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Mass Balance Analysis for the San Joaquin River from Lander Avenue to Vernalis

Report 4.8.3

Ashley Stubblefield
Shelly Gulati
Mary Kay Camarillo
Jeremy Hanlon
William Stringfellow

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Ecological Engineering Research Program
School of Engineering & Computer Sciences
University of the Pacific
3601 Pacific Avenue
Chambers Technology Center
Stockton, CA 95211

List of Acronyms

ADCP	acoustic doppler current profiler
Ammonia	total ammonia nitrogen
APHA	American Public Health Association
b	bias correction term
BOD	biochemical oxygen demand
C	concentration
c	coefficient of variation
CALFED	Collaboration Among State and Federal Agencies to Improve California's Water Supply
CBOD	Carbonaceous Biochemical Oxygen Demand
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CIMIS	California Irrigation Management Information System
D-F	Dupuit-Forchheimer
DO	dissolved oxygen
DWR	Department of Water Resources
DWSC	deep water ship channel
EERP	Ecological Engineering Research Program
ESWD	El Solyo Water District
ET	evapotranspiration
FS	fluorescence
G	correlation coefficient
HDPE	high-density polyethylene
ITRC	Irrigation Training and Research Center
kg	kilograms
l	liters
L	load
l/s	liters per second
mg/L	milligrams per liter
$MgCO_3$	magnesium carbonate
MID	Modesto Irrigation District
mL	milliliter
MODFLOW	modular finite-difference flow model
N	number of continuous samples
n	number of grab samples

List of Acronyms (cont.)

NaOH	sodium hydroxide
NBOD	Nitrogenous Biochemical Oxygen Demand
NIST	National Institute of Standards and Technology
Nitrate	nitrate-nitrite-nitrogen
NTU	Nephelometric turbidity units
Phosphate	dissolved orthophosphate as phosphorus
PID	Patterson Irrigation District
ppb	parts per billion
PTFE	polytetrafluoroethylene
Q	flow
QA	quality assurance
QC	quality control
s	variance
SAS JMP	statistical software
SJR	San Joaquin River
SJRIO	San Joaquin River Input-Output Model
SM	Standard Methods
sonde	YSI 6600 V2 water quality sonde
SpC	specific conductivity
t	time
TDS	Total Dissolved Solids
TID	Turlock Irrigation District
TMDL	Total Maximum Daily Load
TSS	total suspended solids
USGS	United States Geological Survey
UV	ultraviolet
V	volume
VS2DH	software for calculating water flow and energy transport in variably saturated porous media
VSS	volatile suspended solids
VWR	distributor of research laboratory products
WSID	West Stanislaus Irrigation District
Y	number of days in the year
YSI	Yellow Springs International
µS/cm	micro seimens per centimeter

Introduction

In this report, we present the findings of a mass balance analysis that was performed for the San Joaquin River (SJR) using data collected in 2007 in order to identify sources of oxygen-consuming materials in the SJR. The Ecological Engineering Research Program (EERP) performed a dissolved oxygen (DO) study in the SJR, titled "Upstream Dissolved Oxygen Total Maximum Daily Load Project" (CALFED ERP-02D-P63), in which extensive data sets were collected in the upstream portions of the SJR watershed from 2005 to 2007, with 2007 being the year with the most extensive data set. In the current project, the SJR DO Total Maximum Daily Load (TMDL) Project (CDFW E0883006), a mass balance was calculated on the SJR using the data set from 2007. The work herein addresses Subtasks 4.7 and 4.8 of the current project, where the EERP was directed to use and analyze data collected in the previous DO TMDL Project and other existing data sets. These efforts, including identification of sources of oxygen-consuming materials from within the watershed, are supportive of decision-making efforts that are integral to a TMDL project.

To complete the mass balance analysis, the study area was delineated and evaluated and flow and water quality data was collected. Data was collected for locations within the main stem of the SJR, major river inputs (tributaries), and major diversions. The portion of the SJR included in the mass balance analysis is the river section located between the Lander Avenue and Vernalis flow and water quality monitoring stations. These monitoring stations are situated on the main stem of the SJR and are located near the cities of Stevinson, CA and Vernalis, CA, respectively. The station at Vernalis was identified as a lower study boundary because Vernalis is the legal limit of the Delta, it is used for compliance monitoring, extensive data sets have been collected there, and this station is used by multiple agencies. As an upstream boundary, the Lander Avenue station represents the first reasonable access to the SJR with reliable year-round flow and a recognizable stream bed. Some portions of the SJR upstream of the Lander Avenue station have very minimal flow and can run dry seasonally. The mass balance study area comprises a 60-mile portion of the SJR upstream of the Deep Water Ship Channel (DWSC). The year 2007 was selected for analysis because the most complete flow and water quality sampling data sets are available for this year. In addition, the years 2005 and 2006 were extremely wet years and the high flows in the SJR resulted in damage to flow monitoring stations, and in some cases, the capacity of flow monitoring equipment was exceeded.

To complete the mass balance analysis, extensive flow and water quality data were collected and analyzed. Flow data were collected from existing data sources [e.g. California Data Exchange Center (CDEC)] at 29 locations within the study area; five of these locations were within the main stem of the SJR, 21 of these locations were located at the confluence of river inputs (e.g. tributaries) and three of these locations were near areas where water was being diverted from the river for agricultural use (CDEC 2013). Water quality data originated from the previous DO TMDL Project (ERP-02D-P63; Stringfellow et al. 2008) and were collected by analyzing grab samples at 26 of the 29 locations where flow data were collected, as water quality data were not collected at the locations of the three diversions since the diverted water quality is the same as what is observed in the river. Data for the following water quality constituents were analyzed: total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solids (VSS), biochemical oxygen demand (BOD), carbonaceous biochemical oxygen demand (CBOD), nitrogenous biochemical oxygen demand (NBOD), chlorophyll-a (herein termed chlorophyll), total nitrogen, nitrate-nitrite-nitrogen (herein termed nitrate), total ammonia nitrogen including nitrogen derived from ammonium and aqueous ammonia (herein termed ammonia), organic nitrogen, total phosphorus, and dissolved orthophosphate as phosphorus (herein termed phosphate). Continuously collected (e.g. in 15-minute increments) specific conductance data was used to verify the accuracy of three mass load calculation methods: Mean-Load Method, True-Load Method, and the Beale Ratio Method. The method determined to be most accurate for this mass balance analysis was used in all subsequent calculations.

The mass balance analysis was performed by calculating mass loads (concentration times flow) of all tributaries entering the SJR within the study area. Inputs to the SJR were compared, on a mass basis, to determine their relative contributions to the SJR. Also, the mass load contributions were compared relative to their flow contributions to determine the best targets for water quality improvement efforts (Stringfellow 2008). All mass loads upstream of the Vernalis monitoring station (tributary inputs minus diversions) were summed and compared with the mass loads observed at the Vernalis station. The flow contribution from groundwater was estimated by calculating the difference between flow from upstream sources and the downstream observations. Previous studies on groundwater flow and quality for inputs to the SJR were consulted to verify that the calculated TDS concentrations, determined based on the TDS mass balance, were consistent with previously observed values. The estimated groundwater flow contributions were verified as well using results of previous studies for the SJR. The previous work was then used to determine input of nitrogen and phosphorus to the river from groundwater. Flow and mass contributions resulting from precipitation were also considered in the mass balance analysis along with estimated losses from evapotranspiration.

While mass balance closure is expected for flow and TDS, it is not expected for water quality constituents that are not conserved. In this study, water quality constituents that are not expected to be conserved are TSS, VSS, BOD, CBOD, NBOD, chlorophyll, total nitrogen, nitrate, ammonia, organic nitrogen, total phosphorus, and phosphate. The reason that organic matter (BOD and VSS) and many nutrient forms (nitrate, ammonia, organic nitrogen, and phosphate) are not conserved is that these constituents are used by organisms for metabolic function and for synthesis, resulting in conversion of these constituents into other forms (e.g. ammonia is converted to organic nitrogen). Also, phytoplankton growth results in increased TSS, VSS, and chlorophyll concentrations. Total nitrogen may or may not be conserved, depending on whether denitrification is occurring. Total phosphorus also may or may not be conserved, depending on interactions with the river bed sediments since phosphorus has a high affinity for sorption to soil particles. To better understand processing of organic matter and cycling of nutrients within the SJR, calculations for phytoplankton growth were performed and the results were compared with the mass load results. The lack of mass balance closure on some constituents is likely the result of inputs from non-point sources (e.g. increased TSS resulting from stream bed erosion). Differences in the upstream sources and downstream observations highlight some of the biological and chemical processes occurring within the river.

The current study is not the first mass balance analysis performed for the SJR. Previous mass balance studies have been performed (Kratzer et al. 1987; Ohte et al. 2007). Kratzer et al. (1987) used flow and water quality data from 1977-1985 to develop the San Joaquin River Input-Output

Model (SJRIO) for salinity, boron, selenium, and molybdenum. Kratzer et al. (1987) made estimations for all surface and groundwater inputs and outputs as well as precipitation, evapotranspiration, and riparian vegetation water usage. In a mass balance for water years 1981, 1984, and 1985, Mud and Salt Sloughs accounted for 40-55% of the total TDS while the east side tributaries accounted for 15-35% and the west side tributaries accounted for 10-15%; the balance of the TDS mass load originated from agricultural drains, municipal inputs, industrial inputs (Kratzer et al. 1987). Ohte et al. (2007) performed a mass balance on nitrate, soluble reactive phosphorus, and chlorophyll using biweekly sampling from seven river locations and 11 tributaries during the dry seasons of 2000 and 2001. Taking into account nutrient transformation by algal growth, Ohte et al. (2007) were able to account for 60% of the nitrate load and 80% of the phosphate load in the SJR. The objective in the current study was to build on the previous studies by using more recent data than what was used by Kratzer et al. (1987), and collecting data that are relevant to development of low DO conditions. Another objective of the current study was to collect a more expansive data set compared with what was collected in the study by Ohte et al. (2007). Also, it was desirable to collect data that was more spatially expansive than in both previous studies.

The overall goal of this mass balance analysis was to determine the sources of oxygen-demanding substances in the SJR and the sources of substances that contribution to oxygen depletion (e.g. nutrients). This mass balance analysis provides the basis for understanding of DO conditions in the downstream portion of the SJR resulting from activities and conditions in the upstream portion of the SJR watershed. These efforts are supportive of the TMDL process where load allocation is being performed and where determining the best locations for implementation of improvement projects is critical for improving the overall health of the river.

