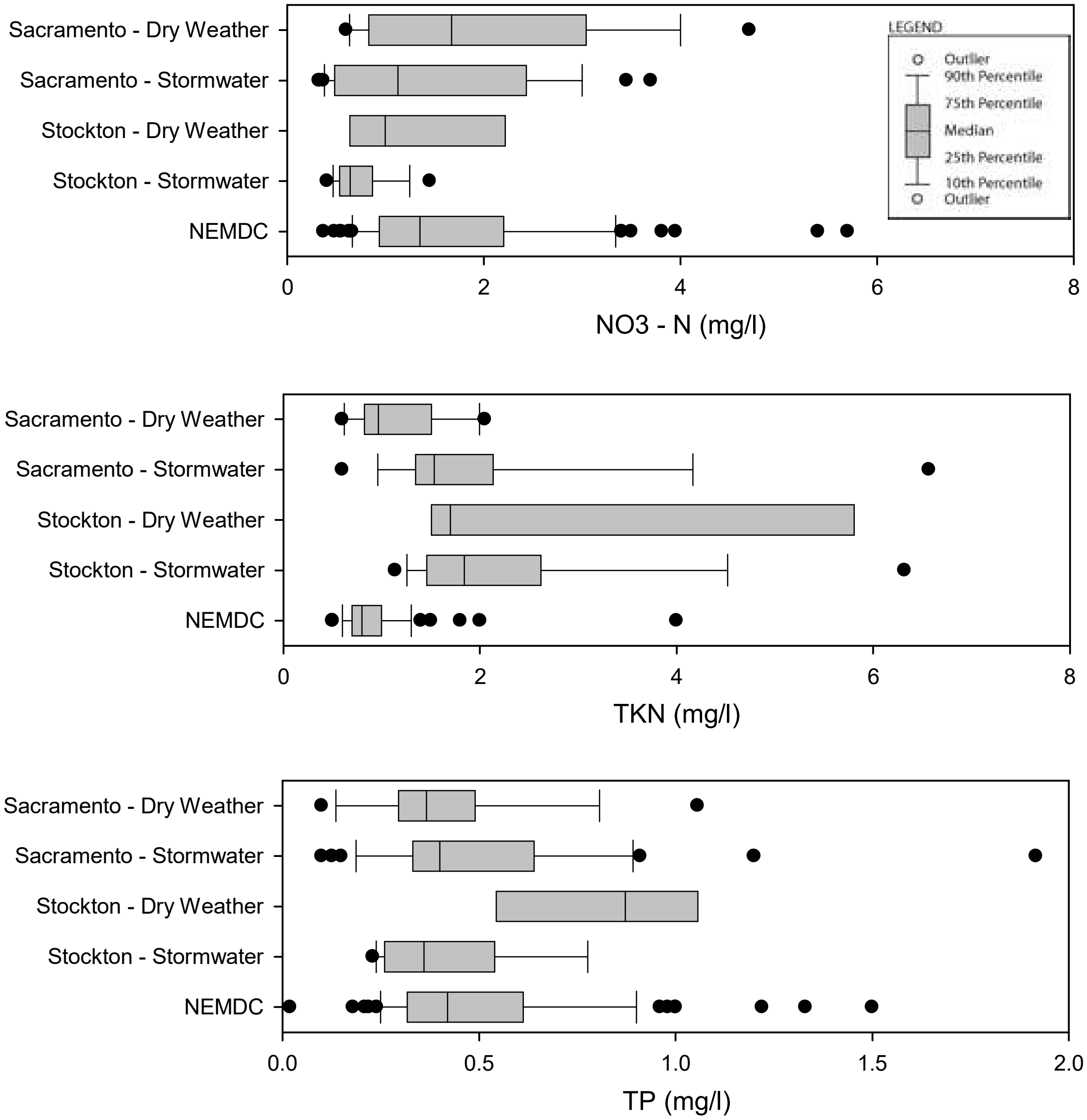


Figure 4-31. Urban runoff nutrient concentration data from Sacramento, Stockton, and the Natomas East Main Drainage Canal (NEMDC).

Table 4-7.
Export rates of nutrients from major land uses in the Central Valley.

NITROGEN

Land Use	**Dry Year Loads (tons/km²/yr)**		**Wet Year Loads (tons/km²/yr)**		**Source**	
	Sac-ramento	*San Joaquin*	*Sac-ramento*	*San Joaquin*	*Sacramento*	*San Joaquin*
Agriculture[1]	0.082	0.41	0.27	0.82	Colusa Basin Drain	Mud Slough
Urban Runoff	0.26	0.13	0.60	0.30	Arcade Creek	Calculated from Sacramento value
Forest/Rangeland	0.047	0.024	0.20	0.10	Yuba River	Calculated from Sacramento value
Wetland-Dominated[2]	0.75	0.37	0.93	0.47	Calculated from San Joaquin value	Salt Slough

PHOSPHORUS

Land Use	**Dry Year Loads (tons/km²/yr)**		**Wet Year Loads (tons/km²/yr)**		**Source**	
	Sac-ramento	*San Joaquin*	*Sac-ramento*	*San Joaquin*	*Sacramento*	*San Joaquin*
Agriculture[1]	0.015	0.012	0.052	0.023	Colusa Basin Drain	Mud Slough
Urban Runoff	0.028	0.014	0.083	0.041	Arcade Creek	Calculated from Sacramento value
Forest/Rangeland	0.0052	0.0026	0.021	0.010	Yuba River	Calculated from Sacramento value
Wetland-Dominated[2]	0.087	0.044	0.11	0.054	Calculated from San Joaquin value	Salt Slough

[1] Available data do not allow separation into crop types.

[2] Wetland-dominated land may include a portion that is agricultural land.

4.4.2 POINT SOURCES

Point source discharges in the Central Valley watershed include municipal wastewater treatment plants, industrial discharges, and fish hatcheries. There were no nutrient concentration data for discharges from fish hatcheries or industrial facilities available for this study. The major municipal wastewater dischargers are shown in Table 4-8 and on Figure 4-32. Nutrient concentration and flow data were available for the majority of plants listed in Table 4-8. The available nutrient concentration data, ammonia-N, NO3-N, and TP, are presented in Figures 4-33 through 4-35, respectively. Effluent flow data are presented in Figure 4-36. Ammonia-N and NO3-N concentrations were added to estimate total nitrogen for the point source loads. TP data were used directly. Annual average data were used in all cases.

Available flow and concentration data for each subwatershed and the resultant load calculations are presented in Table 4-9 and described below. For each subwatershed, the wastewater plants in the basin and the available nutrient data (TN and/or TP) are presented in column 3 of the table. Wastewater plants only appear in this column for TN if both ammonia-N and NO3-N data are available. For example, Chico has ammonia-N data (Figure 4-33) but not NO3-N data (Figure 4-34) and thus does not appear in Table 4-9. Column 4 presents available per capita flow data. Even though plant effluent flow is available for most of the treatment plants (Figure 4-38), the per capita flow can be calculated only for plants for which population-served data are available. Population-served data are readily available (i.e., through an internet search) for Davis (60,300), Vacaville (88,200) and Sacramento Regional (1,128,000). Columns 5 and 6 of the table present subwatershed specific TN and TP concentration data where available, calculated through flow-weighted averaging over all plants in the subwatershed. The load per person per year was calculated using available per capita flow and concentration data (columns 7 and 8). Where these data were not available for a particular subwatershed, data averaged over all subwatersheds were used (per capita flow = 38,400 gal/year; TN = 14.5 mg/l; TP = 2.5 mg/l). The final loads per person vary from 1.3 to 4.2 kg/person/yr for TN and 0.30 to 0.48 kg/person/yr for TP. For each subwatershed, the load per person per year was multiplied by the basin population (column 9) to determine the average annual load for TN and TP (columns 10 and 11).

Table 4-8.
Wastewater treatment plants in the Central Valley and Delta.

Wastewater Treatment Plant		Treatment	Design Flow (MGD)
Sacramento Basin			
	Sacramento Regional	Secondary	181
	Roseville-Dry Creek	Tertiary	18
	Roseville-Pleasant Grove Creek	Tertiary	12
	Vacaville	Secondary	10
	Chico	Secondary	9
	Redding Clear Creek	Secondary	9
	Woodland	Secondary	8
	West Sacramento	Secondary	8
	Davis	Secondary	8
	Yuba City	Secondary	7
	Redding Stillwater	Advanced Secondary	4
Total Flow to Sacramento			*273*
San Joaquin Basin			
	Modesto	Secondary	70
	Stockton (Nov-Jun)	Secondary	55
	Stockton (July-Oct)	Advanced Secondary	55
	Turlock	Secondary	20
	Merced	Secondary	10
	Manteca	Secondary	10
Total Flow to San Joaquin			*165*
Delta			
	Tracy	Secondary	9
	Lodi	Advanced Secondary	7
	Brentwood	Advanced Secondary	5
	Discovery Bay	Secondary	2
Total Flow to Delta			*23*
Total Watershed Flow			**461**

Figure 4-32. Point source discharge locations in the database developed by Central Valley Drinking Water Policy Workgroup.

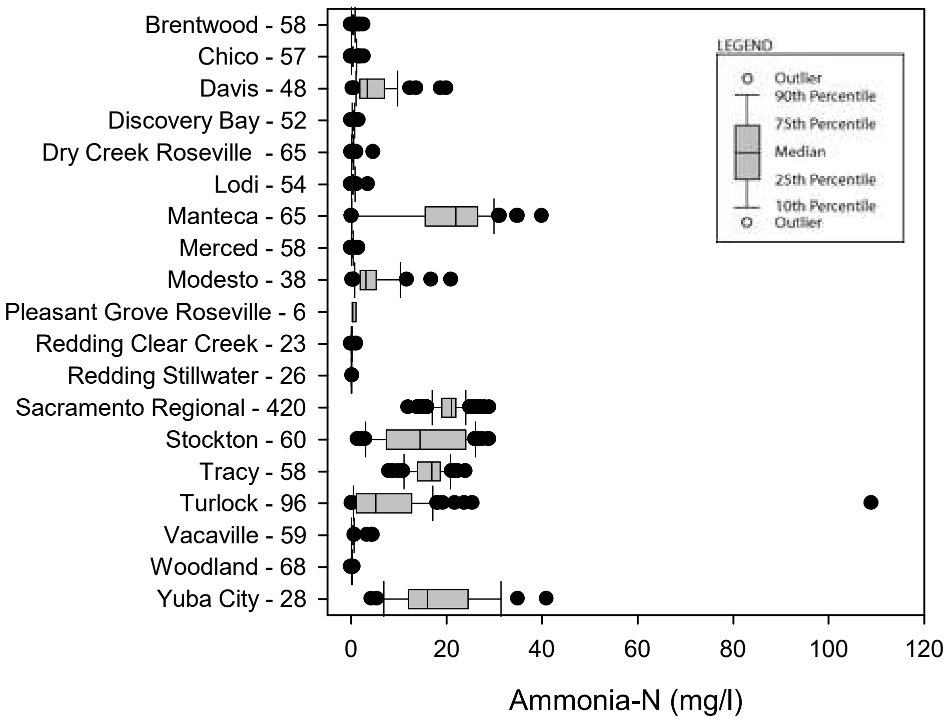


Figure 4-33. Ammonia-N concentration data for wastewater treatment plants in the Central Valley. The number of data points is shown after each plant.

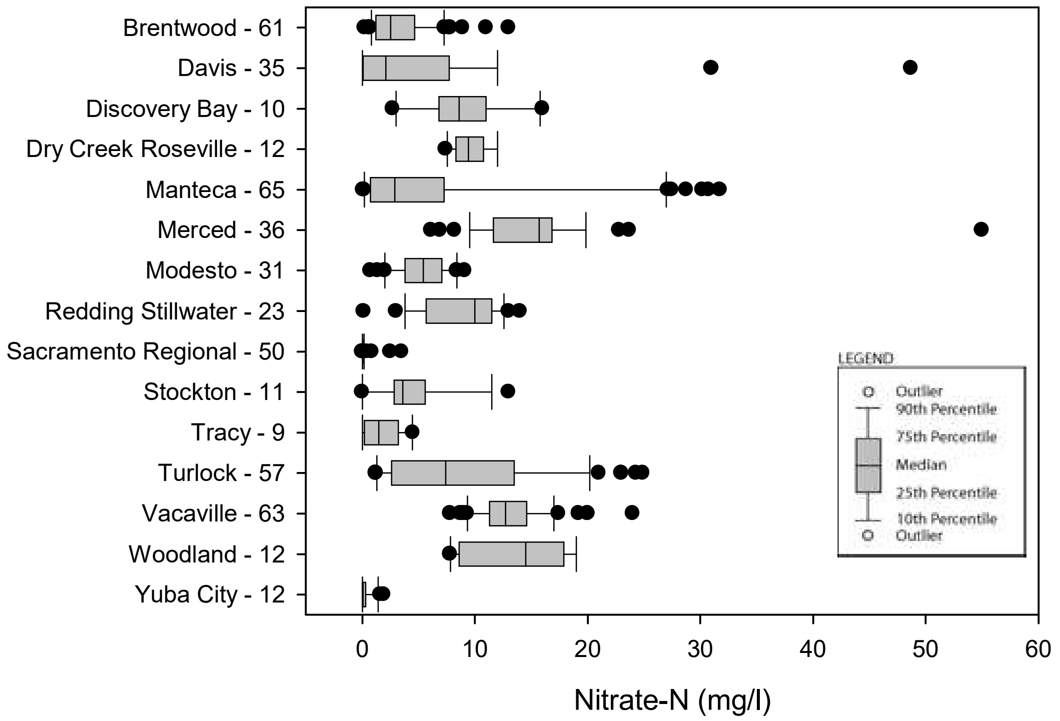


Figure 4-34. NO3-N concentration data for wastewater treatment plants in the Central Valley. The number of data points is shown after each plant.

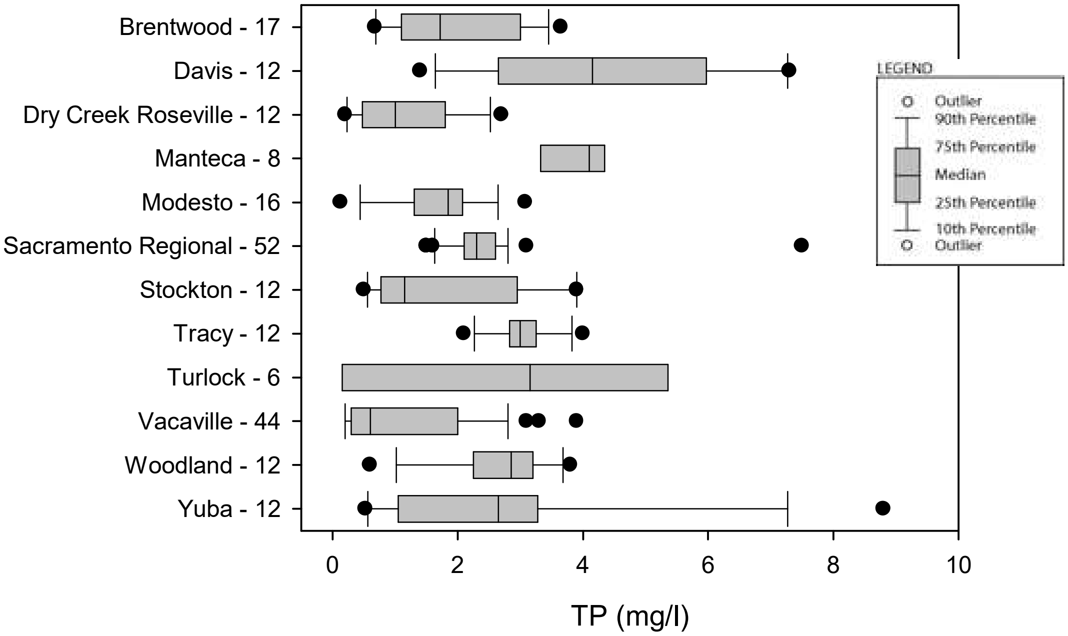


Figure 4-35. TP concentration data for wastewater treatment plants in the Central Valley. The number of data points is shown after each plant.

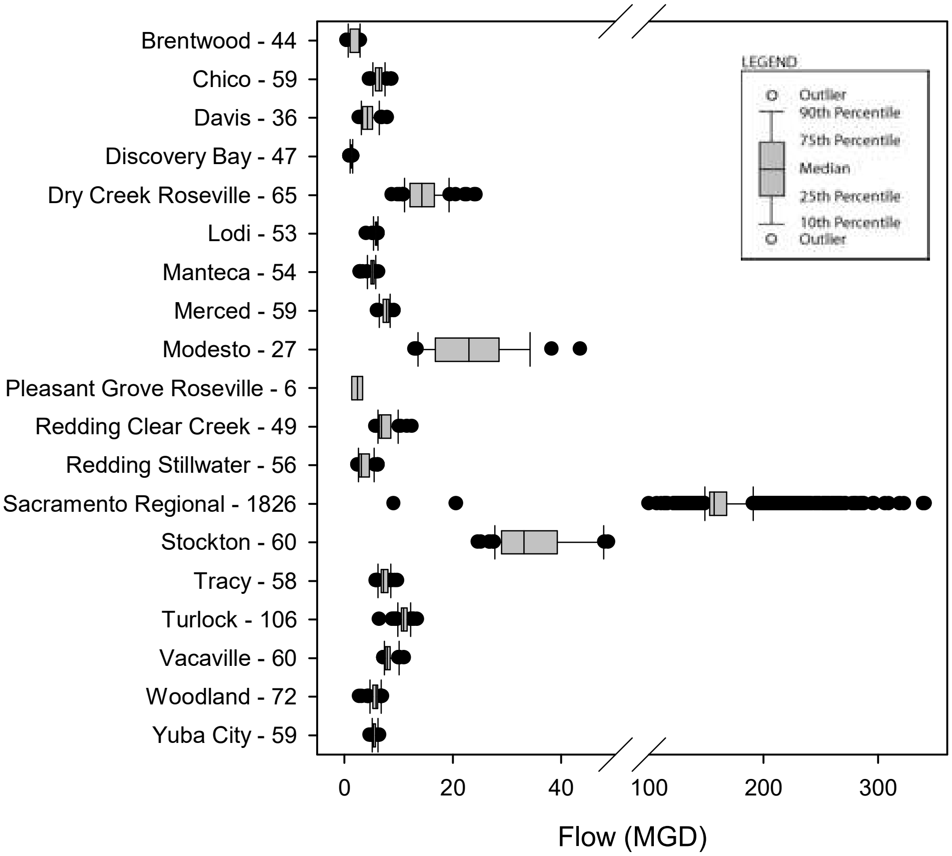


Figure 4-36. Flow data for wastewater treatment plants in the Central Valley. The number of data points is shown after each plant.