Methods

Description of Study Area

The San Joaquin Valley comprises the southern two-thirds of the Central Valley of California and is bound by the Coast Range to the west and the Sierra Nevada Mountains to the east. The valley has a semi-arid Mediterranean climate and receives an average of 5 to 16 inches of rainfall annually, most of which falls between October and March, resulting in a distinct dry season. The SJR originates in the Sierra Nevada, descending west to the valley floor, and draining north to the Sacramento-San Joaquin Delta. Land use in the San Joaquin Valley is dominated by agriculture, which has greatly altered the land surface, including the flow path of the SJR and its tributaries. While some streambeds, located outside of agricultural areas, run dry during the dry season, many tributaries receive flow almost exclusively during the dry season and summer flows are comprised almost entirely of irrigation return flows.

The study area comprises a 60-mile segment of the SJR beginning at the Lander Avenue monitoring station near Stevinson, CA and ending at the Vernalis monitoring station (Figure 1). River flow increases more than 50 fold (averaged over the year) between Lander Avenue and Vernalis due to inputs from tributaries, drains, excess irrigation flows, and groundwater. Three rivers, the Merced, Tuolumne, and Stanislaus, originate in the Sierra Nevada and are impounded in the foothills for agricultural and urban use before draining to the SJR. The Orestimba, Del

Puerto, Ingram, and Hospital Creeks originate in the Coast Range and follow historical creek beds to the valley floor where they have been channelized for use in agricultural drainage conveyance. Mud Slough, Salt Slough, and Los Banos Creek channel both agricultural runoff and wetland drainage from the San Luis National Wildlife Refuge.

In addition to the main tributaries, there are many manmade inputs to and outputs from (diversions) the river. On the east side of the river, agricultural runoff is pumped into the SJR at several locations. At one such location, the TID Harding Drain, agricultural drainage flow is discharged into the SJR along with wastewater treatment plant effluent and stormwater runoff from the City of Turlock. On the west side of the river, drains are used to discharge agricultural drainage such as tailwater runoff, tile drainage, and operational spillage. Tailwater runoff consists of the excess water applied to row crops and orchards that results from flood irrigation practices. The excess water, on the order of 25%, is needed to hydraulically deliver irrigation water across a field or orchard during flooding. For orchards, more efficient irrigation practices, such as drip irrigation, are becoming more commonplace. Tile drainage consists of the applied irrigation water that is collected in ceramic tiles located several feet below ground; tile drainage typically is used in high salinity soils and the resulting drainage water is clear and high in salinity. Operational spillage, similar to tailwater, is excess irrigation water that is necessary to hydraulically deliver water to the fields where it is applied. All of these types of agricultural return flows are discharged into the SJR. In addition, on the west side of the SJR, there are also several pumping stations used by the irrigation districts to divert water out of the SJR for irrigation use.

Sample and Data Collection Locations

In the mass balance analysis, mass loads were calculated for all ten natural tributaries discharging into the SJR (three rivers, two sloughs, and five creeks) along with six eastside drains, five westside drains, and three diversions. All major inputs were included in the mass balance analysis. Sample sites were selected based on data collection sites used in previous studies, locations where on-going data collection programs are in-place, and sites where flow monitoring is conducted. In general, samples were collected near the confluence of tributaries, as restricted by site-specific access limitations. For the smaller inputs and drainage canal, data collection focused on sites where there is a history of flow and mass contributions to the SJR and where there is consistent flow to/from the SJR. Final site selection was conducted based on extensive mapping of the area and site visits, conducted via land and water.

Flow data was obtained for 24 inputs and diversions along the study reach in addition to five locations in the main stem of the SJR (Figure 1). Table 1 contains a list of all sample site locations along with DO TMDL Project number, locations, and predominant sources of flows. Flow data was obtained for all sampling site locations. Water quality data was obtained for all sampling site locations except for the three diversions where sampling was conducted in the river in close proximity to the diversions. The river water quality was assumed to be representative of the water being diverted. In addition, sample collection of pumped diversion water was not ideal as the pumping may alter some water quality constituents such as DO. The five sampling locations in the main stem of the SJR are located at the following flow and water quality monitoring stations: SJR at Lander Avenue (near Stevinson, CA), SJR at Crows Landing, SJR at Patterson, SJR at Maze Road, and SJR at Vernalis (Figure 1).

For most locations of data collection, grab sample sites and flow monitoring stations were located in close proximity to each other. The only exceptions were the sampling sites at the confluences of the Merced, Stanislaus, and Tuolumne Rivers where grab samples for the rivers were taken near the confluence with the SJR; however, flow monitoring stations were located more than 10 miles upstream. Flow inputs to the rivers downstream of the monitoring stations would cause the calculated loads to the SJR to be biased low. However, Kratzer et al. (1987) determined previously that flows do not change significantly between the flow monitoring stations and the confluence with the SJR.

Continuous Flow and Specific Conductance Data

Data Sources

Continuous flow and specific conductance data sets were collected from available sources. Table 2 contains a list of the sample sites along with the data sources, station operator, measurement frequency, and flow data completeness and availability for each station. Continuous data sets for most tributaries, westside drains, and SJR locations were obtained from CDEC (2013). As shown in Table 2, many of the stations are operated and maintained by the U.S. Geological Survey (USGS) and by the California Department of Water Resources (DWR). At these stations maintained by the USGS and the DWR, continuous flow and specific conductance measurements were recorded at hourly to quarter-hourly intervals (Table 2).

In addition, the EERP performs regular maintenance at nine of the continuous monitoring stations included in this study: Los Banos Creek, Hospital Creek, Ingram Creek, Westley Wasteway, Del Puerto Creek, Marshall Road Drain, Ramona Lake Drain, Moran Drain, and Spanish Grant Drain. Continuous flow and specific conductance measurements for these stations maintained by the EERP were recorded at fifteen minute intervals and the data was obtained directly from the station loggers. Some of the data sets collected at the stations maintained by the EERP were also reported to CDEC and made available through their website (CDEC 2013). Continuous data sets for the eastside drains and diversions were obtained directly from the irrigation districts located in Modesto (MID), Turlock (TID), Patterson (PID), and West Stanislaus (WSID) as well as the El Solyo Water District (ESWD). Flow estimations were made based on hourly, daily, and monthly averages of pump meter readings. Specific conductance data was only available for three of the eastside drains: MID Lateral 4, MID Miller Lake, and TID Lateral 6 & 7.

River Stage and Flow Measurement

In practice, flow data for rivers, streams, and conveyance structures (e.g. canals) are developed by recording stage measurements (representing water depth), and by using a rating curve that defines the stage/flow relationship. The continuously monitored stage can then be used to calculate flow rate. Each location has a unique rating curve that is developed by making direct and discrete flow measurements in the field under different stage conditions. Accurate continuous flow measurements are dependent on the accuracy of the discrete flow measurement on which the rating curve is based as well as the accuracy of the stage measurements. The USGS estimates that continuous flow data that are developed using this approach are accurate to within 5-10% (Hirsch and Costa 2004). As stream beds and banks change and shift while stage measuring structures remain static, the rating curves need to be updated periodically. As a result, station operators typically recalibrate rating curves 8 to 12 times a year.

River stage measurements were made using a variety of methods, depending on the size of the water body and other site conditions. In the drains and small tributaries of the SJR, flow measurements are typically made using a sharp crested weir to channel the flow and an ITRC weir stick to measure the stage; the data were then used to calculate flow using the ideal weir equation (Irrigation Training and Research Center 2003). In open streams, pressure sensors and other water level sensor technology are used. In some cases, flumes are also used to measure flow. In the main stem of the SJR and in larger tributaries where flows are tidally influenced, flow measurements are made through the use of acoustic Doppler current profiler (ADCP) technology (Simpson 2001). Use of more sophisticated technology is necessary in tidally influenced water bodies because the flow direction reverses with the tides. Table 2 lists the type of flow measuring structure (weir, flume, pump, or open channel) that is used at each sampling location.

Data Quality

Each sampling location was given an estimated flow data quality rating of good, fair, poor, or unknown (Table 2). The quality rating conveys the accuracy of the flow data, and is based on the occurrences of phenomena which would cause inaccurate flow measurements such as equipment tampering or malfunction, blockages of flow, inconsistent stage to flow relationships, and relative quality of flow measuring structures.

A problem that arises from using rating curves for determination of stream flow data is that a rise in stage is always interpreted as an increase in flow, even when that is not actually the case. At the Marshall, Moran, and Spanish Grant Drains, farmers have been known to block flow downstream of the measuring structures in order to flood-irrigate their land. This causes a rise in stage that is interpreted, using the rating curve, as a sharp increase in flow even though the water is stagnant. A similar phenomenon occurs at Del Puerto Creek where blockages have been known to occur due to debris buildup and beaver dams. The opposite can occur at Marshall, Moran, Spanish Grant, and Ramona Lake Drains where farmers have been known to pull weir boards out in order to more quickly drain their fields. The lowered weirs cause a drop in stage that is interpreted as a decrease in flow. Field notes, correlating site data, precipitation data, firsthand knowledge, and observations of the site were used to omit data points which were believed to be associated with these phenomena. Data points which were believed to be associated with equipment error or malfunction, such as clogged bubbler lines, were also removed from the data sets.

Occasionally, continuous data measurements were missing due to equipment malfunctions and other factors. In order to estimate load by the True-Load method (described in detail in the Mass Load Calculations section), complete datasets were required. For these estimations, missing data points were replaced with averages of adjacent data points. Where more than one week of consecutive data was missing, the time period over which the gap occurred was omitted from the study interval. The total annual load was computed by dividing the total load over the number of days in the shortened study interval and then multiplying by the number of days in the year (365). This calculation was done for 14 of the tributaries: Merced River, Los Banos Creek, Orestimba Creek, MID Lateral 4, MID Miller Lake, TID Westport Drain, Hospital Creek, Westley Wasteway, Del Puerto Creek, Marshall Road Drain, Ramona Lake Drain, Moran Drain, Spanish Grant Drain, and the PID Diversion.

When a rating curve is recalibrated and a new stage to flow relationship is applied to a dataset, it is reflected as a change of flow when little or no change in stage exists. This was the case on 5/23/07 at SJR at Maze Road and 5/24/07 at SJR at Patterson, when the reported flow dropped 2,095 L/s (8%) at Maze Road and 4,757 L/s (26%) at Patterson over a fifteen minute time interval without a significant change in stage. Recalibration of rating curves is routine; however, the severity of the change in these specific cases is unusual. The next recalibrations at these sites occurred on 7/17/07 when the flow rose 7,220 L/s (62%) at Maze Road and 8,891 L/s (206.6%) at Patterson. Upon further inspection of the flow data sets, it was determined that the ratings curves applied during the time period occurring 5/23/07-7/17/07 were inconsistent with other rating curves used throughout the year, indicating that a misrepresentative rating curve may have been applied. For this study, corrected flow datasets were developed for the time period occurring 5/23/07-7/17/07 for these two flow stations by applying the immediately subsequent rating curve (occurring 7/17/07-8/17/07) to the existing stage measurements. The result was a more consistent stage to flow relationship throughout the 2007 calendar year, as shown in Figures 2 and 3.