Table 4-9.
Average concentrations and loads from wastewater dischargers in the Central Valley and Delta.

				Basin specific concentrations (flow weighted averages, mg/l)		Load summary (kg/person/yr)			Load (tons/yr)	
ID	Watershed Name	Plants in Basin with Data[1]	Per capita flow (gal/year)	TN[2]	TP	TN	TP	Population[3]	TN	TP
1	Sacramento River above Bend Bridge	Redding Stillwater (N)	-	8.7	-	1.3	0.36	118,282	165	47
2	Butte Creek	None	-	-	-	2.1	0.36	64,361	150	25
3	Sacramento River at Colusa	None	-	-	-	2.1	0.36	119,638	278	47
4	Yuba River	None	-	-	-	2.1	0.36	19,879	46	8
5	Feather River	Yuba City (N, P)	-	18.7	2.8	2.7	0.40	106,178	318	47
6	Cache Creek	None	-	-	-	2.1	0.36	32,946	77	13
7	American River	None	-	-	-	2.1	0.36	879,576	To Sac R	To Sac R
8	Sacramento River at Hood/Greene's	Sacramento Regional (N, P); Roseville-Dry Creek (N, P)	53,391	20.0	2.3	4.2	0.48	485,552	6,342	724
9	Cosumnes River	None	-	-	-	2.1	0.36	45,600	106	18
10	San Joaquin River at Newman	None	-	-	-	2.1	0.36	70,825	165	28
11	Stanislaus River	None	-	-	-	2.1	0.36	197,194	459	78
12	Tuolumne River	None	-	-	-	2.1	0.36	113,101	263	45
13	Merced River	None	-	-	-	2.1	0.36	1,238	3	0
14	Bear Creek	Merced (N)	-	15.8	-	2.3	0.36	99,300	251	39
15	Chowchilla River	None	-	-	-	2.1	0.36	5,603	13	2
16	San Joaquin River at Sack Dam	None	-	-	-	2.1	0.36	673,960	1568	267
17	Mokelumne River	None	-	-	-	2.1	0.36	39,876	93	16
18	Bear River	None	-	-	-	2.1	0.36	31,355	73	12
19	Putah Creek	None	-	-	-	2.1	0.36	32,250	75	13
20	Delta North	Vacaville (N, P); Davis (N, P); Woodland (N, P)	30,883	13.1	2.4	1.5	0.30	284,376	460	93
21	Delta South	Brentwood (N, P); Discovery Bay (N); Manteca (N, P); Stockton (N, P); Tracy (N, P)	-	19.5	2.1	2.8	0.31	497,805	1553	169
22	San Joaquin River at Vernalis	Modesto (N, P); Turlock (N, P)	-	12.3	2.1	1.8	0.31	136,680	268	46

Basin-wide average data:

Per capita flow (gal/yr) = 38,400

Average TN (mg/l) = 14.5

Average TP (mg/l) = 2.5

Notes:

1. Plants will only be listed here if they have TP data or *both* Ammonia-N and NO3-N (for N).
2. TN = Ammonia-N + NO3-N.
3. Census 2000 data (**http://casil.ucdavis.edu/casil/gis.ca.gov/census/**)

4.4.3 COMPARISON OF WATERSHED AND OUTFLOW LOADS

The relationship between upstream loads, watershed loads corresponding to a stream reach, and downstream exported loads is shown schematically in Figure 4-37. If instream transformation processes are not dominant, the sum of the upstream loads and the watershed loads should be approximately equal to the downstream exported loads. Because instream loads and export rate based watershed loads were computed independently in the previous sections, the comparison of these loads provides a useful check on the calculations so far, and discrepancies are one indication of uncertainties or inaccuracies in the load calculations.

In Figures 4-38 and 4-39 for nitrogen and Figures 4-40 and 4-41 for phosphorus, nutrient load estimates based on in-stream measurements of flow and concentration (termed outflow loads here) are compared with the export rate estimate of loads for each subwatershed for wet years and dry years. The upper portion of each figure illustrates the loads estimated using export rates for each of the landuse categories for each subwatershed. The lower portion of each figure compares the sum of the watershed loads as presented in the upper portion (watershed loads), these watershed loads added to the upstream instream component (watershed loads + upstream inputs), and the outflow loads as computed using instream data, previously presented in Tables 4-3 and 4-4 (outflows). This information is tabulated in Tables 4-10 and 4-11 for nitrogen and Tables 4-12 and 4-13 for phosphorus. The point source category in these tables and figures refers to wastewater effluent only, as this was the only point source quantified for this study.

In general, the load estimates by the two very different approaches are more comparable in wet years than dry years. In several cases, including tributary stations near the Delta, the loads estimated are comparable. In other cases, the load estimates are off by a larger factor, such as the Mokelumne River and American River during dry years, where the estimates are off by a factor of approximately five or greater for both nitrogen and phosphorus. In general, the greatest discrepancies occur at the locations that have the least amount of nutrient concentration data.

Total watershed loads entering the Delta at the major tributary input locations, Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis, are presented in Figure 4-42. These load components are based solely on export rates as applied to the entire watersheds upstream of each location, and thus will be different from loads presented on the top portion of Figures 4-38 to 4-41 for Hood/Greene's Landing and Vernalis, which present loads from the individual subwatersheds for these locations (i.e., subwatersheds 8 and 22). The watershed and outflow loads are shown in a graphical schematic for nitrogen in Figures 4-43 and 4-44 for average wet and dry years and for phosphorus in Figures 4-45 and 4-46 for average wet and dry years.

Several observations are possible from this first attempt at watershed load estimates, as shown in Figure 4-42. For nitrogen, forest/rangeland loads may dominate the overall loads for the Sacramento Basin and agricultural loads may dominate in the overall loads to the San Joaquin Basin, particularly for wet years. Point source loads from wastewater discharges may contribute nearly half or more of the overall nitrogen and phosphorus loads during dry years in both basins, and possibly during wet years for phosphorus in the San Joaquin Basin.

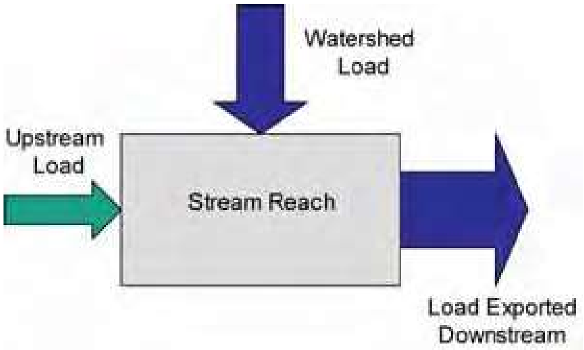


Figure 4-37. The relationship between upstream loads, watershed loads corresponding to a stream reach, and downstream exported loads. These three load values are compared in Figures 4-38 through 4-41.

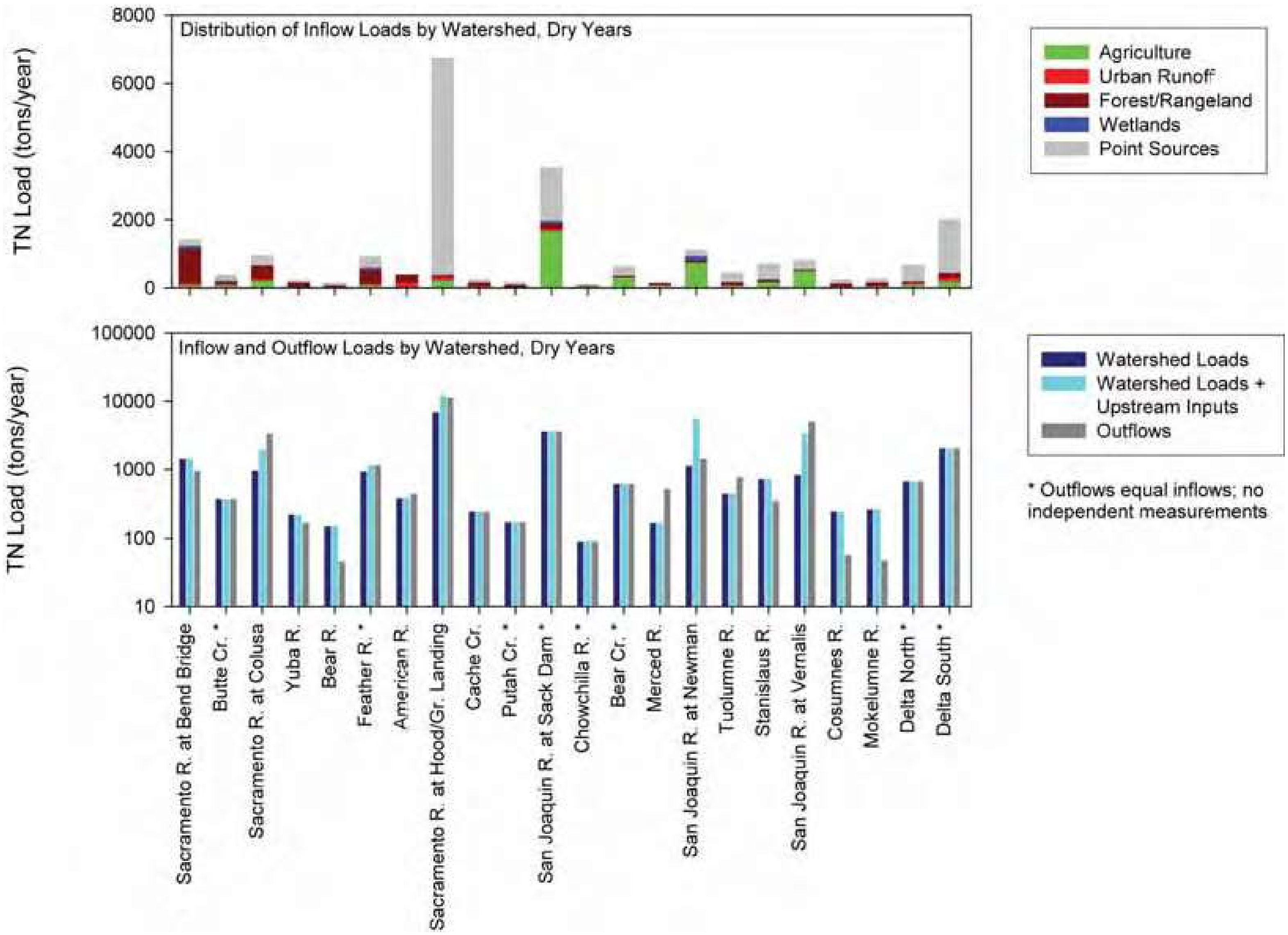


Figure 4-38. Distribution of nitrogen watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for dry years.

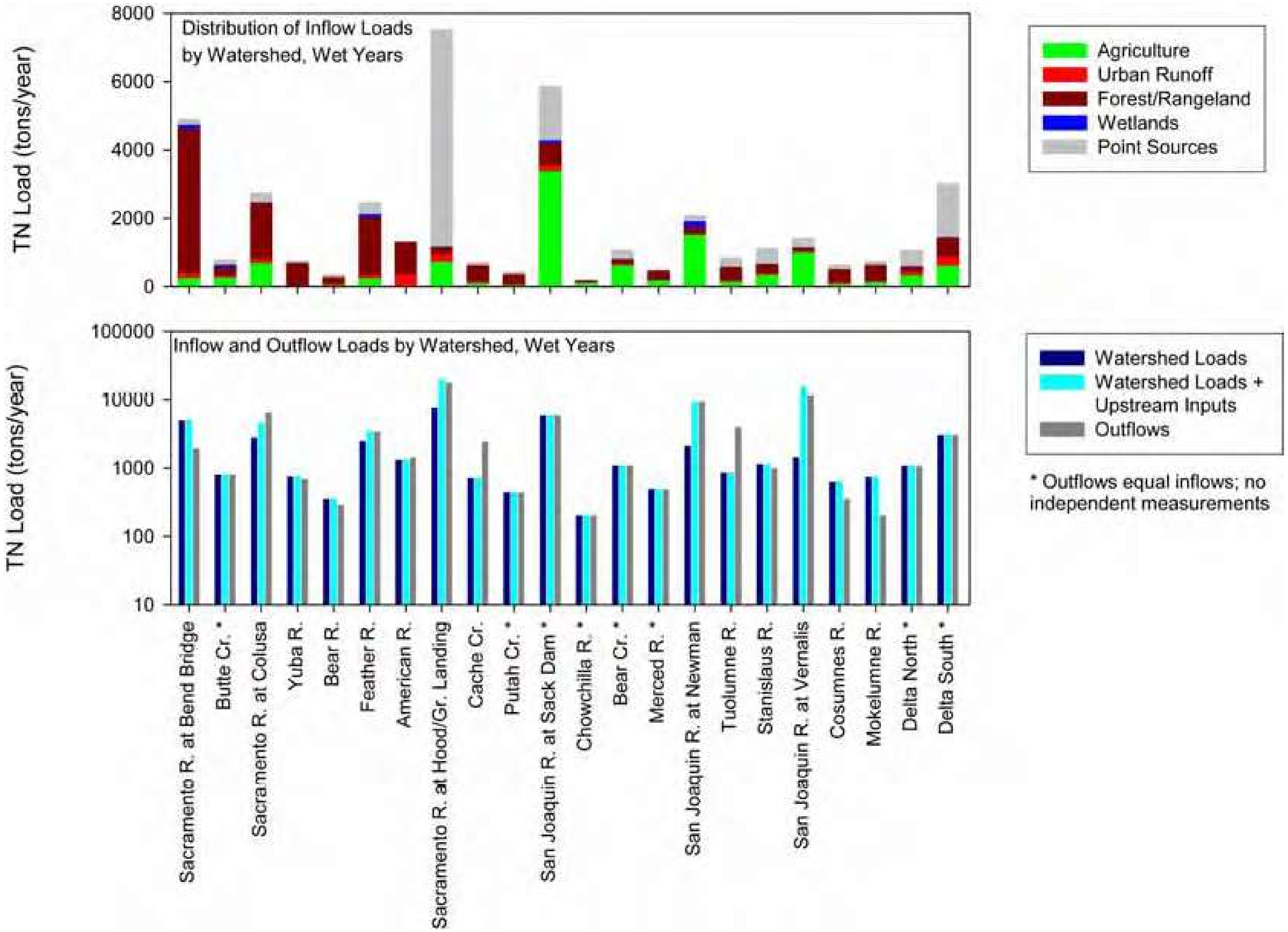


Figure 4-39. Distribution of nitrogen watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for wet years.

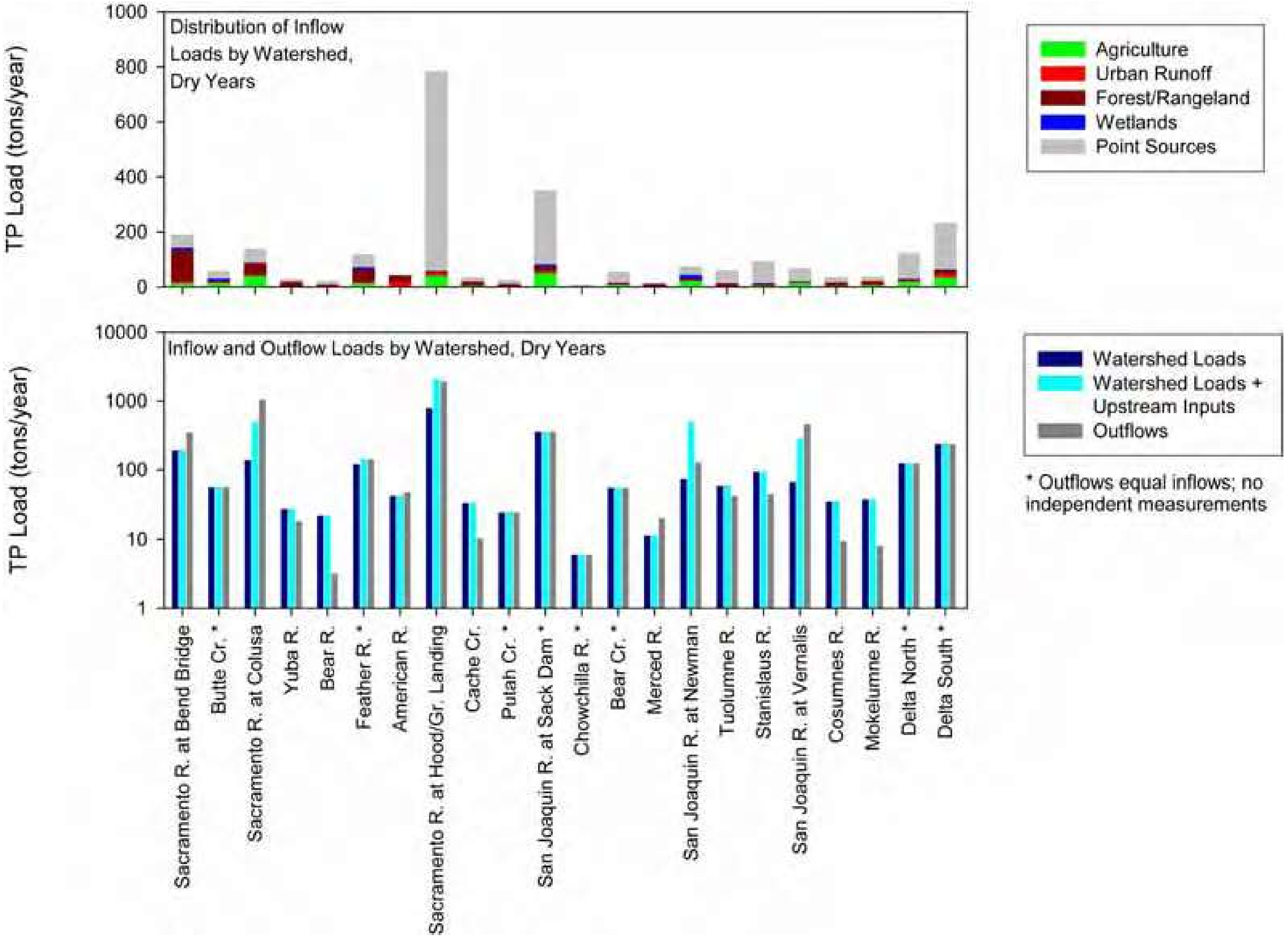


Figure 4-40. Distribution of phosphorus watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for dry years.

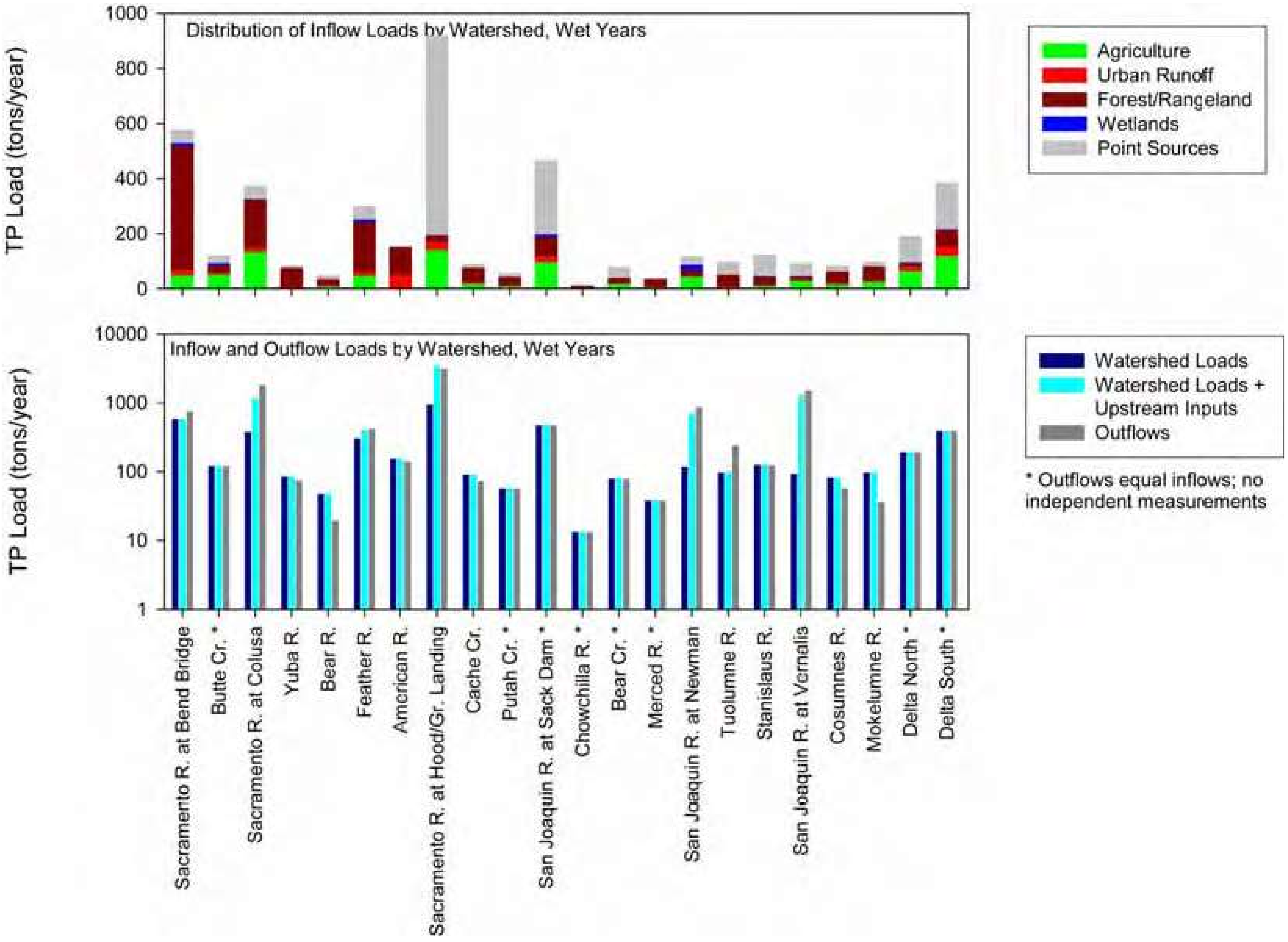


Figure 4-41. Distribution of phosphorus watershed loads by source, and loads flowing out of stream locations are compared with the loads originating from their watersheds for wet years.

Table 4-10.
Comparison of nitrogen upstream load, watershed loads, and downstream exports for dry years.

		Load (tons/year)							
Watershed ID	Watershed Name	Agri-culture	Urban Runoff	Forest/ Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	77	58	1,023	84	165	1,408	1,408	940
2	* Butte Creek	81	22	61	57	150	371	371	*
3	Sacramento River at Colusa	215	49	396	7	278	945	1,885	3,323
4	Yuba River	4	11	158	0	46	219	219	166
5	* Feather River	75	44	408	71	318	916	1,127	*
6	Cache Creek	29	19	118	0	77	243	243	243
7	American River	4	154	226	0	0	383	383	442
8	Sacramento River at Hood/Greene's Landing	224	97	53	7	6,342	6,723	11,987	11,193
9	Cosumnes River	24	19	95	0	106	244	244	57
10	San Joaquin River at Newman	748	9	51	133	165	1,106	5,342	1,411
11	Stanislaus River	169	16	67	4	459	715	715	350
12	Tuolumne River	70	11	100	0	263	444	444	759
13	Merced River	90	2	71	0	3	165	165	528
14	* Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	307	11	37	11	251	618	618	*
15	* Chowchilla River	57	1	17	0	13	88	88	*
16	* San Joaquin River at Sack Dam	1,668	64	164	67	1,568	3,530	3,530	*
17	Mokelumne River	40	16	114	0	93	263	263	47
18	Bear River	14	16	47	0	73	149	149	45
19	* Putah Creek	14	9	71	0	75	169	169	*
20	* Delta North	103	47	32	20	460	661	661	*
21	* Delta South	189	110	137	15	1,553	2,005	2,005	*
22	San Joaquin River at Vernalis	495	14	24	11	268	812	3,331	4,898

* Flow and concentration data are not available to calculate an outflow load.

Table 4-11.
Comparison of nitrogen upstream load, watershed loads, and downstream exports for wet years.

		Load (tons/year)							
Watershed ID	Watershed Name	Agri-culture	Urban Runoff	Forest/ Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	249	134	4,243	105	165	4,896	4,896	1,913
2	* Butte Creek	263	50	254	71	150	787	787	*
3	Sacramento River at Colusa	693	112	1,642	9	278	2,734	4,647	6,447
4	Yuba River	12	25	658	0	46	740	740	687
5	Feather River	242	100	1,694	89	318	2,443	3,414	3,378
6	Cache Creek	94	42	490	0	77	703	703	2,414
7	American River	12	351	939	0	0	1,302	1,302	1,400
8	Sacramento River at Hood/Greene's Landing	721	221	221	9	6,342	7,515	19,527	17,583
9	Cosumnes River	76	44	396	0	106	622	622	350
10	San Joaquin River at Newman	1,514	21	213	165	165	2,077	9,196	9,251
11	Stanislaus River	342	37	280	5	459	1,122	1,122	976
12	Tuolumne River	142	25	413	0	263	844	844	3,901
13	* Merced River	181	4	296	0	3	484	484	*
14	* Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	622	26	152	14	251	1,065	1,065	*
15	* Chowchilla River	116	3	68	0	13	200	200	*
16	* San Joaquin River at Sack Dam	3,376	145	681	83	1,568	5,854	5,854	*
17	Mokelumne River	129	37	473	0	93	731	731	199
18	Bear River	45	36	193	0	73	347	347	284
19	* Putah Creek	46	21	293	0	75	435	435	*
20	* Delta North	332	107	133	25	460	1,056	1,056	*
21	* Delta South	610	253	570	18	1,553	3,004	3,004	*
22	San Joaquin River at Vernalis	1,002	32	100	14	268	1,416	15,544	11,450

* Flow and concentration data are not available to calculate an outflow load.

Table 4-12.
Comparison of phosphorus upstream load, watershed loads, and downstream exports for dry years.

		Load (tons/year)							
Watershed ID	Watershed Name	Agri-culture	Urban Runoff	Forest/ Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	14	6	112	10	47	189	189	341
2	* Butte Creek	15	2	7	7	25	56	56	*
3	Sacramento River at Colusa	39	5	43	1	47	136	477	1,045
4	Yuba River	1	1	17	0	8	27	27	18
5	* Feather River	14	5	45	8	47	119	140	*
6	Cache Creek	5	2	13	0	13	33	33	10
7	American River	1	17	25	0	0	42	42	48
8	Sacramento River at Hood/Greene's Landing	41	10	6	1	724	782	2,072	1,886
9	Cosumnes River	4	2	10	0	18	35	35	9
10	San Joaquin River at Newman	23	1	6	15	28	73	483	128
11	Stanislaus River	5	2	7	0	78	93	93	45
12	Tuolumne River	2	1	11	0	45	59	59	42
13	Merced River	3	0	8	0	0	11	11	20
14	* Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	9	1	4	1	39	55	55	*
15	* Chowchilla River	2	0	2	0	2	6	6	*
16	* San Joaquin River at Sack Dam	50	7	18	8	267	350	350	*
17	Mokelumne River	7	2	13	0	16	37	37	8
18	Bear River	3	2	5	0	12	22	22	3
19	* Putah Creek	3	1	8	0	13	24	24	*
20	* Delta North	19	5	4	2	93	123	123	*
21	* Delta South	35	12	15	2	169	232	232	*
22	San Joaquin River at Vernalis	15	2	3	1	46	66	282	454

* Flow and concentration data are not available to calculate an outflow load.

Table 4-13.
Comparison of phosphorus upstream load, watershed loads, and downstream exports for wet years.

		Load (tons/year)							
Watershed ID	Watershed Name	Agri- culture	Urban Runoff	Forest/ Rangeland	Wetlands	Point Sources	Sum of Watershed Loads	Watershed Loads + Upstream Inflows	Outflows
1	Sacramento River above Bend Bridge	48	19	451	12	47	577	577	746
2	* Butte Creek	51	7	27	8	25	118	118	*
3	Sacramento River at Colusa	134	15	175	1	47	373	1,119	1,770
4	Yuba River	2	3	70	0	8	84	84	73
5	Feather River	47	14	180	10	47	298	390	413
6	Cache Creek	18	6	52	0	13	89	89	72
7	American River	2	49	100	0	0	151	151	141
8	Sacramento River at Hood/Greene's Landing	140	31	24	1	724	919	3,362	3,082
9	Cosumnes River	15	6	42	0	18	81	81	55
10	San Joaquin River at Newman	43	3	23	19	28	115	671	848
11	Stanislaus River	10	5	30	1	78	123	123	122
12	Tuolumne River	4	3	44	0	45	96	96	235
13	* Merced River	5	1	32	0	0	38	38	*
14	* Bear Cr/Owens Cr/Mariposa Cr/Deadmans Cr	18	4	16	2	39	78	78	*
15	* Chowchilla River	3	0	7	0	2	13	13	*
16	* San Joaquin River at Sack Dam	96	20	72	10	267	464	464	*
17	Mokelumne River	25	5	50	0	16	96	96	36
18	Bear River	9	5	21	0	12	47	47	19
19	* Putah Creek	9	3	31	0	13	56	56	*
20	* Delta North	64	15	14	3	93	189	189	*
21	* Delta South	118	35	61	2	169	385	385	*
22	San Joaquin River at Vernalis	28	4	11	2	46	91	1,296	1,502

* Flow and concentration data are not available to calculate an outflow load.

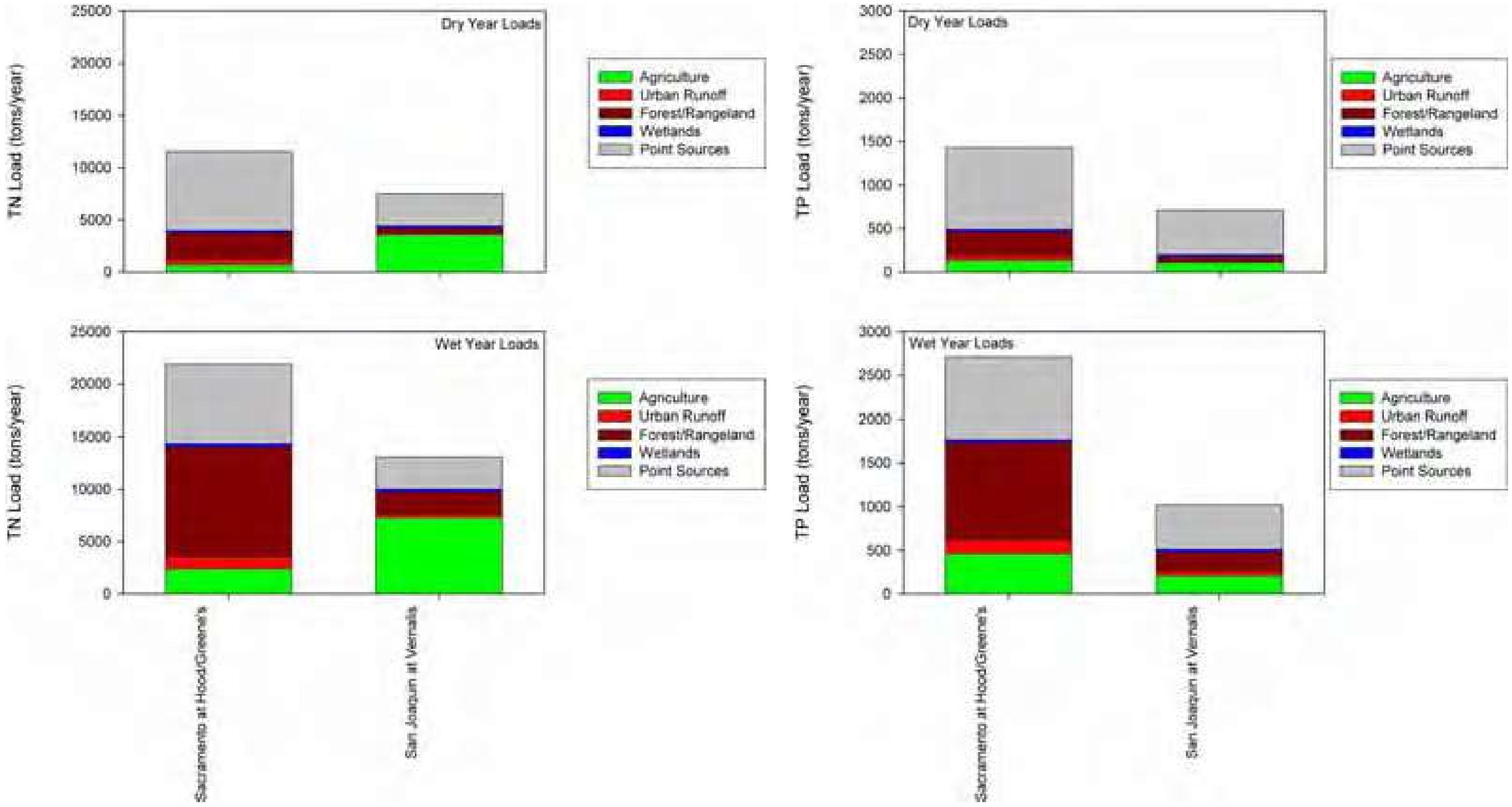


Figure 4-42. Distribution of nitrogen and phosphorus watershed loads by source for the Sacramento and San Joaquin Rivers.