Grab Sample Collection

Grab samples were collected and analyzed by the EERP as described in prior reports (Borglin et al. 2008). All samples were collected, preserved, stored, and analyzed by methods outlined in Standard Methods for the Analysis of Water and Wastewater unless otherwise indicated (APHA 2005; Borglin et al. 2008). Certified standards, trace clean and certified sample bottles, reagent grade chemicals, and high purity water produced by a Milli-Q gradient system (Millipore, Billerica, MA) were used for all analyses. Analysis methods for specific analytes are outlined below and are described in detail in Borglin et al. (2008) and Graham and Hanlon (2008). Detailed information on QA/QC results are available in the 2007 water quality summary report by Borglin et al. (2008).

Water samples were collected in glass 1000 mL bottles (Wheaton Science Products, Millville, NJ), 1000 mL HDPE Trace-Clean narrow mouth plastic bottles (VWR International), 250 mL HDPE Trace-Clean wide mouth plastic bottles (VWR International), and 40 mL trace clean vials with PTFE septa (IChem, Rockwood, TN) in accordance with requirements for different laboratory analyses and volume requirements. All bottles were properly labeled and rinsed with sample water prior to taking a depth-integrated sample. When possible, water was collected by passing the bottle through the water column using a telescoping pole. For sites which could only be accessed by a high bridge or platform, a pre-rinsed bucket and funnel were used to collect and distribute sample water to the bottles. Care was taken to distribute water simultaneously to all sample bottles and not sequentially. Immediately after collection, samples were stored at 4°C and transported to the laboratory on the day of sampling. Date, time, bottle numbers, meter readings, and field observations were recorded in a field notebook.

Water Quality Data Collection Using a Continuous Monitoring Instrument

In addition to grab samples, continuous water quality data was also collected during sampling trips with the use of a YSI 6600 Multiparameter Water Quality Data Sonde in conjunction with a YSI 650 MDS handset. The sonde and handset were calibrated in the laboratory the day before sampling, following procedures in the YSI 6-Series Environmental Monitoring Systems Handbook (YSI Inc., Yellow Springs, CO). Specific conductance was measured with a temperature compensated specific conductance probe, which was calibrated using a 0.01 M KCl conductivity standard with a value of 1408 µS/cm (Radiometer Analytical SAS, Lyon, France). Temperature calibration was checked against an NIST certified thermometer. A fluorescence probe was used to estimate chlorophyll; the output was referenced to Millipore water or 0 NTU water to account for drift. The sonde was also used to measure barometric pressure, DO, pH, oxidation-reduction potential, and turbidity, although the data was not used in the mass balance calculations described herein.

The sonde was programmed to record a measurement for each constituent every four seconds and was deployed at each sampling location for at least two minutes during sampling, ensuring a statistically significant sample size (n>30). Data from the sonde was also recorded in the field notebook. To account for drift during the sampling day, the sonde was post-calibrated within 24 hours of the sampling event using the same calibration solutions described above. Measurements made with sondes that did not pass QA requirements for post-calibration were not included in the mass balance analysis. Further details on QA/QC results for sonde measurements can be found in the 2007 water quality summary report by Borglin et al. (2008).

Grab Sample Frequency

The sampling strategy developed to provide a complete data set for the mass balance analysis was based on a familiarity with the study reach (Stringfellow, 2008), and was implemented in accordance with previous DO TMDL Project objectives. Main stem sites, rivers, and sloughs were sampled at weekly to biweekly intervals during the irrigation season (April-September) and at biweekly to monthly intervals during the remainder of the year. Most creeks and eastside drains were sampled at weekly to biweekly intervals during the irrigation season. Monthly sampling was attempted during the non-irrigation season, but was not always possible as many of the smaller drains and creeks run dry during the non-irrigation season. The sampling sites for Hospital Creek, TID Lateral 2, and MID Lateral 4 were only sampled one to two times in 2007. Westside drains were sampled at differing frequencies. Sampling began in April at Ramona Lake and continued at weekly to monthly intervals through August. The Marshall, Moran, Spanish Grant, and Westley Wasteway drains were only sampled two to three times in 2007.

Sampling was focused on the largest tributaries; the smaller creeks and drains were sampled more infrequently, with the sampling occurring during the irrigation season. In addition, some of the smaller drains are located in close proximity to each other and had very similar water quality.

An objective of the sampling plan was to maximize the amount of samples that were collected and processed and to focus on the most influential sample site locations.

Grab sample frequency can affect the accuracy of mass load calculations that are based on representative concentration data in addition to flow data. In a study by Gulati et al. (2013), TDS loads calculated by five different methods using grab sample data were compared to loads calculated using continuous monitoring data for ten agricultural water bodies in the San Joaquin Valley. It was determined that given continuous flow data sets with occasional gaps lasting a few days or longer, loads calculated using mean or median representations of flow in conjunction with grab sample concentration result in the most accurate characterization. Furthermore, it was found that loads calculated using grab sample data and Equation ii (below) resulted in an overestimation of 0 to 20% and that accuracy was not correlated with sampling frequency (Gulati et al. 2013). Based on these findings, it appears that mass concentrations at sites which were sampled at monthly or greater intervals may be relatively accurately represented; however, for those few sites which were sampled only a few times throughout the year, the concentration characterization is less accurate.

Laboratory Analyses

Samples were received by the laboratory the same day they were sampled and were immediately logged in, inspected for damage, and stored at 4°C until filtering and analysis. Samples were filtered and preserved, as necessary, within 24 hours of collection. Archive filtrate and unfiltered samples were saved from all sites for any re-analysis or additional analysis determined to be necessary. Samples were analyzed for TDS, TSS, VSS, BOD, chlorophyll, total phosphorus, and phosphate at the EERP laboratories. Nitrogen analyses for total nitrogen, nitrate, and ammonia were performed at the University of California, Davis and EERP laboratories.

Unfiltered, unseeded samples were analyzed for biochemical oxygen demand (BOD) by Standard Method (SM) 5210 B (APHA, 2005) with a modification for measurement of oxygen demand at 10 days rather than 5 days to be consistent with previous studies performed in the SJR (Foe et al. 2002; Lee and Jones-Lee 2003). Initial and final DO was measured using a calibrated YSI 5000 DO Meter equipped with a YSI 5010 BOD Probe (YSI, Yellow Springs, OH) and the calibration was verified by Winkler titration according to SM 10200 H (APHA, 2005). Duplicate samples were prepared for every 20 analyses and blanks consisting of BOD buffer solution were prepared according to SM 5210 B. All samples were tested at both full concentration and at a 1:3 dilution using BOD buffer to increase the number of reportable results. All BOD tests were initiated within 24 hours of sample collection. A standard curve was prepared for each sample set consisting of a BOD standard solution (HACH, Loveland, CO) containing glucose and glutamic acid at 1, 2, 3, and 4 mg/L in dilution buffer with 5 mL of seed from a randomly selected sample. If the standard curve resulted in an R^2 value of less than 0.85, all analyses made in association with the standard curve were omitted from the mass balance analysis. In addition, carbonaceous biochemical oxygen demand (CBOD) was determined by adding 0.16 mg of nitrification inhibitor (N-serve, HACH, Loveland, CO) to a duplicate sample set. Nitrogenous biochemical oxygen demand (NBOD) was determined by subtracting CBOD from BOD results. The limit of detection for BOD, CBOD, and NBOD was 1.0 mg/L.

Total suspended solids (TSS) and volatile suspended solids (VSS) was analyzed by SM 2540 D and E (APHA, 2005). Whatman GF/F filters (47 mm, 0.7 µm pore size) were used in the analysis. The filters were pre-rinsed with high purity water (Milli-Q gradient, Millipore, Billerica, MA) and pre-combusted for 6 hours at 550°C prior to filtering. Samples were homogenized before filtration and sample bottle weights were recorded before and after filtration; the difference was recorded as the filtered sample weight. Typically, 1000 mL of sample was filtered on pre-weighed, pre-combusted, Whatman GF/F filters. The filters were placed in an aluminum dish and dried at 105°C under vacuum to constant weight. After drying, the filter and dish were allowed to cool in a desiccator, weighed for TSS determination, then subsequently combusted at 550°C for six hours and reweighed for VSS determination.

Chlorophyll-a was extracted and analyzed using UV absorption as described in SM 10200 H (APHA, 2005). Trichromatic chlorophyll methods were used for quantification. Approximately 1000 mL of sample was filtered using vacuum filtration with a Whatman GF/F filter (47 mm, 0.7 µm pore size) within 24 hours of sample collection. The filters were pre-rinsed with high purity water (Milli-Q gradient, Millipore, Billerica, MA) and pre-combusted for 6 hours at 550°C prior to filtering. Samples were kept in the dark during storage and filtration. After the water was removed, saturated $MgCO_3$ was applied to the sample on the filter and the filter was stored at -20°C for up to 21 days before analysis. Extraction was performed by grinding the filter with a Teflon tissue grinder in acetone saturated with 10% by weight $MgCO_3$. The extracted sample was centrifuged for 20 minutes at 2000 rpm and chlorophyll was quantified by measurement of the supernatant on a PerkinElmer Lambda 35 (Waltham, MA) spectrophotometer using a 5 cm path length.

In order to develop a means for estimating chlorophyll based on fluorescence data, a linear regression analysis using statistical software (SAS JMP) was performed on all paired measurements for laboratory-extracted chlorophyll concentration and in-situ fluorescence (%FS) measurements from sample locations within the SJR during 2005-2007 and 2011-2012. A linear relationship was determined as follows,

$$\text{Chlorophyll-a } [\mu g/L] = 0 + 9.0 * [\%FS] \qquad \text{(i)}$$

Equation (i) was then used to calculate chlorophyll concentrations using sonde fluorescence measurements. Where sonde fluorescence measurements were unavailable, chlorophyll measurements by spectrophotometry were used. Values below the detection limits were omitted (0.2 %FS by fluorometry and 1.0 µg/L by spectrophotometry).