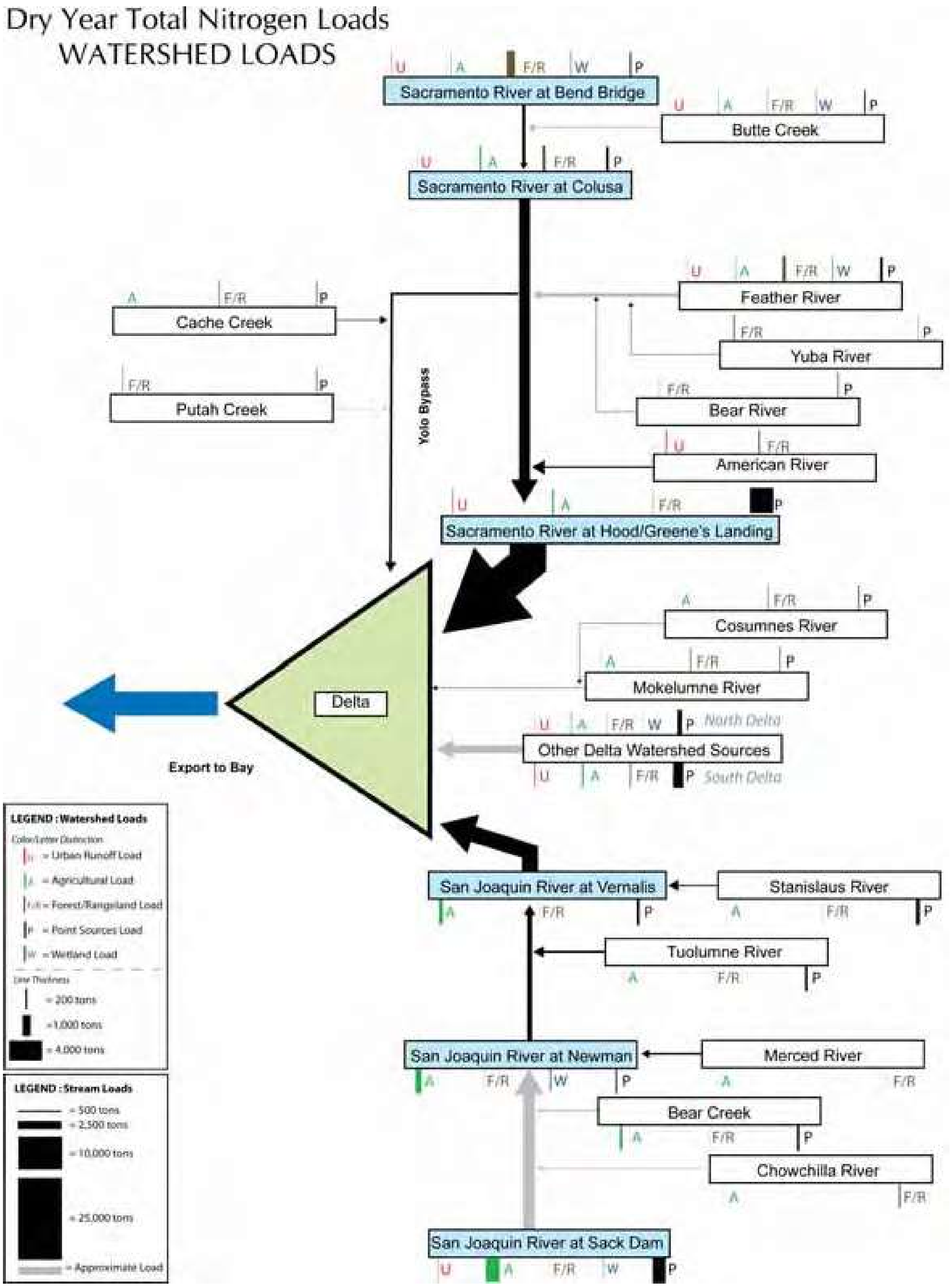


Figure 4-43. Nitrogen watershed and outflow loads for the Central Valley and Delta for average dry years. This figure and the next use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

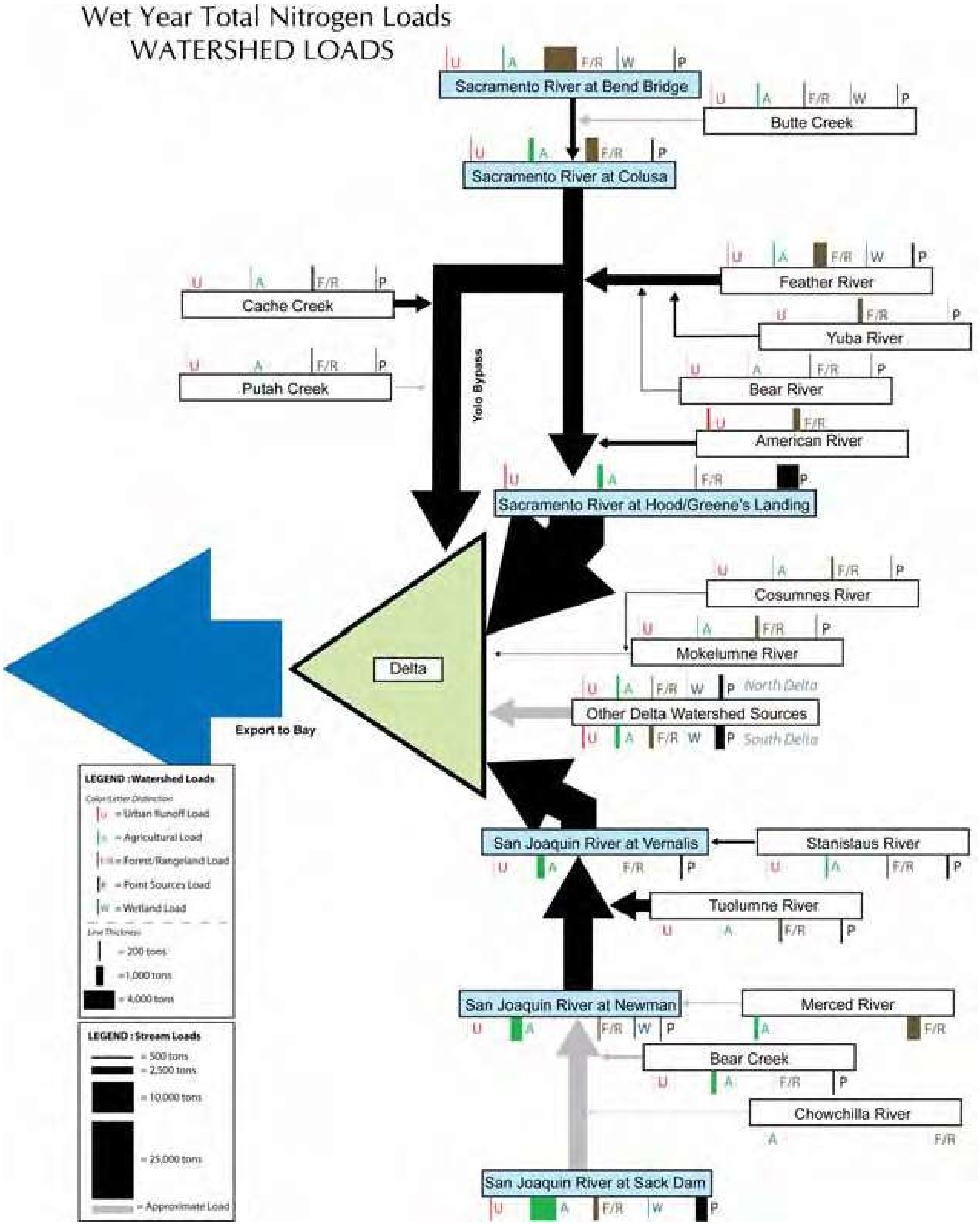


Figure 4-44. Nitrogen watershed and outflow loads for the Central Valley and Delta for average wet years. This figure and the preceding one use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

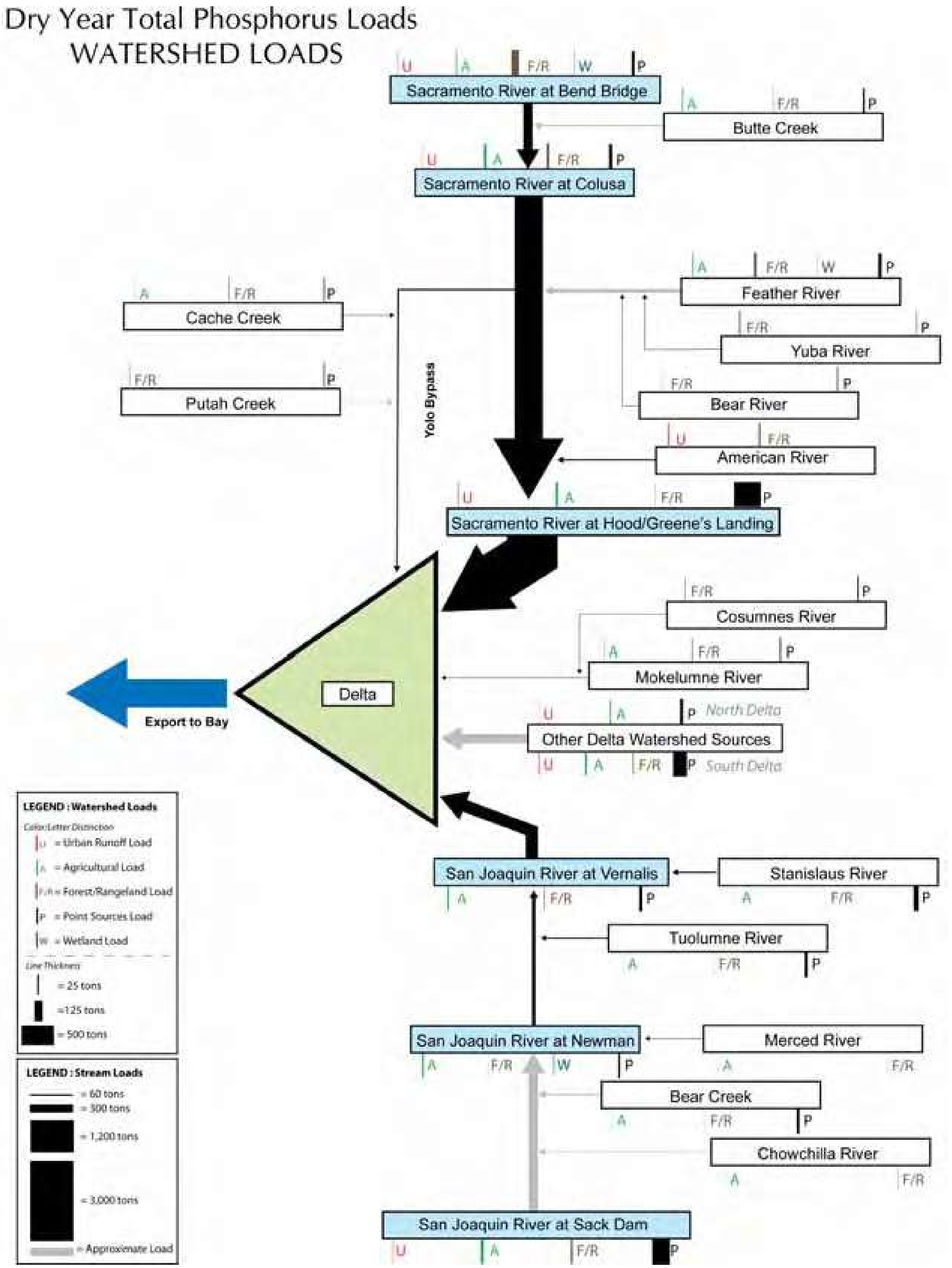


Figure 4-45. Phosphorus watershed and outflow loads for the Central Valley and Delta for average dry years. This figure and the next use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

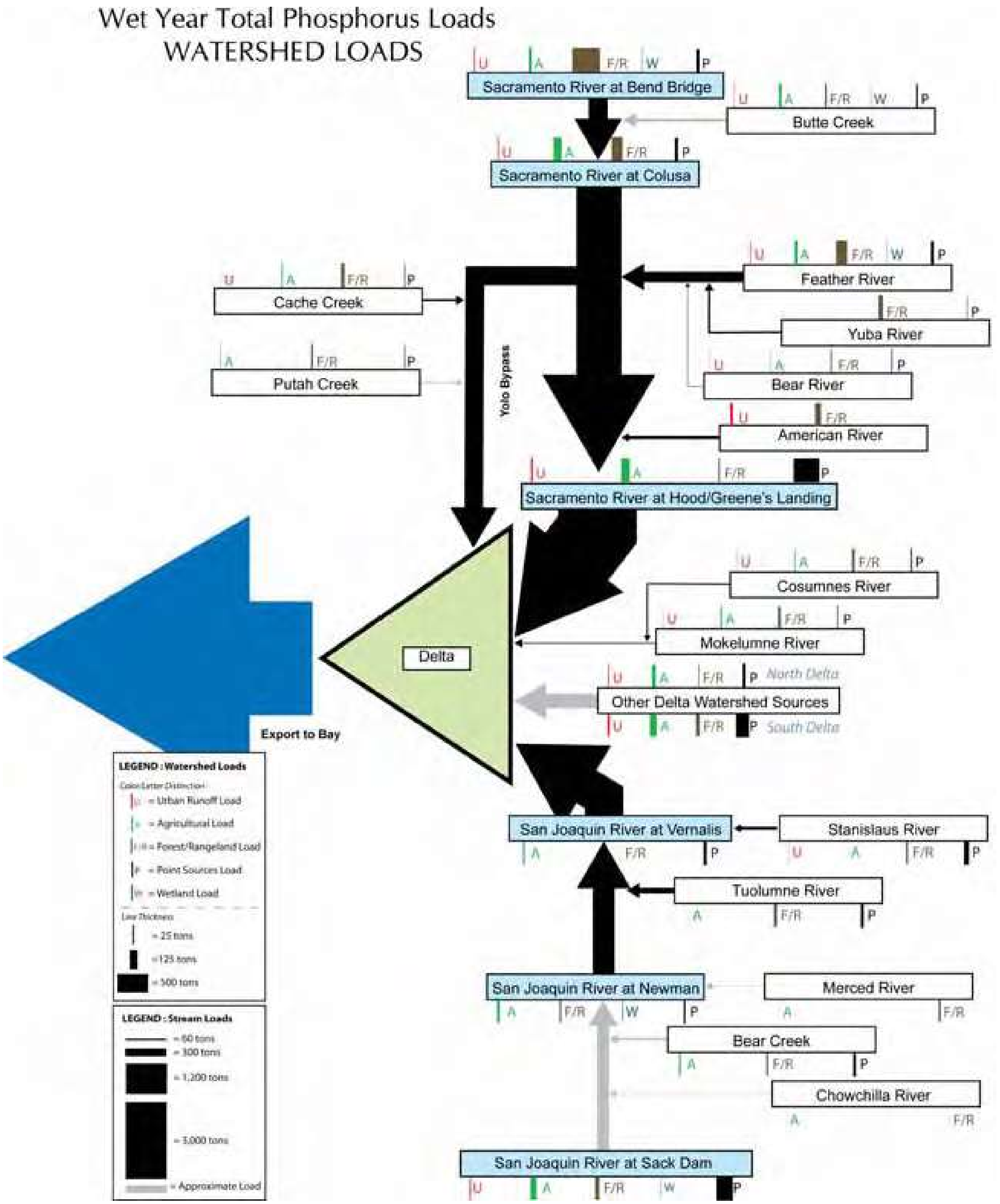


Figure 4-46. Phosphorus watershed and outflow loads for the Central Valley and Delta for average wet years. This figure and the preceding one use the same linear scales to represent stream loads. Watershed loads are shown with a different scale to show some of the smaller load contributions.

4.5 MAJOR FINDINGS

Flows in Central Valley rivers are highly variable, especially in winter months, even though they are controlled by a large number of reservoirs. At most stream sampling locations there are limited concentration data, whereas there are daily flow data. Loads are therefore estimated using monthly average concentration and flow values. At the Sacramento River at Hood/Greene's Landing and the San Joaquin River at Vernalis, stations where the greatest quantity of concentration data were available, the loads estimated by this approach were comparable to loads estimated in previous studies.

4.5.1 ESTIMATED IN-STREAM LOADS

Tributary nutrient loads are substantially greater in the wet season than in the dry season. Tributary loads were found to vary significantly between wet and dry years. Although the nutrient concentrations in the Sacramento River are lower than the concentrations in the San Joaquin River, the Sacramento River load to the Delta exceeds the San Joaquin River load by a factor of nearly two or greater for both nitrogen and phosphorus.

4.5.2 ESTIMATED WATERSHED LOADS

It was not possible to calculate export rates for each type of land use present in the Central Valley and Delta. A limited amount of nutrient data has been collected from watersheds with one particular type of land use. Most of the data available for this analysis were collected at locations that have mixed land uses. Export rates of nutrients (mass of nitrogen or phosphorus exported per unit area per year) were estimated for several land uses: urban land, agricultural land, wetlands, and background areas (including forests, shrubland, and rangeland) based on the limited data. The calculated total watershed exports are comparable to the stream loads at key locations (such as Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis). There were considerable differences in the estimated loads derived from the two methods at locations where there were limited nutrient concentration data. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

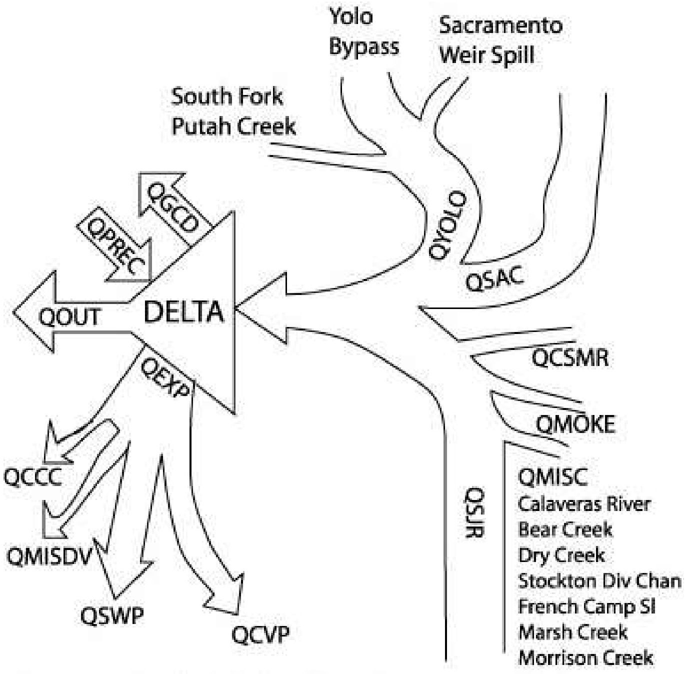
CHAPTER 5.0
NUTRIENT CONCENTRATIONS AND LOADS IN THE DELTA

This chapter is focused on evaluating the sources of nutrients to the Delta in a manner similar to that used for the tributaries in Chapter 4. The load calculations in Chapter 4 and this chapter can be thought of as an accounting process, where, using available data, we have identified the relative magnitudes of different nutrient sources in the Central Valley and Delta region. However, detailed nutrient characterization is only available at a limited spatial and temporal resolution. Until better data are available, therefore, loads of total nitrogen and phosphorus presented herein provide a useful measure of the relative importance of different sources. This information will be refined in future efforts to quantify sources and potential drinking water impacts based on additional data.

5.1 DELTA INFLOWS AND OUTFLOWS

Characterization of flows is central to estimating loads of constituents in moving water bodies. Daily water flows entering and exiting the Delta at various locations, shown in Figure 5-1, were obtained from the DAYFLOW model. DAYFLOW is a computer program developed in 1978 as an accounting tool for determining historical and current Delta hydrology at the boundaries. Inflows in all tributaries, outflows to the San Francisco Bay and diversion by the water supply intakes are represented in the model. However, DAYFLOW does not characterize internal flows in the channels of the Delta and cannot be used to understand the mixing processes of different tributary and internal sources of individual constituents. DAYFLOW output is used extensively in studies conducted by the Department of Water Resources (DWR), the Department of Fish and Game (DFG), and other agencies. Model output is available electronically at http://www.iep.ca.gov/dayflow/index.html.

Annual water supply diversions at the Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Contra Costa Water District's Rock Slough and Old River pumping plants (CCC), and the North Bay Aqueduct's Barker Slough Pumping Plant (NBAQ) are shown in Figure 5-2. The naming conventions on this figure are consistent with the DAYFLOW model diversion names shown in Figure 5-1. Over 95% of the water diverted from the Delta is diverted at the Banks and Tracy pumping plants. The sum of water diversions from the Delta is shown as a percentage of annual flows from the major tributaries (Sacramento and San Joaquin Rivers) in Figure 5-3. Over the water years 1983-2004, the average amount of water diverted was 5.2 million acre feet, varying between 3.1 and 6.3 million acre feet. Compared to the variability of tributary flows into the Delta, the diversion volumes are relatively uniform. In dry years, such as the late 1980s and the early 1990s, diversions by the projects can be nearly 50% of Delta inflows. In more recent years, because of higher tributary inflows, the diversions have been a smaller fraction of the inflows, but even so, diversions of 30-40% are common.



LEGEND

QSJR	San Joaquin River flow
QMISC	Miscellaneous streamflow
QMOKE	Mokelumne River flow
QCSMR	Cosumnes River flow
QSAC	Sacramento River flow
QYOLO	Yolo Bypass flow
GGCD	Gross channel depletion
QPREC	Precipitation runoff
QOUT	Delta outflow
QEXP	Exports
QCCC	Contra Costa Water District Diversions at Rock Slough and Old River
QMISDV	Flooded island and island storage diversion
QSWP	State Water Project exports at Banks Pumping Plant
QCVP	Central Valley Project pumping at Tracy
QNBAQ	North Bay Aqueduct export

Note: In DAYFLOW equations, QMISDV replaced with QNBAQ. Updated figure not available.

Figure 5-1. Delta locations with daily flow data reported in the DAYFLOW model. (Figure reproduced from http://wwwiep.water.ca.gov/dayflow/documentation/fig2.jpg).

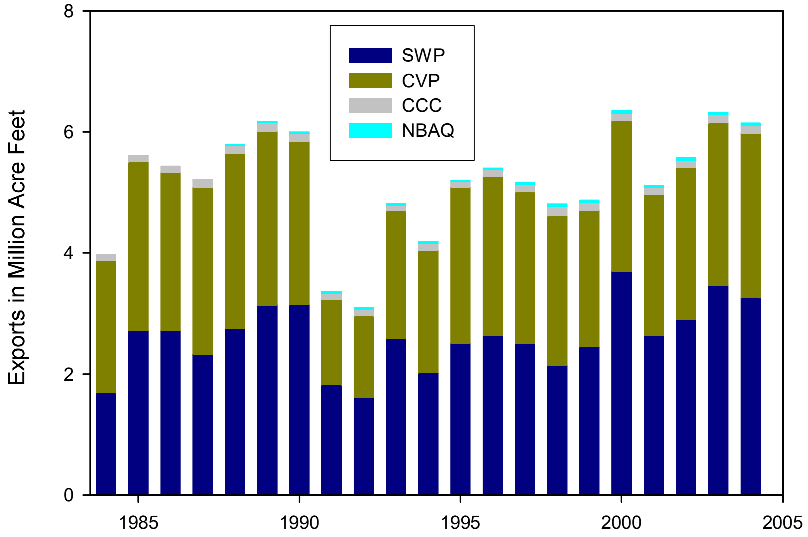


Figure 5-2. **Annual water supply diversions (Banks Pumping Plant (SWP), Tracy Pumping Plant (CVP), Contra Costa Water District's Rock Slough and Old River pumping plants (CCC), and the North Bay Aqueduct's Barker Slough Pumping Plant (NBAQ) as reported in the DAYFLOW model.**

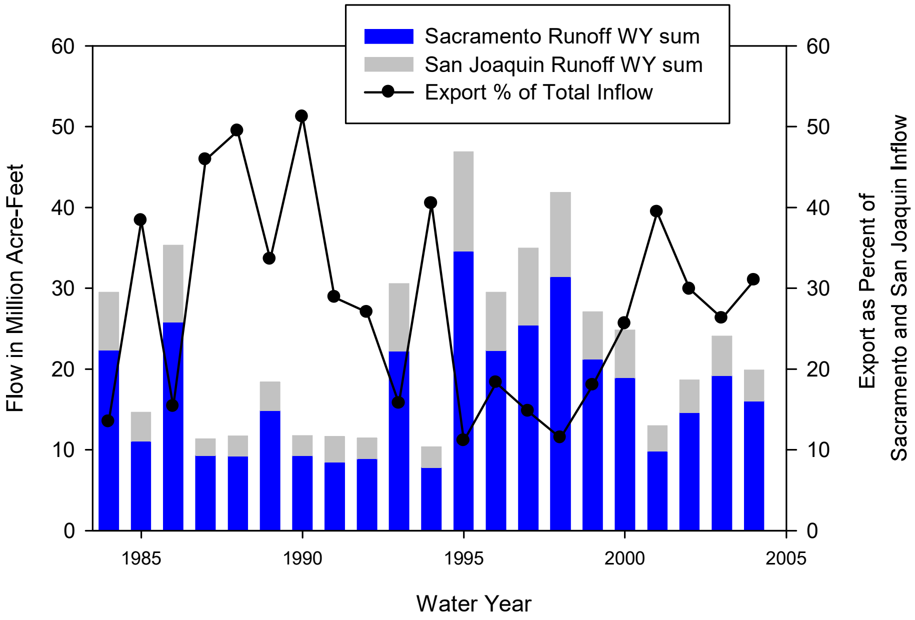


Figure 5-3. **The sum of project diversions as a percentage of annual flows from the major tributaries (Sacramento and San Joaquin Rivers) to the Delta.**

5.2 PATTERNS IN NUTRIENT CONCENTRATIONS

The ratio of NO3+NO2-N plus ammonia-N to TN at three key Delta locations (Banks Pumping Plant, Sacramento River at Hood/Greene's Landing, and the San Joaquin River at Vernalis) is illustrated in Figure 5-4. The median value is similar across the three locations, from about 0.6 to 0.7. The ratio of orthophosphate-P to TP at the three locations is illustrated in Figure 5-5. The median and range is similar at Banks Pumping Plant and Sacramento at Hood/Greene's Landing (approximately 0.6 to 0.65), but slightly lower at the San Joaquin River at Vernalis (approximately 0.5).

Figure 5-6 presents scatterplots of TN and TP concentrations at the three Delta locations where simultaneous measurements were available. Also shown on these plots is the 7:1 ratio line, which denotes the Redfield ratio. As discussed in Chapter 2, if total nitrogen in the water is more than 7 times the total phosphorus, then phosphorus will be in low supply and limit algal growth. If the nitrogen is less than 7 times the phosphorus, then nitrogen will be limiting. These plots show significant scatter with data points on both sides of this line. However, there are more data points to the right of the line (phosphorus limiting) for Banks Pumping Plant and San Joaquin River at Vernalis, and more data points to the left of the line (nitrogen limiting) for Sacramento River at Hood/Greene's Landing.

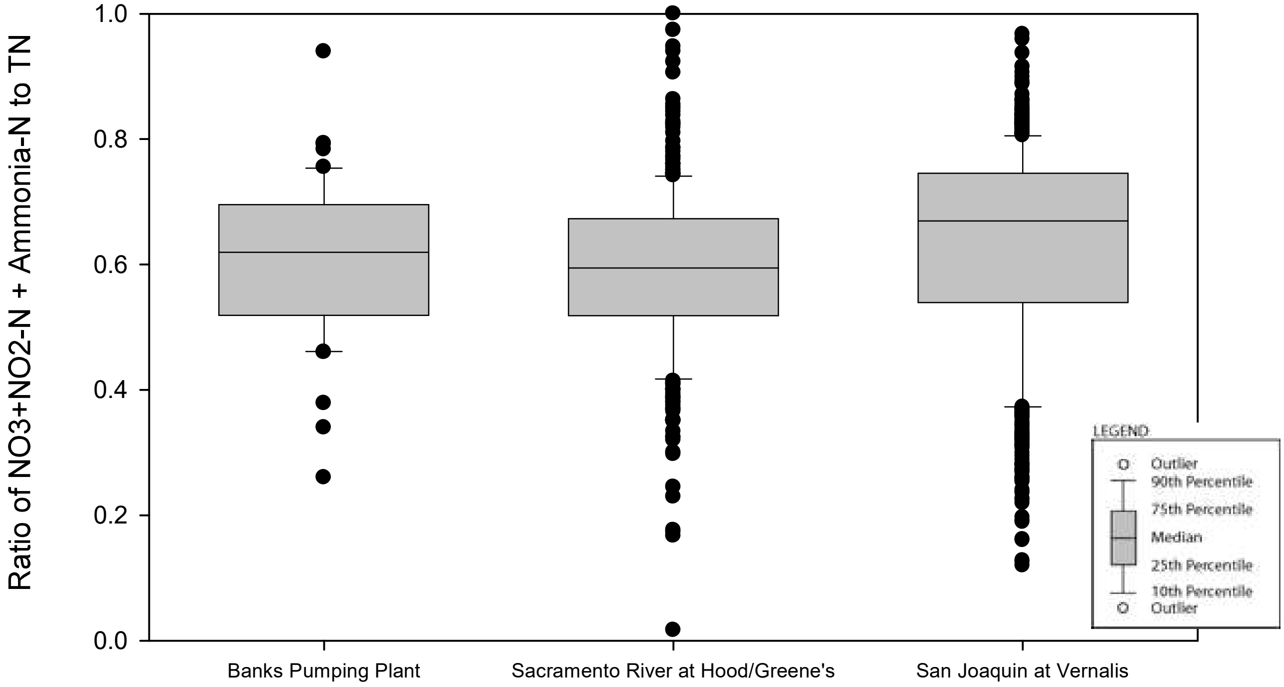


Figure 5-4. Ratio of NO3+NO2-N + ammonia-N to TN at key Delta locations.

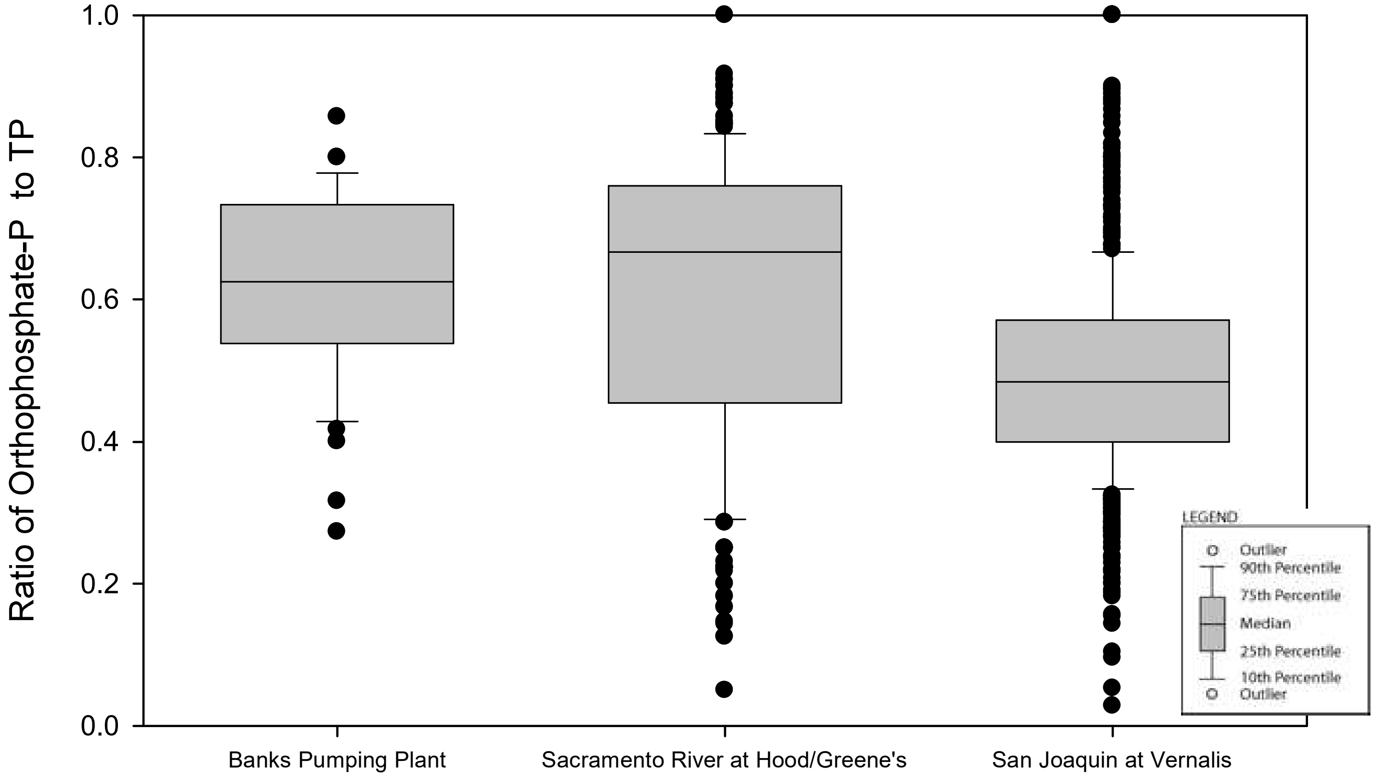


Figure 5-5. Ratio of orthophosphate-P to TP at key Delta locations.

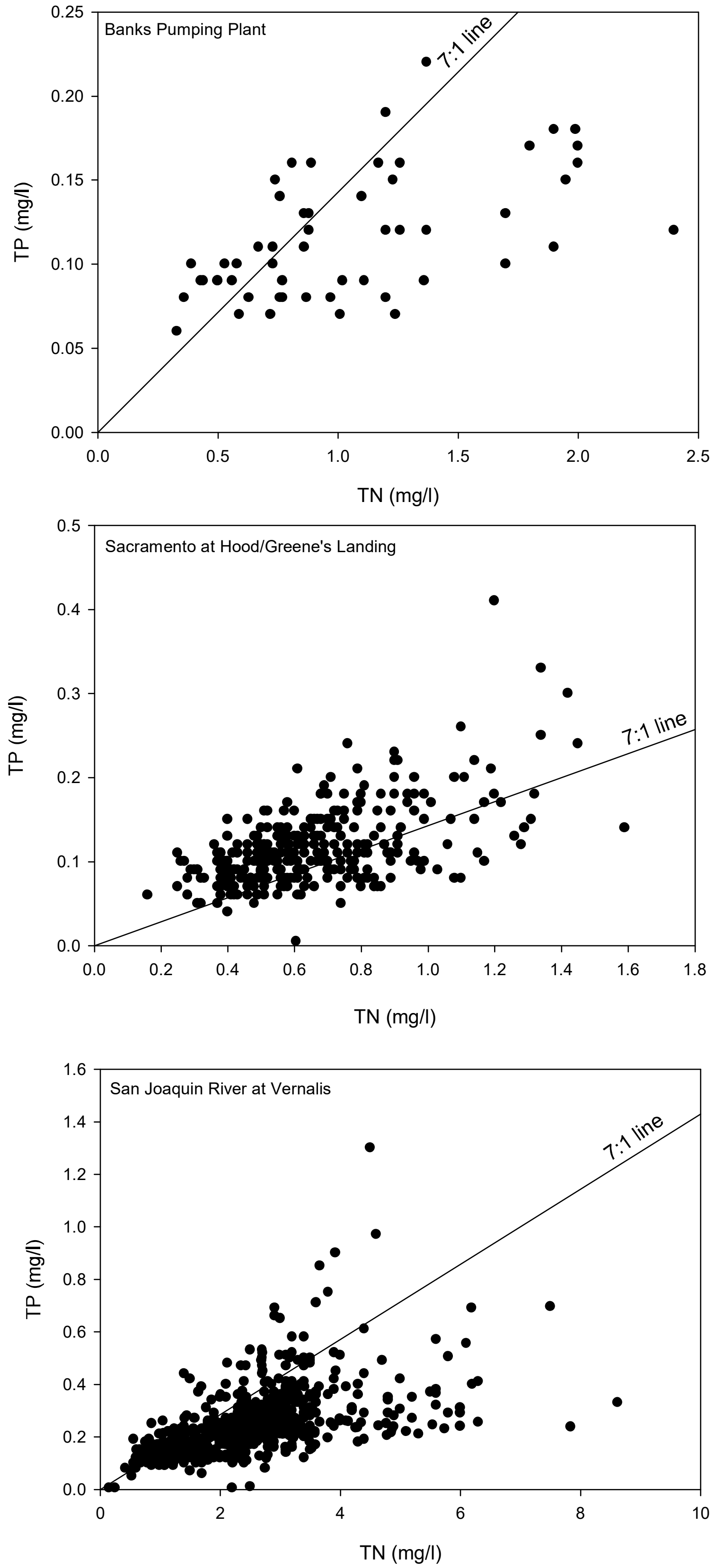


Figure 5-6. TN and TP concentrations at key Delta locations.