Nitrogen analyses for total nitrogen, nitrate, and ammonia were performed by an automated membrane diffusion/conductivity detection method using a Timberline Instruments TL-2800 Ammonia Analyzer (Boulder, CO). Total nitrogen was determined using unfiltered, digested samples. Sample digestion was performed by filling trace clean 16x150 glass tubes with PTFE lined caps (VWR International) with 5.0 mL sample and 5.0 mL digestion reagent, autoclaving for one hour, and then allowing the sample to cool (Yu et al. 1994). Digestion reagent was made with 10 g potassium persulfate, 6 g boric acid, and 3 g NaOH in 1000 mL Millipore water.

Dissolved nitrate and ammonia were determined using filtered samples. The limit of detection for all nitrogen analyses was 50 ppb N. Organic nitrogen was calculated by subtracting nitrate and ammonia from total nitrogen. Nitrite-nitrogen (NO_2-N) is only present in appreciably small amounts in reduced environments, and was assumed to be zero in this study.

Phosphorus analyses for total phosphorus and phosphate were performed using the ascorbic acid method (adapted from SM 4500-P-E) with HACH PhosVer3 packets (Loveland, CO). Total phosphorus was determined using unfiltered, digested samples. Sample digestion was performed by filling trace clean 16x150 glass tubes with PTFE lined caps (VWR International) with 5.0 mL sample and 5.0 mL digestion reagent, autoclaving for one hour, and then allowing the sample to cool (Yu et al. 1994). Digestion reagent was made with 10 g potassium persulfate, 6 g boric acid, and 3 g NaOH in 1000 mL Millipore water. Dissolved phosphate was determined using filtered samples. Spectrophotometric measurements were made at 890 nm on a PerkinElmer Lambda 35 (Waltham, MA) spectrophotometer. The limits of detection were 6.0 ppb for total phosphorus and 18 ppb for phosphate.

Mass Load Calculations

Mass loads were calculated for each sampling site location using continuous flow and grab sample water quality data. For the purposes of this report, the mass load is the mass, in kilograms, which passes through the cross section of a waterbody at the sampling location over a specified period of time. The amount of time over which a load is calculated is referred to as the calculation interval. The duration of calculation intervals is based on sampling frequency with each interval beginning and ending midway between adjacent sampling times. The total load is the mass of a specified water quality constituent that passes through the waterbody over the entire study period and is achieved by summing all calculation interval loads within the study period. Here, the study period begins January 1, 2007 and ends December 31, 2007, unless otherwise specified.

There are many approaches for calculating mass loads using flow and concentration data. Most methods fall into one of three categories: numeric integration, averaging approaches, and ratio estimators (Gulati et al. 2013). Each method has advantages and disadvantages, and the most accurate approach varies depending on the given conditions. An averaging approach was sought here because of the variable flow and mass concentrations within the SJR and its tributaries, and because of the lack of a consistent relationship between flow and concentration, due in part to the regulated nature of the SJR (Gulati et al. 2013). Averaging approaches rely on numeric integration with various average representations of flow and concentration data. In this study, grab sample concentration data was collected less frequently than the continuously collected flow data. As a result, the calculation intervals were based on grab sample frequency and the mean flow over the calculation interval was averaged as shown in the following equation,

$$\text{Mean-Load [mass]} = \sum_{i=1}^{n} C_i \bar{Q}_i \Delta t_i \qquad \text{(ii)}$$

where n is the number of grab samples, C_i is the concentration of grab sample i [mass/volume], Δt_i is half the time between the (i-1)th and the (i+1)th grab samples or the duration of the calculation interval, and $\bar{Q}_i$ is the mean flow rate for the calculation interval [volume/time]. The method of mass load calculation shown in Equation (ii) represents the Mean-Load Method.

The main advantage of using the Mean-Load Method is that it does not require a correlation between concentration and flow. In fact, averaging techniques, such as the Mean-Load Method, tend to bias low if there is a positive correlation between concentration and flow and bias high if there is a negative correlation (Richards 1998). The disadvantage of averaging techniques is that they tend to be less accurate if flow distributions are not normally distributed (Richards 1998). However, Gulati et al. (2013) demonstrated that normality did not significantly impact on overall accuracy in the SJR system. Gulati et al. (2013) further found that using mean flow in load calculations for agricultural watersheds is robust to the normality requirement and outperforms non-parametric methods in some cases.

Mass Load Estimation Quality Check

In order to investigate the overall accuracy of the mass load calculations, TDS loads were calculated using two alternative methods, and the results were compared to estimations made by Equation (ii). The first alternative method is based on numeric integration and is called the True-Load Method. Using this method, mass loads were calculated by multiplying concurrent flow and concentration data measurements and the time interval between those measurements,

$$\text{True-Load [mass]} = \sum_{k=1}^{N} C_k Q_k \Delta t_k \quad \text{(iii)}$$

where N is the number of continuous measurements, C_k is the concentration of the kth measurement [mass/volume], Q_k is the flow rate at the time of the kth measurement [volume/time], and Δt_k is the time between the kth and the (k+1)th continuous measurement. In this study, Δt_k was 15 minutes, with a few exceptions.

The second alternative method is a ratio method called the Beale Ratio Method. Here, mass loads were calculated by determining the average daily loads for days in which grab samples were taken and adjusting them proportionally to the average daily loads for which continuous measurements were taken. The total load is found by multiplying the average daily load by the number of days in the study interval,

$$\text{Beale Ratio Load [mass]} = b * \bar{l}_0 \frac{\bar{q}_a}{\bar{q}_0} \quad \text{(iv)}$$

Where $\bar{l}_0$ is the mean daily load [mass] for days when samples were collected, $\bar{q}_a$ is the mean daily flow averaged over the entire year [volume/time], $\bar{q}_0$ is the mean daily flow on days when samples were collected [volume/time], and b is the bias correction term. The bias correction b term is calculated based on the relationship between flux and flow as shown in the following equation,

$$\text{Bias correction term} = \left[\frac{1 + \left(\frac{1}{n} - \frac{1}{Y} \right) \frac{s_{lq}}{\bar{l}_0 \bar{q}_0}}{1 + \left(\frac{1}{n} - \frac{1}{Y} \right) \frac{s_{qq}}{\bar{q}_0^2}} \right] \quad \text{(v)}$$

where n is the number of days when samples were collected (which is equal to the number of grab samples, since no more than one grab sample was taken per day), Y is the number of days in the year, s_{lq} is the covariance between flux and flow, and s_{qq} is the variance of the flow data.

Continuous TDS concentration data sets were needed for mass load calculations performed using the True-Load Method and the Beale Ratio Method, so the continuously collected specific conductance measurements were converted to TDS using the following relationship,

$$\text{TDS [mg/L]} = 0.64 * \text{SpC } [\mu\text{S/cm}] \quad \text{(vii)}$$

Nearly complete continuous specific conductance data sets were available for 15 of the 29 flow and water quality stations within the study reach. Because the Beale Ratio Method is dependent on the calculation of flux variance, it requires at least two grab sample measurements, which further excluded two sites. The 13 samples sites included in the TDS mass load estimation comparisons were SJR at Vernalis, SJR at Maze, SJR at Crows Landing, Tuolumne River, Merced River, Mud Slough, Salt Slough, Los Banos Creek, Orestimba Creek, Ingram Creek, Westley Wasteway, Del Puerto Creek, and Marshall Road Drain.

The percent difference between the TDS mass loads using the Mean-Load Method and the two alternative methods (the True-Load Method and the Beale Ratio Method) was found using the following equation,

$$\text{Difference (\%)} = 100 * \frac{\text{QA-load} - \text{mean-load}}{0.5 * (\text{QA-load} + \text{mean-load})} \quad \text{(viii)}$$

where mean-load is the TDS load calculated using Equation ii and QA-load is the TDS load calculated using Equation iii or iv.

Mass Load Calculations for Diversions

Because concentration data was not available for diversions, diverted mass loads were calculated based on the ratio of the diverted volume to the river volume, given by the following equation,

$$\text{Load}_{\text{diversion}} \text{ [mass]} = \frac{V_d}{V_r} L_r \quad \text{(ix)}$$

V_d is the volume of water that passed through the diversion over the calculation interval [volume], V_r is the volume of water that passed through the river just upstream of the diversion over the calculation interval [volume], and L_r is the total load that passed through the river just upstream of the diversion over the calculation interval [mass]. The volume is calculated by summing the product of the flow measurements and the time between each measurement. The total load of the river just upstream of the diversion is calculated by adding all upstream tributary loads and subtracting all upstream diversion loads. This mass balance method of calculating diversion mass loads assumes complete and instantaneous mixing of river contents throughout the cross section at the location where the diversion discharges into the river.

Mass Balance Analysis

The estimated mass loads at Vernalis were determined by adding the 22 tributary mass loads upstream of Vernalis and subtracting the three mass loads originating from the diversions located along the study reach of the SJR (Figure 1). A schematic was used to illustrate the relative position of each surface water input and diversion (Figure 4). The SJR at Lander Avenue sample site, which is the upstream study boundary, was considered a tributary (input) in the mass balance analysis. Mass loads were also computed at four river locations along the study reach. The river mass loads are herein termed observed loads. The locations of observed loads coincide with the locations of continuous water quality monitoring stations located near the cities of Vernalis (SJR at Vernalis), Grayson (SJR at Maze Road), Patterson (SJR at Patterson), and Crows Landing (SJR at Crows Landing) (Figure 1). To evaluate the effects of irrigation on mass loads into the SJR, mass loads were calculated separately for the irrigation season and for the 2007 calendar year as a whole. The irrigation season is defined as April 1, 2007 through September 30, 2007.

Precipitation and Evapotranspiration in the Mass Balance for Flow

Volume input to the SJR from precipitation was calculated using hourly incremental precipitation data from the California Irrigation Management Information System (CIMIS) station in Modesto (station #71) (CIMIS 2013). To calculate total precipitation input to the SJR, precipitation data was summed over the year and multiplied by the river's surface area between the Lander Avenue and Vernalis monitoring stations. Estimated surface area of the SJR between the Lander Avenue and Vernalis flow stations is 1634 acres as obtained from a California State Water Resources Control Board report on the regulation of agricultural drainage (Kratzer, 1987).

Volume output from the SJR from evapotranspiration (ET) was determined using pan evaporation and riparian vegetation water use data. Daily pan evaporation data was obtained from the Hidden Dam (Hensley) monitoring station located in Madera County (CDEC 2013). This station utilizes a Class A evaporation pan and is monitored by the U.S. Army Corps of Engineers. Pan evaporation measurements were converted to ET values for surface water using a 0.92 conversion factor (Doorenbos and Pruitt 1977, Kratzer et al. 1987). Total volume loss in the SJR by evaporation was calculated by multiplying summed ET values by the SJR surface area. Riparian vegetation water use data for the water years 1977-1985 was obtained from Kratzer et al. (1987) and was used for lack of more recent information. Kratzer et al. (1987) calculated riparian vegetation water use by estimating the area of riparian vegetation along the SJR using maps developed from aerial photos (Katibah et al. 1980) and an annual evapotranspiration requirement for riparian vegetation of 3.75 Acre-feet/acre/year based on the use of this factor by the Central Valley Water Use Study Committee of the California Department of Water Resources (1986).

It is assumed that the net volume loss/gain due to precipitation and evapotranspiration only affects the flow volume balance and does not affect the mass balance as rainwater and condensate has minimal ion content.

Results and Discussion

Flow Volume Balance

During 2007, approximately 1.7 trillion liters of water was estimated to flow through the SJR at the Vernalis flow station compared to 32.2 billion which flowed through the river at Lander Avenue (Table 4). The difference in these discharge volumes demonstrates that approximately 97% of the flow at Vernalis originated from inputs between the Lander Avenue and Vernalis monitoring stations. All but 7.8% of the total flow in 2007 was accounted for in the flow volume balance for surface water inputs (Figure 5). The Stanislaus River (33.2%), Tuolumne River (18.1%), Merced River (18.0%), Salt Slough (7.6%), and Mud Slough (4.7%) were the greatest contributors to total inflow (Figure 5). Together, the five creeks (Los Banos, Ingram, Hospital, Orestimba, and Del Puerto) accounted for 3.1% of the total inflow, the eastside drains (MID Lateral 4, MID Miller Lake, TID Lateral 2, TID Westport Drain, TID Harding Drain, and TID Lateral 6 & 7) accounted for 5.3% of the total inflow, and the westside drains (Westley Wasteway, Marshall Road, Ramona Lake, Moran, and Spanish Grant) accounted for 1.1% of the total inflow. Approximately 8% of the total inflow was diverted for irrigation use. Flow volumes for the year 2007 are listed by waterbody in Table 4.

The irrigation season (6 months, April-September) accounted for 43.0% of the annual flow at Vernalis (Table 4). Nearly 12% of the total inflow measured at Vernalis during the irrigation season was not accounted for in the flow volume balance for surface water (Figure 6). Together, the three rivers (Stanislaus, Tuolumne, and Merced) accounted for 78.9%, the two sloughs (Salt and Mud) accounted for 9.2%, the five creeks accounted for 3.1%, the eastside drains accounted for 6.6%, and the westside drains accounted for 1.8% of the total inflow to the SJR during the irrigation season; only 3.5% of the total inflow originated in the SJR upstream of Lander Ave. The greatest contributors to flow were the Stanislaus River (33.8%), Tuolumne River (17.8%), Merced River (17.3%), Salt Slough (6.2%), and TID Harding Drain (2.2%) (Figure 6).

It was estimated that approximately 2.5% of the SJR volume is lost annually through net evapotranspiration and precipitation (Table 4). A total of 7.05 inches of precipitation was measured at the CIMIS Modesto station over 2007, translating to an input of 1.2 billion liters to the SJR. The Hidden Dam monitoring station recorded a total of 101.91 inches of pan evaporation over 2007 which translated to a loss of 15.7 billion liters in the SJR. Kratzer et al. (1987) calculated an annual loss of 27.5 billion liters of water from the SJR due to riparian vegetation water use, and this value was also used in this study. Together, the net loss from evaporation, precipitation, and riparian vegetation water use was 42 billion liters (2.5% of total SJR volume).

Groundwater

When comparing the summation of SJR inputs (tributary flows minus diversions) upstream of Vernalis to observations made at the Vernalis monitoring station, it is apparent that 142.7 billion liters is unaccounted for in the surface water flow volume balance in 2007. Most of the unaccounted volume occurs during the irrigation season (in the absence of precipitation), where the difference in the sum of upstream flows and downstream observations is approximately 106.7 billion liters. When considered with precipitation, evapotranspiration, and riparian vegetation water use estimates, these unaccounted volumes are equivalent to an average flow rate of 98 L/s per river mile over the entire year. The differences in surface water flow volumes are likely the result of groundwater inflows, which have been previously documented and are significant.

The SJR Input-Output Model developed by Kratzer et al. (1987) included a steady-state, one dimensional deterministic groundwater model based on Dupuit-Forchheimer (D-F) assumptions. It was used to estimate groundwater flow rates ranging from 15.1-17.7 L/s per river mile between Lander Avenue and Vernalis during the 1984 and 1985 water years. These estimations may be low; however, as more recent data has shown that use of the D-F assumptions can cause underestimations in groundwater flow to the SJR by as much as 25% (Grismer and Rashmawi 1993).

Phillips et al. (1991) estimated groundwater flow rates to the SJR near the Newman, Crows Landing, and Patterson monitoring stations using MODFLOW, a modular finite-difference flow model for groundwater that was developed by the USGS. The model results suggested that groundwater contributes approximately 57 L/s per river mile on average (Phillips et al. 1991). For comparison, a second estimate of groundwater flow rate was made using a water budget method; the resulting estimates were 91 L/s per river mile for October 1986 and 190 L/s per river mile for June 1989 (Phillips et al. 1991). It was noted that the simulation was conducted during the third year of a drought and that groundwater pumping during that year was relatively high, resulting in relatively low groundwater inflow to the SJR.

Zamora et al. (2013) used three different methods to estimate groundwater inflows to the SJR between the confluence with Salt Slough and the Vernalis monitoring station. Using a mass balance approach similar to the one described in this paper, groundwater inflows of 103 L/s per river mile for August 2006 to December 2007 and 123 L/s per river mile for August 15, 2007 to September 7, 2007 were estimated. An updated version of the MODFLOW program used in the Phillips et al. (1991) study found an average inflow of 28 L/s per river mile. In addition, temperature and stage measurements were used in conjunction with the USGS numerical model, VS2DH, in order to estimate groundwater inflow. However, these results were determined to be low due to the one-dimensional nature of the model which only included vertical groundwater flows and not horizontal flows.

The results of these previous studies demonstrate that the unaccounted volumes in the flow volume balance could reasonably be explained by groundwater inflow at the rate of 98 L/s per river mile annually. As such, the unaccounted flow volume is attributed to groundwater inflows in subsequent analyses described below.

Quality Assurance for Load Calculations

Results for the TDS mass loads calculations made by the Mean-Load Method, True-Load Method, and Beale Ratio Method are shown in Table 5. The True-Load Method results were, on average, 7.1% less than results obtained using the Mean-Load Method, with a maximum difference of -32.4%. The Beale Ratio Method results were, on average, -1.8% different than Mean-Load Method results, with a maximum difference of -14.0% (Marshall Road Drain). Achieved error rates ranged from 6.2% (SJR at Crows Landing) to 66.9% (Marshall Road Drain). The achieved error rates for the six largest tributaries (the SJR sites at Vernalis, Maze Road, and Crows Landing as well as Tuolumne River, Mud Slough, Salt Slough) were low, ranging from 6.2 to 12.7%. The highest error rates were for water bodies with lower flow rates. When used with data sets that have a high sampling frequency, such as continuously monitored flow and water quality data sets, the True-Load Method gives the most accurate calculation of mass load. As measurements are missed due to vandalism, equipment malfunction, or other factors, gaps in the data sets must be filled with averages of adjacent data points and this introduces bias. The True-Load Method was not chosen as the primary load calculation method in this study because continuous water quality measurements do not exist for most constituents at most sites.

The Beale Ratio Method was chosen as a quality assurance method because of its established use in TMDL regulation in the Great Lakes (Young et al. 1988) and because it is commonly cited as being more accurate and precise than averaging methods when ample flow data but limited concentration data are available (Dolan et al. 1981; Preston et al. 1992; Richards 1998; Young et al. 1988). However, the accuracy of Beale Ratio Method is dependent on several criteria. The first is a positive linear relationship between flux and flow. Also, ratio estimators require a sample size of at least 30 and coefficients of variation of less than 10% for both mean discharge and load (Cochran 1977). Very few of the sample sites included in this study meet all or any of the criteria, which is why the Beale Ratio Method was not chosen as the primary load calculation method. The Beale Ratio Method, however, has been shown to be robust to these shortcomings and is still included in this study as a means of comparison. To give an idea of the level of confidence to which Beale Ratio estimates are made, achieved error rate was calculated for each TDS load by dividing the root mean square error by the annual load and multiplying by 100 (Baun 1982).

At three out of five sites where the differences between True-Load and Mean-Load were greater than 10% (Westley Wasteway, Merced River, and Tuolumne River), Beale Ratio Load resulted in worse characterizion of True-Load, suggesting that Beale Ratio did not do a significantly better job at load characterization compared to Mean-Load (Table 5). Furthermore, these sites have a slight negative relationship between flow and concentration (not apparent at other sites) which could indicate that mass loads calculated using the Mean-Load Method will be overestimated.

Mass Balance Analysis

Mass loads were calculated and organized into tables according to the 29 sample sites where data were collected (described in Table 1) and the 11 water quality constituents analyzed (Tables 6 to

10). Pie charts were used to illustrate the various sources of the mass load inputs to the SJR (odd numbered Figures 7 to 57). Each pie slice represents the proportion of the total mass load to the SJR from an individual source (e.g. derived from a tributary). Load designated as "other" or "overestimated" represents sinks and sources other than surface water inputs (described in Table 1), which was calculated by subtracting the net sum input mass loads (inputs minus diversions) from the mass load observed at the Vernalis monitoring station.

To investigate the roles of concentration and flow in each of the mass load calculations, the total volume was plotted against mass load and the plots were divided into quadrants (even numbered Figures 8 to 58). The quadrants were defined by dividing the plots at the average mass load and average volume. The quadrant analysis is important since two tributaries with equal mass load, but varying flows, may present unequal targets for watershed management (Stringfellow 2008). The first quadrant contains tributaries with high flows and high mass loads. While these tributaries are large load contributors, these tributaries are less attractive targets for watershed management because their large flows make them difficult to treat and implement best management practices and their mass concentrations are often already lower than other tributaries. The second quadrant contains tributaries with low flows and high loads. These tributaries are attractive targets for water quality improvement due to their smaller flows and higher impacts on river water quality. The third quadrant contains tributaries with low flows and low loads, constituting a majority of the tributaries. These tributaries are easier to target for water quality improvement projects, but their improvement may have less impact on the total load in the river compared with other tributaries. The final quadrant contains high flow and low load tributaries. These tributaries are the least attractive for watershed management improvement efforts.