Some of the longest records of nutrient concentrations exist at the Sacramento River at Greene's Landing/Hood, San Joaquin River at Vernalis, and the Banks Pumping Plant. The two river locations are important because they constitute the majority of the flow into the Delta, and the Banks Pumping Plant is the largest water diversion from the Delta. Average concentrations at these locations are presented in Table 5-1. Figures 5-7 and 5-8 present concentrations of nitrogen species and phosphorus species, respectively, at these locations from 1980 to 2004. Several observations result:

- The average concentration of ammonia-N is about two times higher in the Sacramento River than the San Joaquin River. NO3+NO2-N and TN concentrations are substantially higher in the San Joaquin River (average data are ten times and four times higher, respectively).

- Average concentrations at Banks Pumping Plant lie between San Joaquin River concentrations and Sacramento River concentrations for TN and NO3+NO2-N, while for ammonia-N and TKN, average concentrations at Banks Pumping Plant are lower than both Sacramento and San Joaquin River concentrations.

- Average concentrations of TKN are slightly higher in the San Joaquin River than in the Sacramento River or at Banks Pumping Plant.

- Average concentrations of orthophosphate-P and TP are approximately two times higher in the San Joaquin River than in the Sacramento River or at Banks Pumping Plant.

Table 5-1.
Average nutrient concentrations at key Delta Locations.

Constituent	Sacramento at Hood/Greene's Landing	San Joaquin at Vernalis	Banks Pumping Plant
NO3+NO2-N (mg/l)	0.14	1.5	0.61
Ammonia-N (mg/l)	0.23	0.10	0.064
TKN (mg/l)	0.50	0.85	0.44
TN (mg/l)	0.64	2.5	1.1
Orthophosphate-P (mg/l)	0.070	0.12	0.071
TP (mg/l)	0.12	0.25	0.12

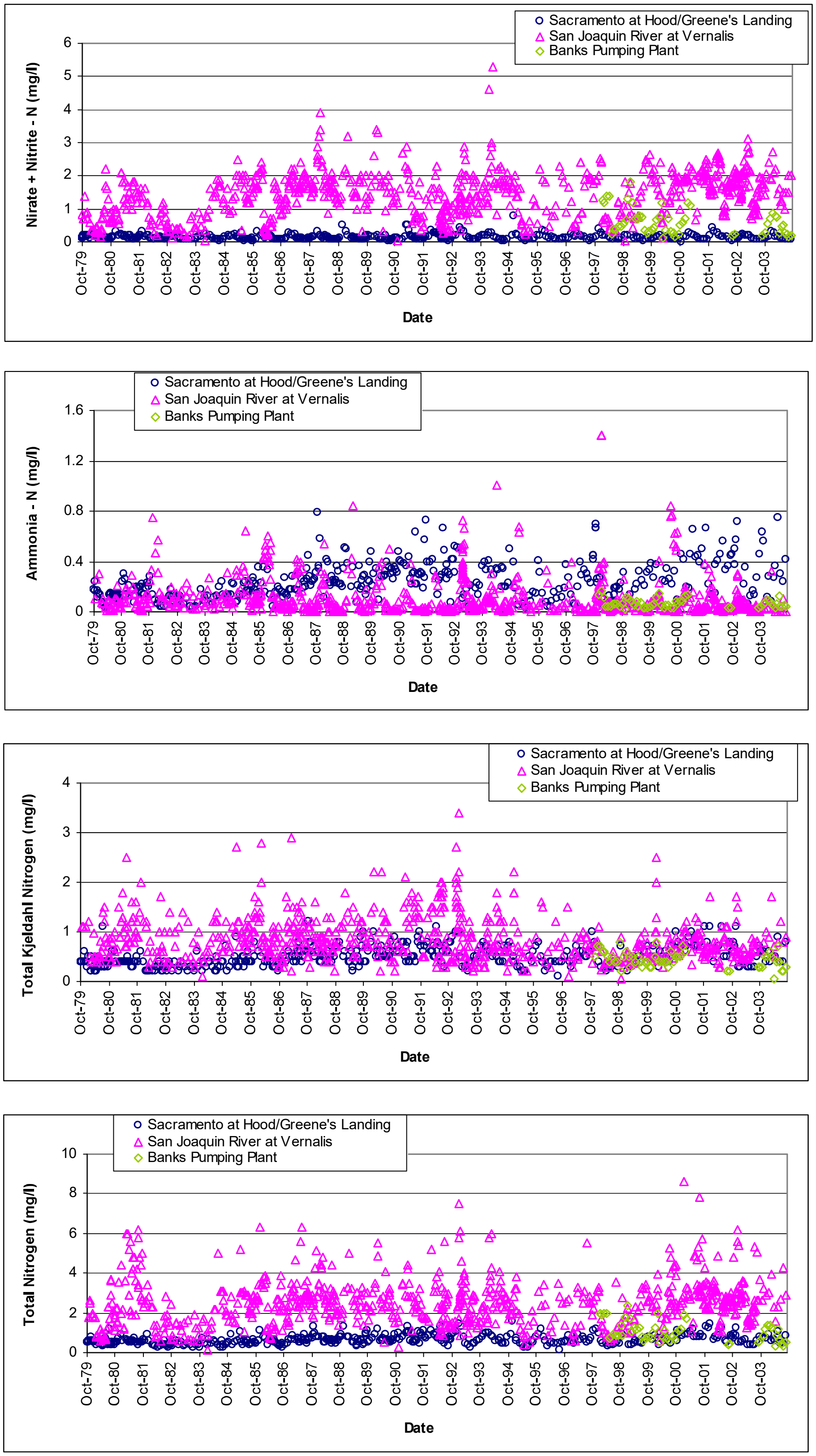


Figure 5-7. Nitrogen species concentrations at Sacramento River (Hood), San Joaquin River (Vernalis), and Banks Pumping Plant.

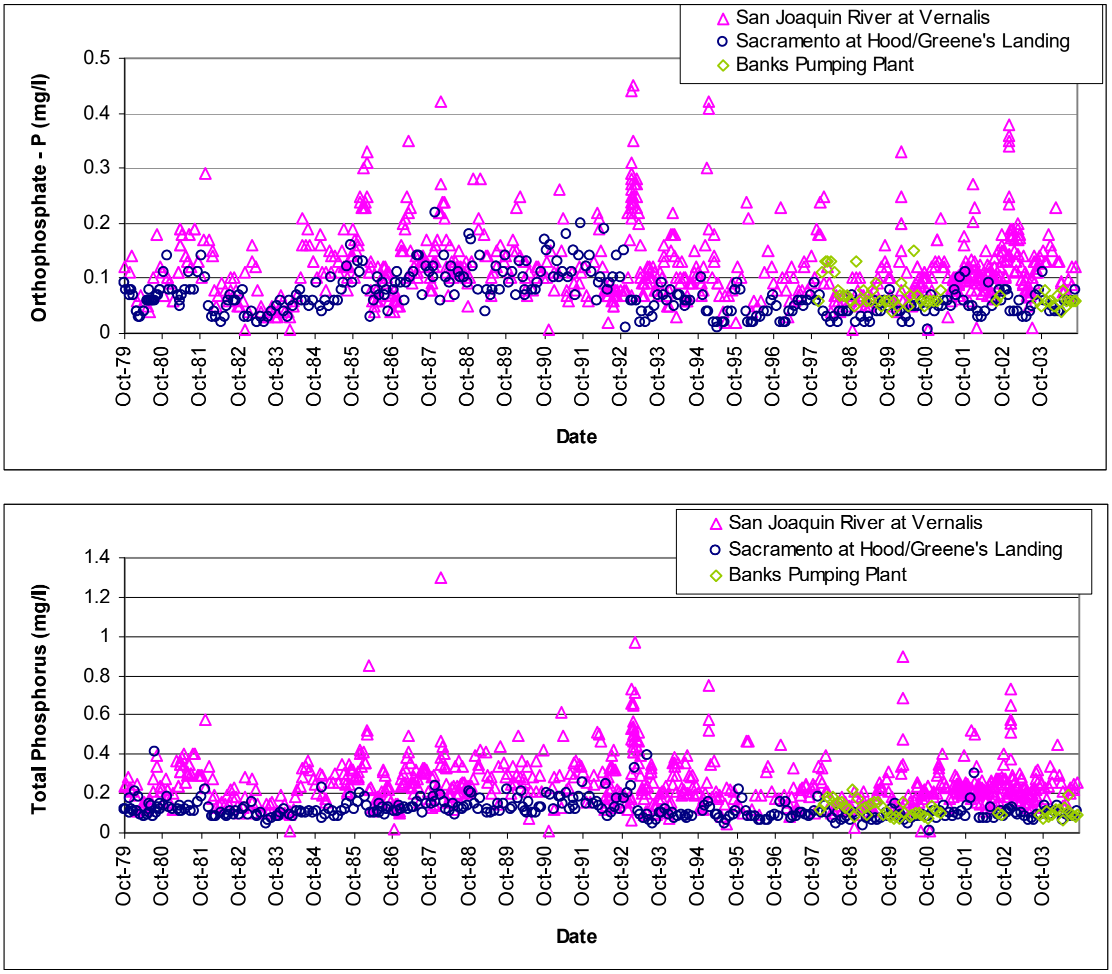


Figure 5-8. Phosphorus species concentrations at Sacramento River (Hood), San Joaquin River (Vernalis), and Banks Pumping Plant.

5.3 NUTRIENT LOADS

To account for the various inflows and outflows of nutrients in the Delta, the inputs from tributary and in-Delta sources and the exports to San Francisco Bay and water supply diversions were quantified. The tributary inputs and the exports to the Bay were estimated in Chapter 4. This chapter describes the approach used to estimate nutrients exported in the water supply diversions and loads generated within the Delta.

5.3.1 EXPORT IN WATER SUPPLY DIVERSIONS

Nutrient concentration data from the four major water supply diversions in the Delta are paired with flow rates to estimate the exported nutrient loads. Loads are calculated in the same manner as described in Chapter 4 for the stream loads, using monthly average concentration and flow data. Nutrient concentration data was obtained from the MWQI program through the internet at http://wdl.water.ca.gov/wq-gst/. TN data are obtained by summing NO3+NO2-N and TKN. The monthly average nutrient concentrations for the water supply diversions, along with the data count, are shown in Figure 5-9. These concentrations were used to estimate monthly loads of nitrogen and phosphorus using DAYFLOW flow data. Phosphorus data were not available for the Tracy Pumping Plant (CVP).

The annual nitrogen and phosphorus exports over the water years 1984-2004 are shown in Figure 5-10. The annual average phosphorus load for the Tracy Pumping Plant (CVP) was scaled from the nitrogen load by using the same ratio of nitrogen load at Tracy to the nitrogen load at Banks (SWP) to calculate the phosphorus load at Tracy. Because the flow volumes in the exports are relatively uniform, the estimated annual loads vary over a fairly narrow range, from 4,500 to 8,500 tons/year for nitrogen and 600 to 850 tons/year for phosphorus.

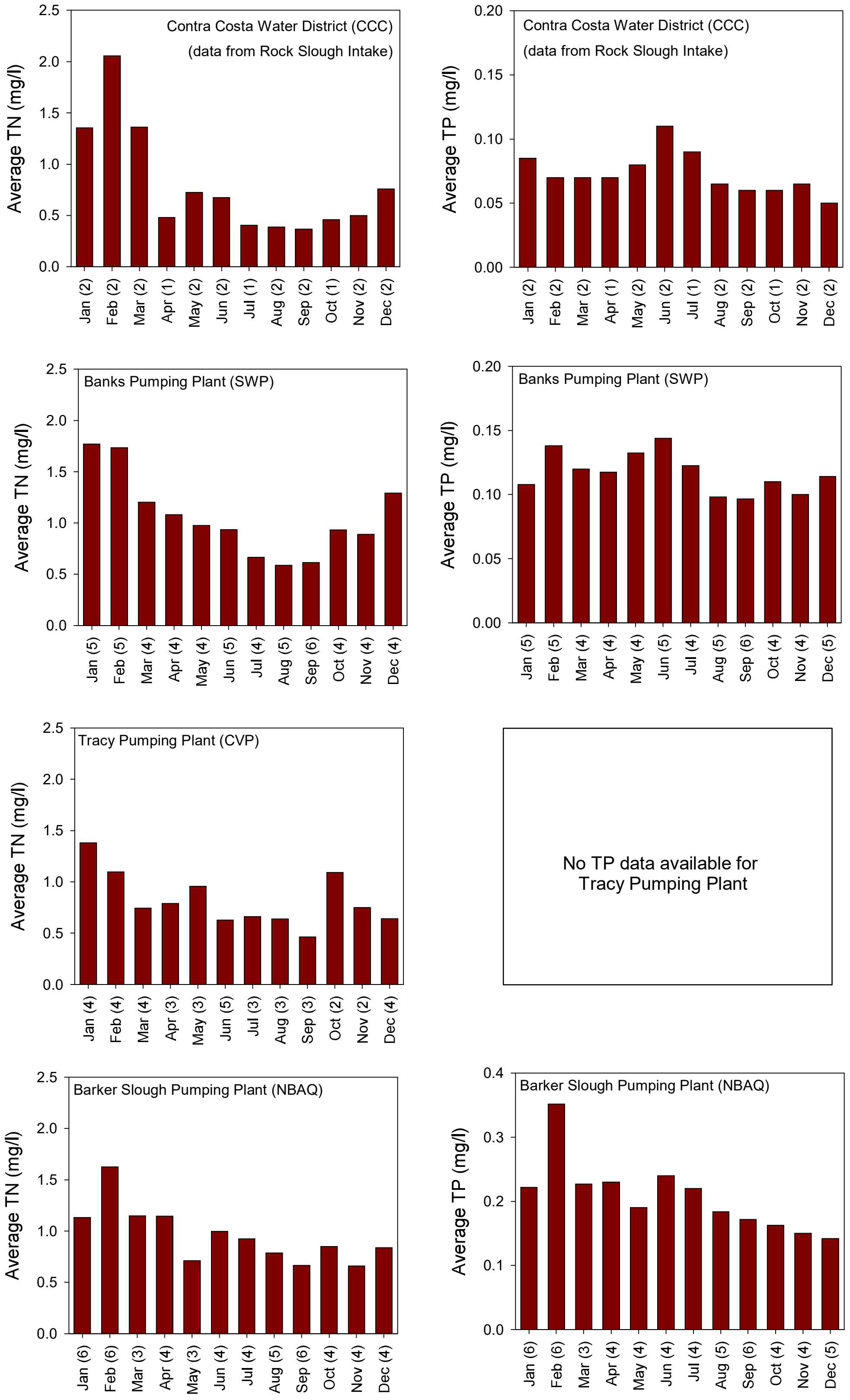


Figure 5-9. Nutrient concentrations at water supply diversions. The number of data points is shown after each month.