Total Dissolved Solids

Over the year 2007, 641.8 million kg of TDS was measured in the SJR at Vernalis (Table 6). Approximately two thirds (63.0%) of the TDS load at Vernalis was accounted for by surface water loads (Table 6). Mud Slough (18.8%), Salt Slough (18.2%), Tuolumne River (5.4%), Stanislaus River (4.5%), and Merced River (4.1%) were the greatest TDS contributors to the SJR (Figure 7); all occupied the first quadrant of Figure 8. Los Banos Creek accounted for 3.1% of total inputs to the SJR and was the sole occupant of the second quadrant in Figure 8, making it a good target for management actions taken to reduce TDS loads in the SJR. The remaining tributaries were in the third quadrant.

The irrigation season accounted for 43.0% of the annual TDS load (Table 6). Approximately half of the TDS load measured at Vernalis over the irrigation season was accounted for by surface water loads (Table 6). The sloughs and rivers were the greatest observed contributors of TDS (Figure 9). The SJR at Lander Ave (3.0%) and TID Harding Drain (2.6%) were the next largest contributors; their high load to flow ratios make them ideal targets for management actions taken to reduce TDS load in the SJR during the irrigation season (Figure 10).

The mass balance on surface water inputs indicates that a large proportion (37.0% annually) of the TDS mass load may be due to groundwater flows (Table 6). The quantity of groundwater entering the SJR at the study site was calculated to be 184.8 billion liters (Table 4). Assuming the 237 billion grams of TDS, which was unaccounted for by surface loads, originated from groundwater (Table 6), the groundwater would have a TDS concentration of 1286 mg/L (or a specific conductance of 2009 μS/cm using equation vii). In order to determine if this estimate is reasonable, previous studies were consulted to determine typical concentrations for TDS in the groundwater entering the SJR in the vicinity of the study area (Phillips et al. 1991; Zamora et al. 2013).

Using MODFLOW at the SJR sites at Newman, Crows Landing, and Patterson, Phillips et al. (1991; explained above) estimated that groundwater inflows have a specific conductance of 2230 μS/cm. Using a mass balance approach, Phillips et al. (1991) estimated that the specific conductance of groundwater inflows was 1473 μS/cm. Using a TDS to specific conductance ratio of 0.64, the reported specific conductance values are equivalent to a TDS concentration range of 943-1427 mg/L. Our estimated 1286 mg/L TDS falls within this range.

In another study investigating groundwater inputs in the SJR, Zamora et al. (2013) measured water quality parameters of groundwater flowing directly in the SJR. Samples were collected along a 60-mile stretch of the SJR, from the confluence with Salt Slough to the Vernalis monitoring station, four times during the summer months of 2007-2009. Samples were collected from the hyporheic zone and tested for numerous parameters. The data sets reported by Zamora et al. (2013) were obtained directly from the USGS (USGS 2013) and were used to calculate average TDS concentrations for groundwater. The length of the study area was divided into 20 uniform river segments and the average concentration in the hyporheic zone was calculated for each segment. By averaging the values for all segments and converting specific conductance to TDS using Equation vii, the average TDS concentration was found to be 2239 mg/L. Given the difficultly in characterizing groundwater quality through direct sampling and the fact that only 1-4 samples were collected at each location within the river over a three year period, we believe the TDS concentration results of the Zamora et al. (2013) study to be comparable to our own estimates.

Total Suspended Solids

Over 70.5 million kg of TSS was measured over 2007 at Vernalis, over two thirds of which was accounted for by surface water loads (Table 7). Salt Slough (17.4%), Stanislaus River (9.5%), Merced River (7.3%), Tuolumne River (5.6%), and Mud Slough (5.0%) were the greatest contributors to TSS in the SJR (Figure 11) and occupied the first quadrant of Figure 12. Ingram Creek (4.0%) and Hospital Creek (3.5%) were the next largest contributors and occupied the second quadrant, making them ideal targets for management actions taken to reduce TSS load in the SJR. The westside drains and creeks tended to have higher TSS concentrations than eastside drains (Table 6).

The irrigation season accounted for 53.0% of the annual TSS load at Vernalis (Table 7). Ingram Creek (6.8%), Spanish Grant Drain (4.7%), and Hospital Creek (4.7%) had their largest flows and TSS concentrations during the irrigation season, putting them in the top five contributors, behind Salt Slough (16.5%) and the Stanislaus River (9.3%) (Figure 13), which makes them ideal targets for TSS reduction (Figure 14).

Similar to the TDS mass balance, a significant portion of the TSS mass load at Vernalis was unaccounted for in the tributary inputs to the SJR. Based on the data analyzed, 35.1% of the annual TSS mass load inputs were from sources other than tributaries (Table 7). Similarly, 39.1% of the TSS mass load during the irrigation season originated from sources other than surface loads (Table 7). Although algal biomass accounts for some of the observed increase in TSS, much of the unaccounted for TSS mass load is likely the result of bank erosion and in-stream sediment resuspension.

Volatile Suspended Solids

Over 2007, 12.4 million kg of VSS was measured at the Vernalis monitoring station, half of which was accounted for by surface water loads (Table 8). Salt Slough (11.6%), Stanislaus River (8.1%), Tuolumne River (6.3%), Mud Slough (6.0%), and Merced River (5.1%) were the greatest contributors (Figure 15). The upstream SJR (SJR at Lander Ave, 3.0%) was the only attractive target for VSS reduction based on its flow to load ratio (Figure 16). Typically, VSS made up 15-30% of TSS during the irrigation season and 10-20% during the non-irrigation season at Vernalis.

During the irrigation season, 47.3% of the VSS load was accounted for by surface water loads (Table 8) indicating that more than half of the VSS is being produced in the river, probably as a result of algal growth. Salt Slough (11.9%), Stanislaus River (8.7%), Tuolumne River (5.4%), Merced River (4.7%), and Mud Slough (3.9%) were the greatest contributors (Figure 17). Mud Slough, Ingram Creek (3.1%), and SJR at Lander Ave (2.6%) were disproportionally high VSS load contributors (Figure 18).

Volatile suspended solids (VSS) is a water quality constituent that is not necessarily conserved in river systems. Here, the increase in algal biomass from the Lander Avenue location to the Vernalis monitoring station results in an increase in VSS, as the majority of the biomass is present as VSS (organic matter). Additional inputs of VSS are likely present as the result of erosion and other processes.

Biochemical Oxygen Demand

Five and a half million kg of BOD was measured at Vernalis over 2007, nearly two thirds of which was accounted for by surface water loads (Table 9). The Stanislaus River (10.4%), Mud Slough (9.3%), Tuolumne River (8.8%), Salt Slough (8.4%), and the Merced River (6.2%) were the greatest contributors (Figure 19). SJR at Lander Ave (5.3%) and Los Banos Creek (4.6%) were the best targets for BOD reduction in the SJR due to their relatively small volumes and large loads (Figure 20).

The irrigation season accounted for 47.2% of the annual BOD load from surface water inputs (Table 9). Over half of the BOD load during the irrigation season was not accounted for by surface water loads (Table 9). The rivers and sloughs were the greatest contributors (Figure 21). Mud Slough (4.3%), SJR at Lander Ave (4.0%), and Los Banos Creek (3.2%) were attractive targets for BOD reduction in the SJR (Figure 21).

Similar to TSS and VSS, BOD is not typically conserved in rivers, and there are many potential sources of BOD in addition to those monitored in this study (Table 1). Non-point sources are, in particular, significant sources of BOD within watersheds. Algal growth also contributes to BOD, which is reflected in the fact that 97.7% of non-surface loads occurred during the irrigation season (Table 9).

Carbonaceous Biochemical Oxygen Demand

CBOD accounted for 56.8% of the annual BOD measured at Vernalis. Surface water loads accounted for 66.2% of the CBOD load measured at Vernalis (Table 10). Mud Slough (10.6%), Stanislaus River (10.4%), Tuolumne River (8.9%), Salt Slough (7.7%), and Merced River (6.9%) were the greatest contributors (Figure 23). SJR at Lander Ave (6.7%) and Los Banos Creek (5.5%) were the best targets for management actions taken to reduce CBOD in the SJR based on their disproportionately smalls flows and large loads (Figure 24).

The irrigation season accounted for 67% of the annual CBOD load at Vernalis, 46.4% of which was accounted for by surface water loads (Table 10). Stanislaus River (9.0%), Salt Slough (6.3%), Tuolumne River (6.0%), Merced River (5.3%), and SJR at Lander Ave (5.2%) were the greatest contributors (Figure 25). Mud Slough, SJR at Lander Ave, and Los Banos Creek (3.9%) occupied the second quadrant of Figure 26.

Nitrogenous Biochemical Oxygen Demand

NBOD accounted for 43.2% of the annual BOD measured at Vernalis. Surface water loads accounted for 57.1% of the NBOD load measured at Vernalis (Table 11). The Stanislaus River (10.3%), Salt Slough (9.3%), Tuolumne River (8.7%), Mud Slough (7.5%), and the Merced River (5.3%) were the greatest contributors (Figure 27). Of the smaller tributaries, SJR at Lander Ave (3.4%) and Los Banos Creek (3.4%) were the best targets for NBOD reduction in the SJR (Figure 28).

The irrigation season accounted for 65% of the annual NBOD load at Vernalis, 41.6% of which was accounted for by surface water loads (Table 11). The Stanislaus River (9.7%), Salt Slough (7.5%), Tuolumne River (6.3%), Merced River (3.9%), and Mud Slough (3.1%) were the greatest contributors (Figure 29). Due to their smaller flows and larger loads, Mud Slough, SJR at Lander Ave (2.3%), and Del Puerto Creek (2.2%) were ideal targets for management actions taken to reduce NBOD in the SJR during the irrigation season (Figure 30).

Chlorophyll-a

Fifty thousand kg of chlorophyll was measured at Vernalis over 2007, only 22.9% of which was accounted for by surface water loads (Table 12), with the remainder being produced in-stream. Mud Slough (6.7%), Salt Slough (4.6%), SJR at Lander Ave (4.0%), Los Banos Creek (2.1%), and the Merced River (1.4%) were the greatest contributors to chlorophyll load in the SJR (Figure 31). Due to their relatively smaller flows, SJR at Lander Ave and Los Banos Creek were the best targets for chlorophyll reduction in the SJR (Figure 32). MID Lateral 4 and TID Lateral 2 did not contain any detectable chlorophyll load (Table 12), though the number of concentration measurements taken at these sites is small (Table 3).

The irrigation season accounted for 76.9% of the annual chlorophyll load at Vernalis (Table 12). Only 11.0% of the chlorophyll load measured at Vernalis during the irrigation season was accounted for by summing the contributions from the tributaries (Table 12). Mud Slough (3.7%), Salt Slough (3.3%), SJR at Lander Ave (1.8%), Merced River (1.5%), and Ramona Lake Drain (0.8%) were the greatest contributors (Figure 33). Mud Slough, SJR at Lander Ave, Los Banos Creek (0.7%), and Ingram Creek (0.7%) occupied the second quadrant of Figure 34, making them ideal targets for management actions taken to reduce chlorophyll in the SJR. Ramona Lake (0.8%) also occupied the second quadrant of Figure 34, however, samples were only taken during the irrigation season, so there could be a higher bias.