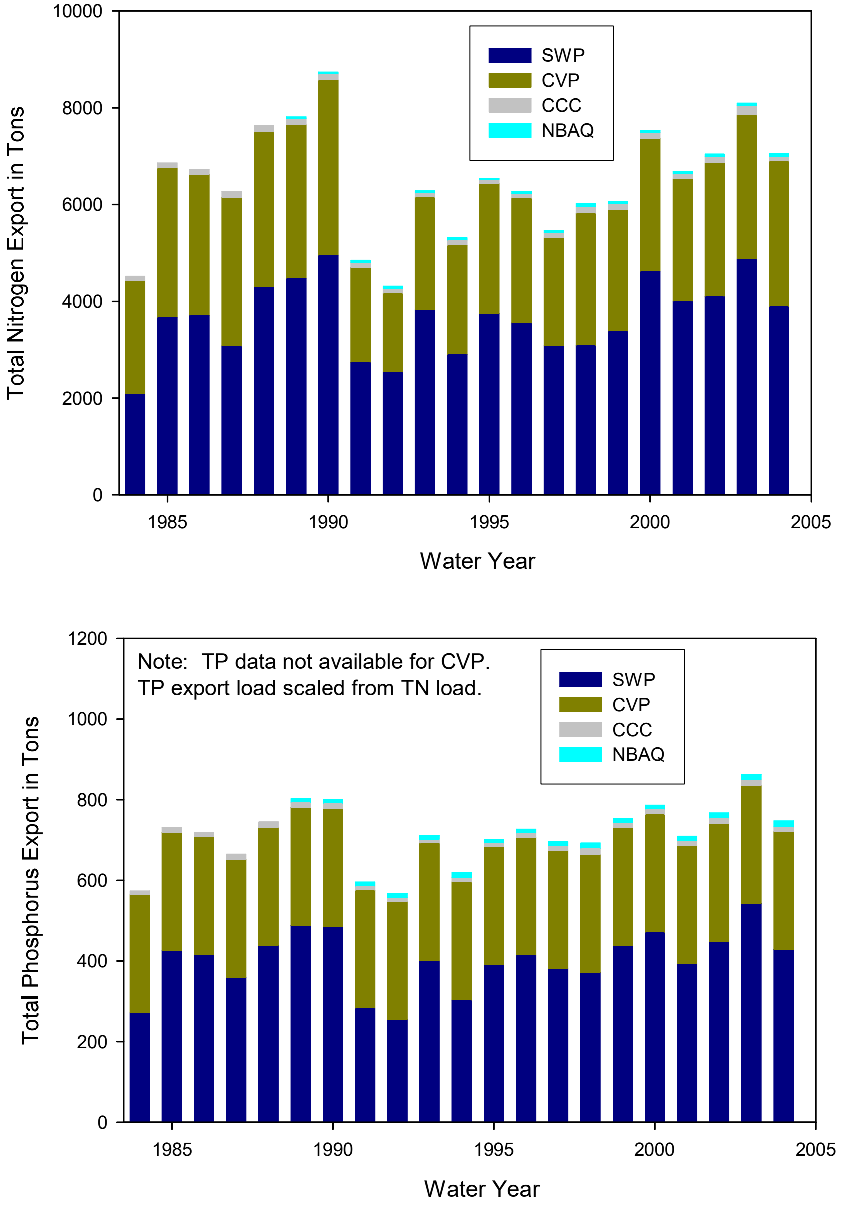


Figure 5-10. Annual nitrogen and phosphorus exports over water years 1984-2004.

5.3.2 NUTRIENT SOURCES INTERNAL TO THE DELTA

Export from agriculture on Delta Islands is the major source of nutrients internal to the Delta. Contributions from Delta agriculture were estimated using agricultural drain concentration data and total flow approximations from the Delta Island Consumptive Use (DICU) computer model. NO3-N data is the only nutrient species from Delta agricultural drains collected by MWQI, as shown in Figure 5-11. As shown in Figure 5-12, there is little variability by month. The Delta agricultural drainage concentrations for NO3-N are similar to the TN concentration values from agricultural drainage from the Sacramento River watershed (Colusa Basin Drain; monthly averages from 0.8 to 1.6 mg/l) but much lower than the concentration values from agricultural drainage from the San Joaquin River watershed (Mud Slough; monthly averages from 4 to 14 mg/l) discussed in Chapter 4.

The DICU model was developed to estimate the diversions and return flows of Delta waters into agricultural land on Delta islands. The model is calibrated from a detailed hydrologic study on Twitchell Island conducted in 1960. DICU estimates of flow for each month were coupled with mean monthly NO3-N concentration data observed at all island drains from Figure 5-12, to estimate the load of NO3-N from Delta agricultural drainage. The average annual load is estimated to be 1800 tons/year. This load estimate should be considered as a lower bound value because it uses NO3-N data instead of TN data. As shown in Figure 5-13, the highest loads of NO3-N occur in the wet winter months (January and February) that correspond with a peak in calculated discharge from the islands. Flows are also elevated in June through July, although these are associated with lower concentrations. Existing information does not allow consideration of year-to-year variability.

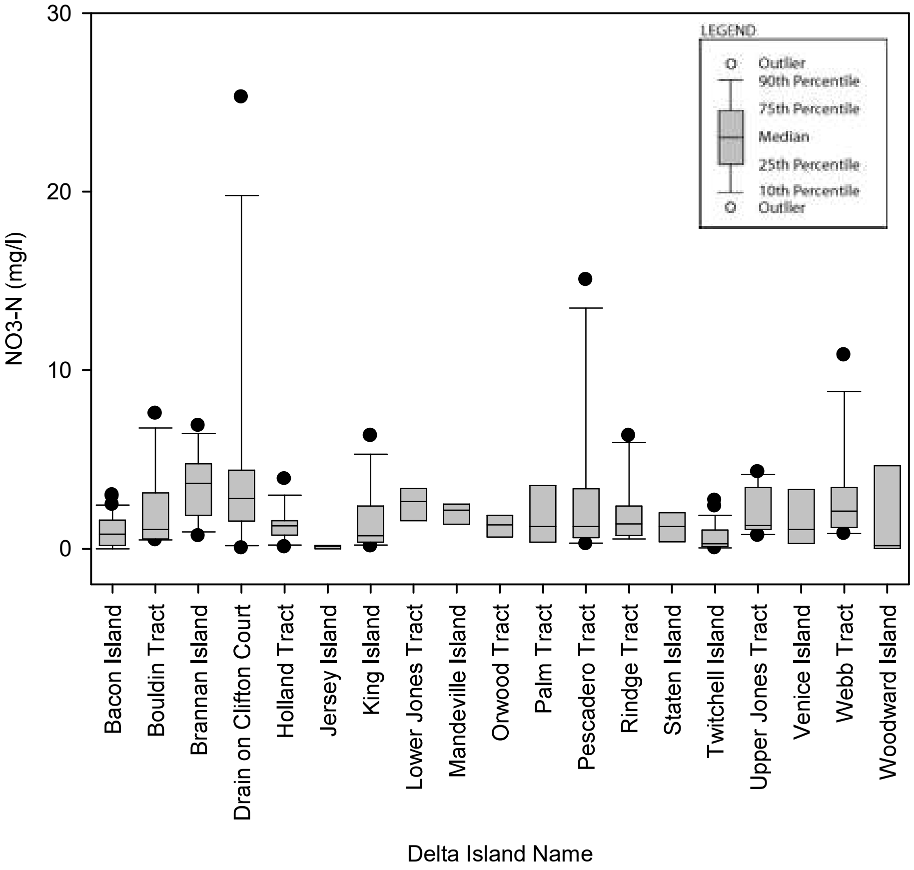


Figure 5-11. NO3-N concentrations in Delta agricultural drainage.

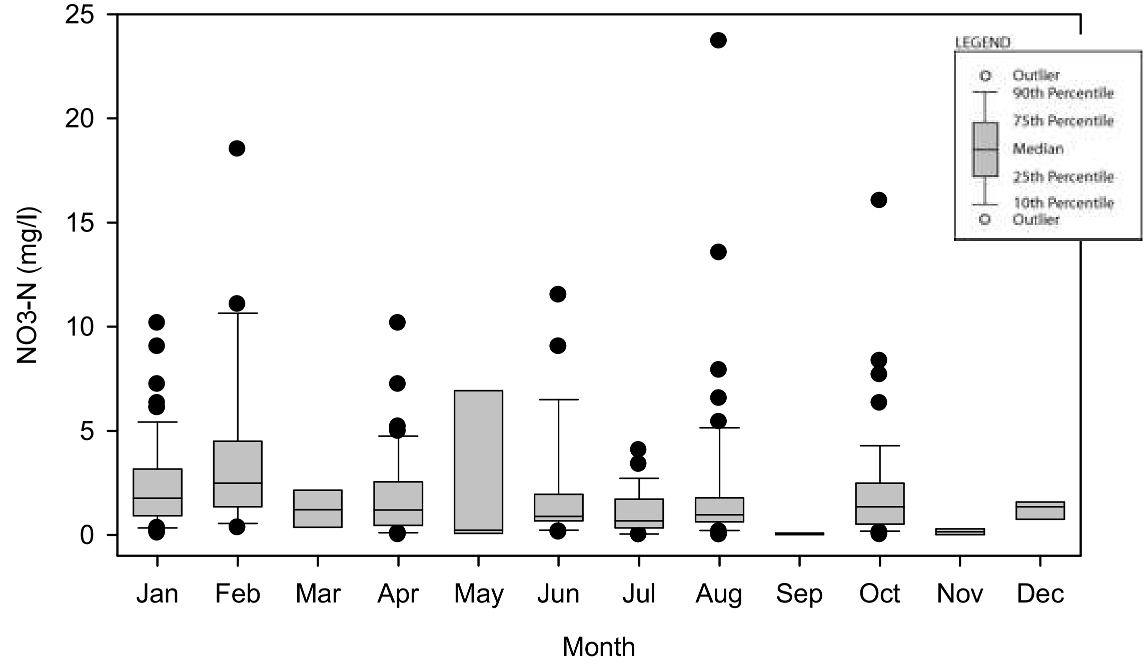


Figure 5-12. Seasonal variation in Delta agricultural drainage NO3-N concentrations.

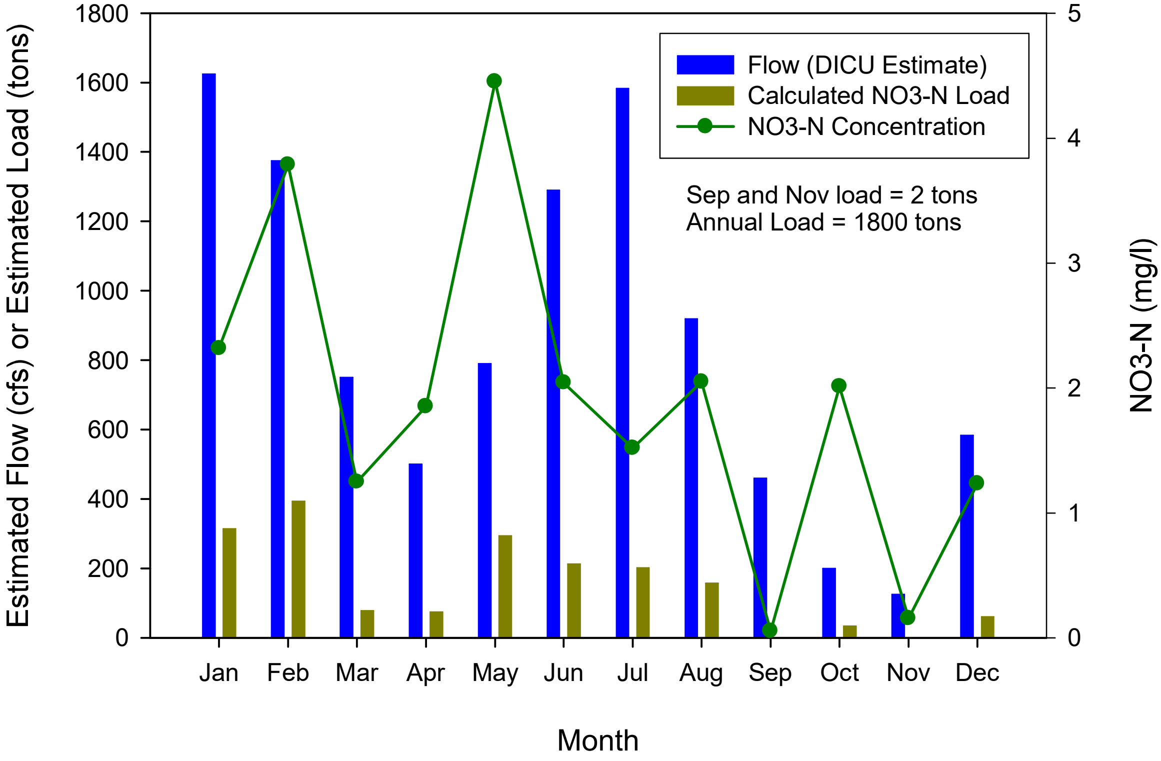


Figure 5-13. DICU estimates of flow for each month coupled with mean monthly concentration data observed at all island drains from Figure 5-12, used to estimate the contribution of NO3-N from agriculture on Delta islands.

Due to the lack of phosphorus data from Delta agricultural drainage, phosphorus export rates for agriculture were used to estimate the phosphorus load. An export rate of 0.030 tons/km^2, calculated by averaging the Sacramento Basin value (0.042 tons/km^2) and San Joaquin Basin value (0.017 tons/km^2) was used. Note that these are composite values for all years, and thus are between the numbers presented for wet and dry years separately in Table 4-7. The total area of the Delta (700,000 acres) was multiplied by the fraction devoted to agriculture (2/3) to obtain the agricultural acreage on the Delta Islands of 466,700 acres or 1,890 km^2 (DWR, 1995). The export rate multiplied by the agricultural area gives a total annual phosphorus load of 56 tons. Due to the uncertainty inherent in this estimate, separate values for wet and dry years were not calculated.

5.3.3 SUMMARY OF NUTRIENT LOADS IN THE DELTA

Figures 5-14 and 5-15 present annual averages of the tributary loads estimated in Chapter 4 and the in-Delta loads estimated in this chapter for nitrogen and phosphorus, respectively. The tributary loads were presented in Tables 4-10 through 4-13, and represent outflow loads (calculated using in-stream flow and concentration data) where available. The loads denoted ‘Delta Watersheds’ are the sum of watershed loads from sub-watersheds 20 and 21 (from the ‘Sum of Watershed Loads’ column in Tables 4-10 through 4-13). In-delta loads of both nitrogen and phosphorus are a small portion of total tributary loads during both wet and dry years. The nutrient export in water diversions is relatively uniform from year to year, particularly when compared with the tributary loads. In dry years, the export of nitrogen and phosphorus in water diversions is similar in magnitude to their export to the Bay.

Figure 5-14 shows that during both wet and dry years the load of nitrogen to the Delta (tributaries and in-Delta agriculture) exceeds the exports from the Delta (to the Bay and the water diversions) by approximately 7,000 tons. Figure 5-15 shows that during both wet and dry years the load of phosphorus to the Delta (tributaries and in-Delta agriculture) exceeds the exports from the Delta (to the Bay and the water diversions) by approximately 1,000 tons. These are not precise numbers due to the uncertainty in the load estimates; however, some of this nitrogen and phosphorus is likely taken up as a food source by Delta organisms.

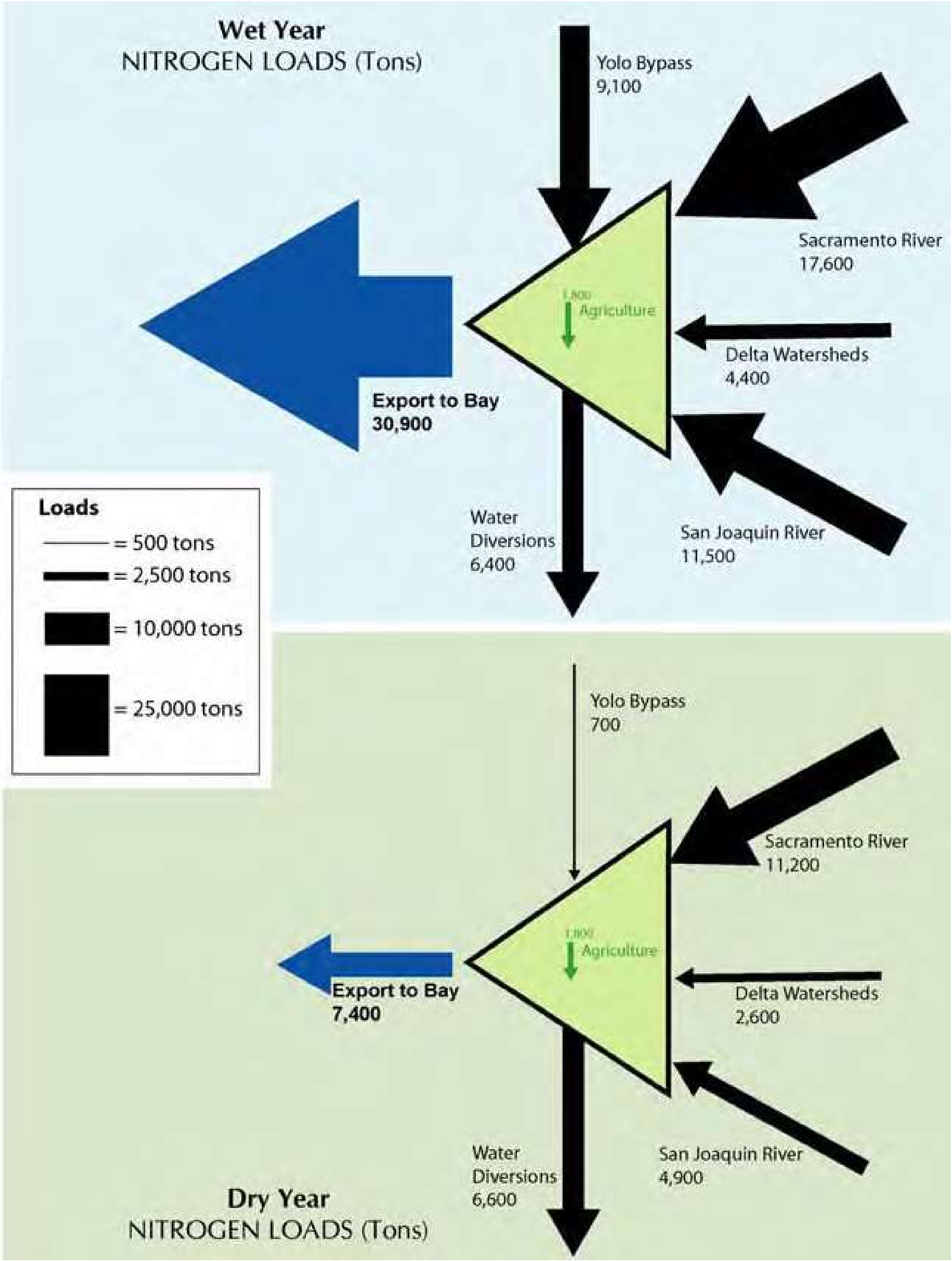


Figure 5-14. Nitrogen tributary loads calculated in Chapter 4, along with the internal loads estimated in Chapter 5.