The difference between chlorophyll mass loads at the Lander Avenue and Vernalis monitoring stations demonstrates the amount of algal growth that is occurring in the main stem of the SJR. The tributary inputs of algae are minimal compared to growth in the river. The quantity of algal biomass observed at the Vernalis monitoring station also represents significant mass loads of TSS, VSS, BOD, total nitrogen, organic nitrogen, and total phosphorus. Also, the productivity in the SJR is resulting in transformations of nitrogen and phosphorus, which is discussed below.

Total Nitrogen

A total of 3.3 million kg of total nitrogen was measured in the SJR at the Vernalis flow station, nearly all of which was accounted for by surface water loads (Table 13). The Merced River (24.9%), Tuolumne River (14.7%), Mud Slough (10.5%), TID Harding Drain (10.0%), and TID Westport Drain (8.3%) were the greatest contributors (Figure 35). TID Harding Drain, TID Westport Drain, and TID Lateral 6 & 7 (5.0%) were the best targets for total nitrogen reduction in the SJR based on their relatively smaller flows and large loads (Figure 36).

The irrigation season accounted for 44.9% of the annual nitrogen load at Vernalis (Table 13). An additional 6.2% of the total nitrogen load measured at Vernalis was accounted for by surface water loads (Table 13). Merced River (34.0%), Tuolumne River (12.4%), TID Harding Drain (9.5%), TID Westport Drain (7.7%), and Mud Slough (6.9%) were the greatest contributors (Figure 37). Due to their smaller flows, TID Harding Drain, TID Westport Drain, and Mud Slough were the best targets for total nitrogen reduction in the SJR during the irrigation season (Figure 38).

Based on the surface load mass balance, a small portion of the total nitrogen load at Vernalis (35.5 thousand kg; 1.1%) is estimated to originate from groundwater flows annually. Given that groundwater accounted for a total inflow of 184.8 billion liters (Table 4), the estimated concentration of total nitrogen in groundwater was 0.19 mg/L. This is consistent with finding from Zamora et al. (2013), which found that groundwater accounted for only 9% of dissolved inorganic nitrogen loads from surface water (it is assumed that all nitrogen loads from groundwater are of the inorganic form).

Inorganic Nitrogen

Nitrate accounted for 77.8% of the total nitrogen at Vernalis. Surface water loads accounted for 103.0% of the nitrate load measured at Vernalis (Table 14). Merced River (28.3%), Tuolumne River (15.1%), TID Harding Drain (11.4%), Mud Slough (9.4%), and TID Westport Drain (9.2%) were the greatest contributors (Figure 39). Like total nitrogen, TID Harding Drain, TID Westport Drain, and TID Lateral 6 & 7 (5.8%) were the best targets for nitrate reduction due to their disproportionately low flows and high loads (Figure 40).

The irrigation season accounted for 43.3% of the annual nitrate load at Vernalis, an additional 16.8% of which was accounted for by surface water loads (Table 14). Merced River (37.7%), Tuolumne River (12.9%), TID Harding Drain (10.0%), TID Westport Drain (7.8%), and Mud Slough (6.8%) were the greatest contributors (Figure 41); the latter three occupied the second quadrant of Figure 42 along with TID Lateral 6 & 7 (4.7%).

Ammonia accounted for only 1.9% of the total nitrogen load at Vernalis and 2.5% of total nitrogen inputs to the SJR, suggesting transformation. Surface water loads accounted for an additional 25.6% than what was measured at Vernalis (Table 15). Salt Slough (18.4%), Stanislaus River (16.0%), Tuolumne River (13.9%), Merced River (11.4%), and Mud Slough (9.0%) were the greatest contributors (Figure 43). Due to their relatively low flows and high impact on the SJR, Del Puerto Creek (8.9%) and TID Harding Drain (6.2%) were the best targets for management actions taken to reduce ammonia (Figure 44).

The irrigation season accounted for 25.8% of the annual ammonia load measured at Vernalis (Table 15). The mass balance on surface water loads accounted for 206.3% of the ammonia load measured at Vernalis during the irrigation season (Table 15). Salt Slough (20.0%), Stanislaus River (13.6%), Merced River (12.4%), Tuolumne River (11.7%), and TID Harding Drain (9.9%) were the greatest contributors (Figure 45). TID Harding Drain, Del Puerto Creek (7.9%), and Ingram Creek (5.1%) had disproportionately large impacts on ammonia loads in the SJR during the irrigation season, making them ideal targets for regulation (Figure 46).

As described in the previous section, it was estimated that groundwater contributed approximately 35.5 thousand kg of inorganic nitrogen (nitrate + ammonia) to the SJR over 2007. When groundwater and surface water inputs are considered together, an additional 130.6 thousand kg of inorganic nitrogen is put into the SJR compared to the output at Vernalis (Table 16). It is assumed that this excess mass load is used in algal biomass production and estimates based on Redfield Ratio were used to validate this assumption. Given that the tributaries contributed only 11.5 thousand kg of chlorophyll and that 50.0 thousand kg of chlorophyll was observed at the Vernalis station, the increase is likely attributed to algal growth. Using a carbon to chlorophyll mass ratio of 40 (Jassby and Cloern 2000) and a carbon to nitrogen mass ratio of 5.7 (Redfield 1958), it would be expected that 270.3 thousand kg of inorganic nitrogen was converted to organic nitrogen within the SJR, which we believe to be comparable to our original estimate of 130.6 thousand kg, based on our mass balance. Differences in the two estimates could be due to the variable nature of the carbon to chlorophyll mass ratio and the carbon to nitrogen mass ratio in the SJR.

Organic Nitrogen

Organic nitrogen accounted for 20.3% of the total nitrogen measured at Vernalis, 80.7% of which was accounted for by surface water loads (Table 17). Mud Slough (13.9%), Tuolumne River (11.2%), Stanislaus River (10.6%), Salt Slough (10.5%), and Merced River (9.7%) were the greatest contributors (Figure 47). SJR at Lander Ave (4.8%), TID Westport Drain (4.3%), and Los Banos Creek (3.8%) occupied the second quadrant of Figure 48 with TID Harding Drain (3.6%) just below the divide between the second and third quadrants, making them ideal targets for organic nitrogen regulation.

The irrigation season accounted for 52.7% of the annual organic nitrogen load measured at Vernalis, 67.9% of which was accounted for by surface water loads (Table 17). The rivers and sloughs were the greatest contributors of organic nitrogen during the irrigation season (Figure 49). Mud Slough (6.0%), TID Westport Drain (5.9%), TID Harding Drain (4.9%), and SJR at Lander Ave (4.0%) were all good targets for organic nitrogen reduction in the SJR based on their relatively large loads and smaller flows (Figure 50).

Surface water loads do not account for 130.6 thousand kg of organic nitrogen in the SJR annually, compared to measurements at Vernalis. It is likely that the missing load is made up by nitrogen transformation due to algal biomass growth. This is confirmed by the fact that the 130.6 thousand kg of missing organic nitrogen is comparable to the 130.6 thousand kg of excess inorganic nitrogen in the SJR.

Total Phosphorus

A total of 318.4 million kg of total phosphorus was measured at Vernalis over 2007, 74.7% of which was accounted for by surface water inputs (Table 18). TID Harding Drain (21.1%), Salt Slough (12.0%), Stanislaus River (10.6%), Tuolumne River (9.6%), and Mud Slough (6.4%) were the greatest contributors (Figure 51). TID Harding Drain was the best target for total phosphorus regulation due to its high impact on the SJR and smaller flows; by this standard, Los Banos Creek (3.4%) was also a good target (Figure 52).

The irrigation season accounted for 42.7% of the annual total phosphorus measured at Vernalis, 68.3% of which was accounted for by surface water inputs (Table 18). TID Harding Drain (21.3%), Tuolumne River (11.4%), Salt Slough (11.0%), Stanislaus River (9.2%), and Merced River (4.7%) were the greatest contributors (Figure 53). TID Harding Drain was the only good target for total phosphorus regulation during the irrigation season (Figure 54).

Based on the surface load mass balance, 80.6 thousand kg of total phosphorus is estimated to originate from groundwater flows annually. Given that groundwater accounted for a total inflow of 184.8 billion liters (Table 4), the estimated concentration of total phosphorus in groundwater was 0.44 mg/L. In the groundwater study by Zamora et al. (2013) the average phosphate concentration for groundwater inputs was measured to be 0.51 mg/L. Assuming that all phosphorus inputs from groundwater are inorganic, we believe our estimates for total phosphorus concentration in groundwater to be accurate, based on the similarities between our estimates and the estimates from Zamora et al. (2013).

Dissolved Orthophosphate as Phosphorus

Phosphate accounted for 57.6% of the total phosphorus load at Vernalis, 88.6% of which was accounted for by surface water loads (Table 19). TID Harding Drain (34.4%), Stanislaus River (10.9%), Tuolumne River (10.8%), Salt Slough (8.5%), and Mud Slough (5.5%) were the greatest contributors (Figure 55). TID Harding Drain was the only occupant of the second quadrant in Figure 56, illustrating the importance of this source of phosphate to the SJR.

The irrigation season accounted for 43.0% of the annual phosphate load at Vernalis, 88.6% of which was accounted for in the mass balance (Table 19). TID Harding Drain (33.3%), Tuolumne River (15.2%), Stanislaus River (10.9%), Salt Slough (9.8%), and Merced River (4.8%) were the greatest contributors (Figure 57). Due to its smaller flows, TID Harding Drain was the best target for management actions taken to reduce phosphate loads in the SJR (Figure 58).

Based on the mass balance on total phosphors (described above), 80.6 thousand kg of phosphate was estimated to enter the SJR through groundwater flows. When surface and groundwater loads are considered together, an excess of 59.7 thousand kg of phosphate is put into the SJR compared to the outflow at Vernalis. It is likely that this excess phosphate is used in algal biomass production and estimates based on Redfield Ratio were used to validate this assumption. Assuming algal growth of 38.5 thousand kg (Table 12), and using a carbon to chlorophyll mass ratio of 40 (Jassby and Cloern 2000) and a carbon to phosphorus mass ratio of 41 (Redfield 1958), it was estimated that 37.6 thousand kg of phosphate would be used in algal biomass production, which we believe to be comparable to our original estimate of 59.7 thousand kg, based on our mass balance. Differences in the two estimates could be due to the variable nature of the carbon to chlorophyll mass ratio and the carbon to phosphorus mass ratio in the SJR.