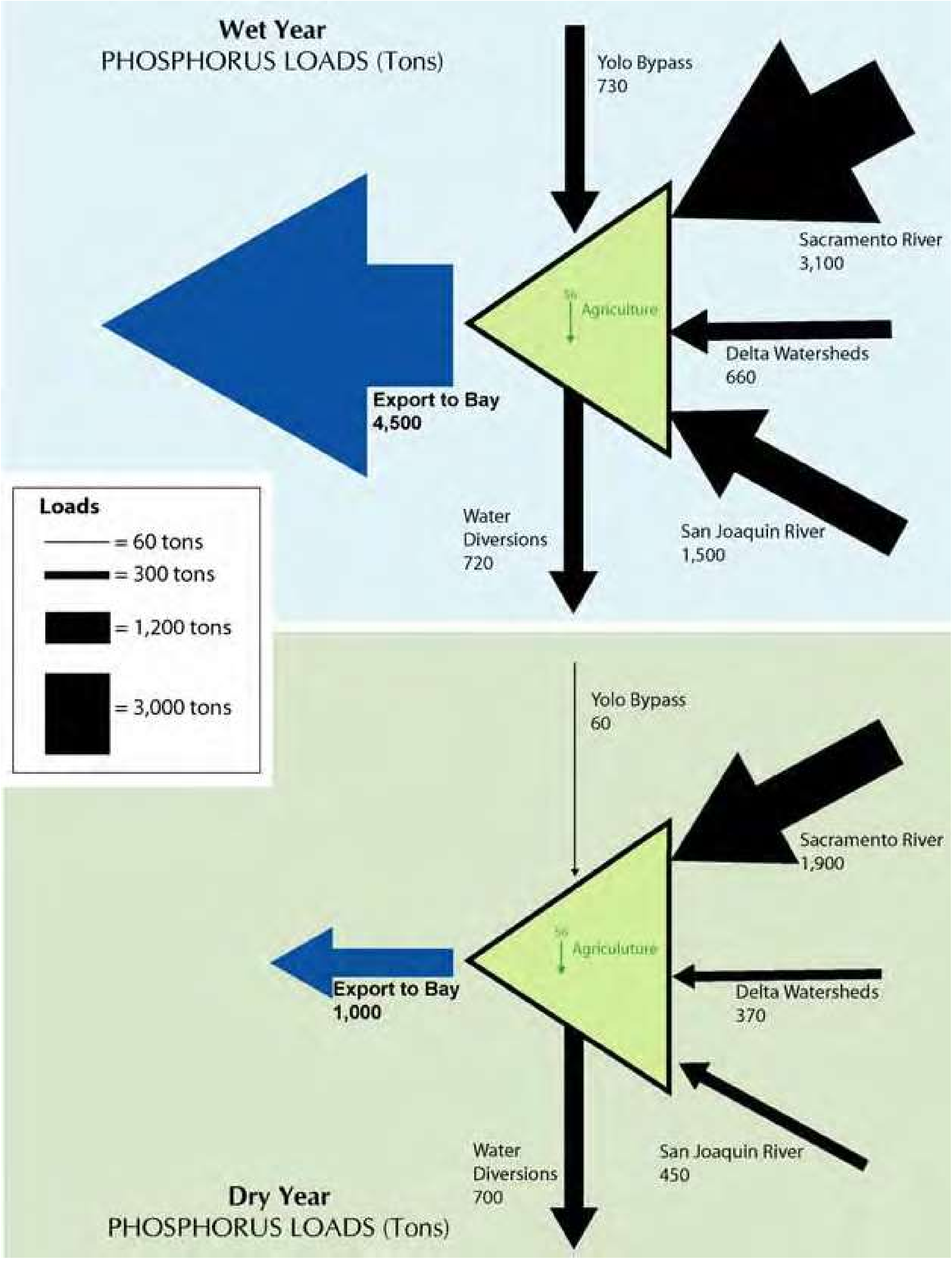


Figure 5-15. Phosphorus tributary loads calculated in Chapter 4, along with the internal loads estimated in Chapter 5. Note that the scale is different in this figure for phosphorus loads than the scale in the previous figure for nitrogen loads.

5.4 MAJOR FINDINGS

At location in the Delta over the period 1980 to 2004, the average concentration of ammonia-N was two times higher in the Sacramento River than the San Joaquin River. For other nutrient species, average concentrations were higher in the San Joaquin River than the Sacramento River (up to a factor of ten higher for NO3+NO2-N). In general, average concentrations at the Banks Pumping Plant lie between average concentrations in the Sacramento and San Joaquin Rivers, except for ammonia-N and TKN, where average concentrations at Banks are lower than both Sacramento and San Joaquin River average concentrations.

The major source of in-Delta contribution of nutrients is from Delta island agricultural drainage. NO3-N is the only nutrient species data collected by MWQI from Delta agricultural drains. Estimates from this study show that annual loads of nutrients from the tributaries are substantially greater than the loads from in-Delta agricultural drainage. As previously shown in Chapter 4, Sacramento River nutrient loads to the Delta are larger than San Joaquin River nutrient loads, especially in dry years.

The nutrient export in water diversions is relatively uniform from year to year, particularly when compared with the tributary loads. In dry years, the exports of nitrogen and phosphorus in water diversions are similar in magnitude to their export to the Bay.

CHAPTER 6.0
MAJOR FINDINGS AND RECOMMENDATIONS FOR FUTURE WORK

The development of the conceptual model in this report involved the synthesis of a large amount of data and information from published reports. The conceptual model can be used to direct future investigations to improve understanding of nutrient-related sources, impacts, and management. This chapter summarizes key findings and recommendations for future work.

6.1 MAJOR FINDINGS

Temporal and spatial patterns in nitrogen and phosphorus transport in the Central Valley are related to the flows in the rivers, which are highly variable, especially on an inter-annual basis. Tributary nutrient loads are substantially greater in the wet season than in the dry season. Tributary loads were also found to vary significantly between wet and dry years. Although the nutrient concentrations in the Sacramento River are lower than the concentrations in the San Joaquin River, the Sacramento River load to the Delta exceeds the San Joaquin River load by a factor of nearly two or greater for both nitrogen and phosphorus. Concentrations of nitrogen and phosphorus in San Joaquin River and in the Delta were fairly high, suggesting that these waters could be classified as eutrophic. The San Joaquin River exhibits many classic symptoms of eutrophication such as low dissolved oxygen levels in deeper waters that adversely affects many beneficial uses. Given the abundance of nutrients, primary productivity in the Delta is fairly low suggesting that factors other than nutrients are limiting, specifically light limitation caused by suspended solids. In the absence of other limiting factors, as might occur during transport of these waters in aqueducts, and storage in reservoirs, these high nutrient levels may express themselves as high levels of algal growth. Further, future changes in Delta conditions that change these limiting conditions, such as increased clarity due to greater abundance of submersed plants, could cause the phytoplankton productivity to increase.

In evaluating the watershed nutrient loads, it was not possible to calculate export rates for each type of land use present in the Central Valley and Delta. A limited amount of nutrient data has been collected from watersheds with one particular type of land use. Most of the data available for this analysis were collected at locations that have mixed land uses. Export rates of nutrients (mass of nitrogen or phosphorus exported per unit area per year) were estimated for several land uses: urban land, agricultural land, wetlands, and background areas (including forests, shrubland, and rangeland) based on the limited data. The calculated total watershed exports are comparable to the stream loads at key locations (such as Sacramento River at Hood/Greene's Landing and San Joaquin River at Vernalis). There were considerable differences in the estimated loads derived from the two methods at locations where there were limited nutrient concentration data. Export rates, as currently approximated, could be improved through focused flow and concentration data collection in small, relatively homogenous watersheds.

Using watershed export rates, preliminary conclusions can be drawn about nutrient loads from different sources. Forest/rangeland loads for nitrogen may dominate the overall loads for the Sacramento Basin and agriculture loads for nitrogen may dominate in the overall loads for the San Joaquin Basin, particularly for wet years. Point source loads from wastewater discharge may contribute nearly half or more of overall nitrogen and phosphorus loads during dry years in both basins, and during wet years for phosphorus in the San Joaquin Basin.

At location in the Delta over the period 1980 to 2004, the average concentration of ammonia-N was two times higher in the Sacramento River than the San Joaquin River. For other nutrient species, average concentrations were higher in the San Joaquin River than the Sacramento River (up to a factor of ten higher for NO3+NO2-N). In general, average concentrations at the Banks Pumping Plant lie between average concentrations in the Sacramento and San Joaquin Rivers, except for ammonia-N and TKN, where average concentrations at Banks are lower than both Sacramento and San Joaquin River average concentrations.

The major source of in-Delta contribution of nutrients is from agricultural drainage on Delta islands. NO3-N is the only nutrient species data collected by MWQI from Delta agricultural drains; phosphorus loads are estimated using watershed export rates developed in Chapter 4. Current estimates show that annual loads of nutrients from the tributaries are substantially greater than the loads from in-Delta agricultural drainage. The nutrient export in water diversions is relatively uniform from year to year, particularly when compared with the tributary loads. In dry years, the exports of nitrogen and phosphorus in water diversions are similar in magnitude to their export to the Bay.

6.2 RECOMMENDATIONS FOR FUTURE WORK

This section focuses on the uncertainties associated with the quantitative information presented in preceding chapters, and identifies key data gaps that should be addressed in future work, primarily through targeted monitoring. A summary of the uncertainty associated with the quantitative information presented in Chapters 3, 4, and 5 is shown in Table 6-1. Uncertainties and recommendations for nutrients largely follow those presented for organic carbon in Tetra Tech, 2006.

Table 6-1.
Relative levels of uncertainty and importance of sources identified in the Conceptual Model.

Source	Level of Uncertainty	Importance
Tributary Loads		
Sacramento Basin		
Sacramento R. at Bend Bridge	**Medium**	Medium
Butte Cr.	High	Low
Sacramento R. at Colusa	**Medium**	Medium
Yuba R.	**Medium**	Medium
Bear R.	Medium	Low
Feather R.	High	Medium
American R.	Medium	Medium
Sacramento R. at Hood/Greene’s Landing	Low	High
Cache Cr.	**Medium**	Low
Putah Cr.	High	Low
San Joaquin Basin		
San Joaquin R. at Sack Dam	High	Low
Chowchilla R.	High	Low
Bear Cr.	High	Low
Merced R.	**Medium**	Medium
San Joaquin R. at Newman	Medium	Medium
Tuolumne R.	Medium	Medium
Stanislaus R.	Medium	Medium
San Joaquin R. at Vernalis	Low	High
Delta		
Cosumnes R.	Medium	Low
Mokelumne R.	Medium	Low
Delta North	High	Medium
Delta South	High	Medium
In-Delta Sources		
Delta Island Agricultural Drainage	High	High
Export Rates		
Agricultural Land	High	High
Urban Runoff	**Medium**	High
Background Areas	High	High
Wetlands	**High**	High
Other		
Point Source Discharges	**Medium**	High
Reservoirs	High	Medium

Note: The Level of Uncertainty or Importance is bolded where different from organic carbon data (Tetra Tech, 2006).

6.2.1 TRIBUTARY LOADS

Uncertainty and Importance

The number of water quality samples and the length of the flow data record were used to assign the rankings of low, medium, and high uncertainty associated with each of the subwatersheds listed in Table 6-1. The loads in the Sacramento River at Hood/Greenes Landing and the San Joaquin River at Vernalis are well characterized due to many years of data collection. In general, the loads of nutrients in the other subwatersheds that discharge to the Sacramento and San Joaquin rivers are not as well characterized. It is interesting to note that compared to organic carbon data availability, some uncertainty levels went from high to medium due to *more* data at these locations for nutrients.

Recommendations

There are substantial data that were not used in this study because the concentration data were collected at locations for which there are no flow data or because the database did not contain latitude and longitude information. The Workgroup should review all of the data that have been collected for each of the subwatersheds and determine the key locations that require additional monitoring. In addition, it is recommended that for future monitoring programs and future versions of the database, a consistent set of nutrient names is used. In the version of the database used for this study, 22 different variations of nutrient species names were present for the six constituents reported in this document.

Finer resolution of the sub-watershed delineation may be necessary to enhance understanding of load sources. For example, finer resolution on the Sacramento River between Colusa and the Delta would facilitate understanding of the importance of the agricultural and urban loading in this area.

6.2.2 DELTA AGRICULTURAL DRAINAGE

Uncertainty and Importance

Drainage volumes are currently estimated with the DICU model. NO3-N data is the only nutrient species from Delta agricultural drains collected by MWQI. It is important to have an accurate estimate of the phosphorus concentrations, total nitrogen concentrations, and drainage volumes before management options can be considered.

Recommendations

USGS is currently monitoring drainage volumes on Twitchell Island and MWQI is conducting a study of drainage volumes on Staten Island. These measured drainage volumes should be compared to estimates from the DICU model to assess how accurately the model predicts drainage volumes. Then decisions can be made on the importance of obtaining additional drainage volume data. Phosphorus data should be collected in Delta agricultural drains so that phosphorus loads can be more accurately estimated.

6.2.3 EXPORT RATES

There is an extensive amount of nutrient concentration data collected in the major streams in the Central Valley. These data can be used to compute export rates from mixed land uses. However, for distinguishing sources, it is important to estimate the contribution of specific land uses. To meet this objective, focus should be placed on studying small indicator watersheds or specific sources.

Agriculture

Uncertainty and Importance

Over 5,460,000 acres (20%) of the Central Valley watershed is used for agricultural production. There are currently limited data on the loads of nutrients discharged from agricultural land in the tributary watersheds. The data from the Colusa Basin Drain in the Sacramento Basin is representative of loads from rice fields. Information is needed on other types of agricultural in the Sacramento Basin, such as orchards and row crops. Mud Slough, which receives drainage from agricultural lands, was used to estimate agricultural loads in the San Joaquin Basin due to lack of other available data. Due to different sources of water and different methods for management of drainage in the San Joaquin Basin, the loads of nutrients from agricultural operations may differ by crop type, and loads on the west side of the San Joaquin Basin may differ from those on the east side of the Basin.

Recommendations

The Workgroup should obtain data collected by the agricultural waiver monitoring programs and from the Regional Board agricultural monitoring to determine if nutrient loads from agricultural lands can be adequately estimated or if more focused monitoring is needed. In addition, USGS recently started a project to estimate contaminant loads from a small agricultural watershed, Willow Slough. This study should be tracked, and, when the results are available, they should be used to refine the estimate of agricultural loads.

Urban Runoff

Uncertainty and Importance

The export rate for urban runoff was estimated from seven years of data (USGS NWIS: 1996-98; 2001-04) from a single developed watershed, Arcade Creek. Additional data on urban runoff loads are needed to refine the load estimates presented in this report.

Recommendations

MWQI is completing a seven year study on loads from a rapidly urbanizing watershed in Sacramento and Placer counties. The Workgroup should review the MWQI study results and compare the export rate with the one calculated from Arcade Creek. In addition, the Workgroup should work with the City and County of Sacramento and the City of Stockton to determine if loads can be calculated from the data collected as part of their NPDES storm water permit programs.

6.2.4 POINT SOURCE LOADS

Wastewater Treatment Plants

Uncertainty and Importance

Nutrient and flow data were available for most wastewater treatment plants in the Central Valley and Delta, however per capita flow data was only available for three plants (Sacramento Regional Wastewater Treatment Plant, Davis and Vacaville).

Recommendations

Loads could be better characterized with per capita flow data for all wastewater dischargers. In addition, nutrient data should be further analyzed by treatment process type. This would help to determine if nutrient loads are related to treatment processes and to improve the estimates of nutrient loads from wastewater treatment plants.

Fish Hatcheries

Uncertainty and Importance

Fish hatcheries are permitted to discharge up to 352 MGD (average dry weather flow of 256 MGD) into Central Valley waters. There are currently no data in the project database on nutrient concentrations in fish hatchery waste, however literature data is likely available. The importance of this source is currently unknown and should be investigated.

Recommendations

The Workgroup should collect nutrient data from several fish hatcheries during the next year or two. These data will be useful in determining if fish hatcheries are a source of nutrients that should be included in refined conceptual models.

6.2.5 RESERVOIRS

Uncertainty and Importance

There are reservoirs on most of the rivers in the Central Valley watershed but there are currently limited data on the concentrations of nutrients released from the reservoirs.

Recommendations

The Workgroup should gather any additional data that are available on concentrations of nutrients in reservoir releases. If sufficient data are not available, additional data should be collected on the major rivers immediately downstream from reservoirs.

6.2.6 OTHER RECOMMENDATIONS

The Delta Simulation Model (DSM2) was used to simulate dissolved oxygen (DO) in the Delta as part of the technical studies for the In-Delta Storage Project Feasibility Study (DWR, 2004). As part of the DO modeling, the nutrient cycle is simulated. Published results, however, relate only to DO. It is recommended that the workgroup work with DSM2 developers to obtain nitrogen and phosphorus specific model simulation results.

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