Conclusions

Surface water loads accounted for 91.5% over the year and 86.6% during the irrigation season compared to measurements made in the SJR at Vernalis. The remaining volume originated from groundwater which is consistent with previous studies. Two thirds of the TDS was accounted for by surface water loads, with the remaining TDS also originating from groundwater. Data collected from previous studies was used to validate our estimated 1286 mg/L TDS concentration for groundwater.

Surface water loads accounted for 62.2% of the BOD load and 22.9% of the chlorophyll load over the year. The missing BOD and chlorophyll load was due to algal growth in the main stem of the river. This is supported by the fact that the irrigation season, a time of accelerated algal growth, accounts for 97.7% of the annual BOD and 88.8% of the annual chlorophyll loads from non-surface water inputs.

Surface water loads accounted for 98.9% of the total nitrogen measured at Vernalis, suggesting that little nitrogen enters the SJR through groundwater. Mass balance results for inorganic and organic nitrogen suggested that inorganic nitrogen was transformed to organic nitrogen within the mainstem of the SJR. The nitrogen transformation was likely due to phytoplankton growth and was supported by inorganic nitrogen consumption estimations based on Redfield's ratio. The hypothesis was further supported by the fact that excess inorganic nitrogen in the SJR was nearly equal to the organic nitrogen deficit between surface water inputs and measurements made at the Vernalis monitoring station. Furthermore, ammonia is transformed at a much greater rate than nitrate, suggesting a preference for ammonia consumption by algae.

Surface water loads accounted for 74.7% of the total phosphorus load at Vernalis, with the remaining load originating from groundwater. Surface water and groundwater loads accounted for an excess of 32.6% of phosphate in the SJR compared to measurements at Vernalis, likely a result of phosphate uptake by algal biomass growth occurring within the main stem of the river. Phosphate uptake quantification was supported by estimations based on Redfield's Ratio.

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Table 1. Site list with location, situation, and predominant flow source.

Site Number	Site Name	Latitude	Longitude	Relation to SJR	Predominant Flow Source
5	SJR at Vernalis	37.679	-121.265	Mainstem	
6	SJR at Maze Road	37.640	-121.230	Mainstem	
7	SJR at Patterson	37.494	-121.081	Mainstem	
8	SJR at Crows Landing	37.432	-121.012	Mainstem	
10	SJR at Lander Avenue	37.295	-120.851	Mainstem	Agricultural and Sierra drainage
12	Stanislaus River	37.702	-121.177	Tributary	Sierra drainage
14	Tuolumne River	37.603	-121.131	Tributary	Sierra drainage
16	Merced River	37.350	-120.962	Tributary	Sierra drainage
18	Mud Slough	37.263	-120.906	Tributary	Agricultural and wetland drainage
19	Salt Slough	37.248	-120.852	Tributary	Agricultural and wetland drainage
20	Los Banos Creek	37.275	-120.955	Tributary	Agricultural and wetland drainage
21	Orestimba Creek	37.414	-121.015	Tributary	Agricultural drainage
22	MID Lateral 4	37.631	-121.159	Eastside Drain	Agricultural drainage
25	MID Miller Lake	37.542	-121.094	Eastside Drain	Agricultural and wetland drainage
27	TID Lateral 2	37.565	-121.138	Eastside Drain	Agricultural drainage
28	TID Westport Drain	37.542	-121.094	Eastside Drain	Agricultural drainage
29	TID Harding Drain	37.464	-121.031	Eastside Drain	Agricultural and urban drainage
30	TID Lateral 6 & 7	37.398	-120.960	Eastside Drain	Agricultural drainage
33	Hospital Creek	37.600	-121.225	Tributary	Agricultural drainage
34	Ingram Creek	37.600	-121.225	Tributary	Agricultural drainage
35	Westley Wasteway	37.558	-121.164	Westside Drain	Agricultural drainage
36	Del Puerto Creek	37.539	-121.122	Tributary	Agricultural drainage
38	Marshall Road Drain	37.436	-121.036	Westside Drain	Agricultural drainage
40	Patterson Irrigation District Diversion	37.497	-121.083	Diversion	San Joaquin River
41	West Stanislaus Irrigation District Diversion	37.584	-121.201	Diversion	San Joaquin River
43	El Solyo Pumping Station	37.640	-121.230	Diversion	San Joaquin River
57	Ramona Lake Drain	37.479	-121.069	Westside Drain	Agricultural drainage
64	Moran Drain	37.435	-121.036	Westside Drain	Agricultural drainage
65	Spanish Grant Drain	37.436	-121.036	Westside Drain	Agricultural drainage

Table 2. Continuous monitoring data source information, availability, and measurement characteristics for each site in mass balance analysis

Sampling Site	Continuous Data Source	Flow Structure	Flow Data Availability for 2007	Estimated Flow Data Quality[1]	Flow Measurement Frequency	Flow Data Completeness (%)	Specific Conductivity Measurement Frequency
SJR at Vernalis	CDEC	Open channel	01/01 - 12/31	Good	15 minute	98.50	15 minute
SJR at Maze Road	CDEC	Open channel	01/01 - 12/31	Good	15 minute	71.50	15 minute
SJR at Patterson	CDEC	Open channel	01/01 - 12/31	Good	15 minute	98.40	hourly
SJR at Crows Landing	CDEC	Open channel	01/01 - 12/31	Good	15 minute	97.30	15 minute
SJR at Lander Avenue	CDEC	Open channel	01/01 - 12/31	Good	15 minute	97.90	hourly
Stanislaus River	CDEC	Open channel	01/01 - 12/31	Good	15 minute	98.60	N/A
Tuolumne River	CDEC	Open channel	01/01 - 12/31	Good	15 minute	96.70	15 minute
Merced River	CDEC	Open channel	02/09 - 12/31	Good	15 minute	94.90	hourly
Mud Slough	CDEC	Open channel	01/01 - 12/31	Good	15 minute	98.40	15 minute
Salt Slough	CDEC	Open channel	01/01 - 12/31	Good	15 minute	98.40	15 minute
Los Banos Creek	EERP	Open channel	01/01 - 09/10	Good	15 minute	100.00	15 minute
Orestimba Creek	CDEC	Open channel	01/01 - 09/12; 11/01 - 12/31	Good	15 minute	94.30	15 minute
MID Lateral 4	MID	Weir	03/15 - 10/17	Unknown	hourly	100.00	hourly
MID Miller Lake	MID	Weir	03/24 - 11/07	Unknown	hourly	97.00	hourly
TID Lateral 2	TID	Weir	01/01 - 12/31	Unknown	daily	100.00	N/A
TID Westport Drain	TID	Flume	02/08 - 12/28	Poor	daily	89.60	N/A
TID Harding Drain	TID	Weir	01/01 - 12/31	Unknown	daily	99.50	N/A
TID Lateral & 7	TID	Weir	01/01 - 12/31	Unknown	daily	100.00	15 minute
Hospital Creek	EERP	Weir	01/01 - 10/08	Good	15 minute	100.00	15 minute
Ingram Creek	EERP	Weir	01/01 - 12/31	Good	15 minute	100.00	15 minute
Westley Wasteway	EERP	Weir	01/20 - 12/31	Good	15 minute	100.00	15 minute
Del Puerto Creek	EERP	Open channel	01/17 - 12/31	Fair	15 minute	100.00	15 minute
Marshall Road Drain	EERP	Weir	01/04 - 12/28	Good	15 minute	99.90	15 minute
Patterson Irrigation District Diversion	PID	Pump	03/01 - 12/31	Unknown	monthly	100.00	N/A
West Stanislaus Irrigation District Diversion	WSID	Pump	01/01 – 12/31	Unknown	monthly	100.00	N/A
El Solyo Pumping Station	ESWD	Pump	01/01 – 12/31	Unknown	monthly	100.00	N/A
Ramona Lake Drain	EERP	Weir	04/14 - 12/31	Good	15 minute	100.00	15 minute
Moran Drain	EERP	Weir	01/04 - 12/28	Poor	15 minute	98.50	15 minute
Spanish Grant Drain	EERP	Weir	01/04 - 12/28	Fair	15 minute	90.00	15 minute

[1]Estimated flow data quality refers to the trueness of the data and is based on occurrences of phenomena which would cause inaccurate flow measurements such as stream blockages, equipment tampering or malfunction, measuring structure quality, and inconsistency of stage to flow relationships.

Table 3. Number of water quality grab samples by time of year for each sample site.

	Number of Grab Samples 1/1/07 – 12/31/07	Number of Grab Samples 4/1/07 – 9/30/07
SJR at Vernalis	33	25
SJR at Maze Road	32	24
SJR at Patterson	34	26
SJR at Crows Landing	40	28
SJR at Lander Avenue	40	28
Stanislaus River	27	20
Tuolumne River	27	20
Merced River	27	20
Mud Slough	38	26
Salt Slough	43	30
Los Banos Creek	25	14
Orestimba Creek	23	18
MID Lateral 4	1	1
MID Miller Lake	19	15
TID Lateral	3	3
TID Westport Drain	23	20
TID Harding Drain	27	20
TID Lateral 6 & 7	22	19
Hospital Creek	2	2
Ingram Creek	24	20
Westley Wasteway	2	2
Del Puerto Creek	25	20
Marshall Road Drain	3	3
Patterson Irrigation District Diversion	0	0
West Stanislaus Irrigation District Diversion	0	0
El Solyo Pumping Station	0	0
Ramona Lake Drain	18	16
Moran Drain	3	3
Spanish Grant Drain	3	3

Table 4. Total volume by sample site for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The Volume Summary represents sum of all surface water inputs to the SJR upstream of Vernalis.

	Annual Volume		Irrigation Season Total Phosphorus Load		
Site Name	Total (10^6 L)	Proportion of Vernalis (%)	Total (10^6 L)	Proportion of Vernalis (%)	Proportion of Annual (%)
SJR at Vernalis	1,686,456		797,639		47.3
SJR at Maze Road	1,054,788		415,440		39.4
SJR at Patterson	584,399		248,483		42.5
SJR at Crows Landing	622,860		277,205		44.5
SJR at Lander Avenue	32,240	1.9	11,281	1.4	35.0
Stanislaus River	604,746	35.9	308,638	38.7	51.0
Tuolumne River	329,474	19.5	162,752	20.4	49.4
Merced River	328,566	19.5	158,183	19.8	48.1
Mud Slough	86,131	5.1	17,331	2.2	20.1
Salt Slough	138,794	8.2	56,222	7.0	40.5
Los Banos Creek	20,633	1.2	5,733	0.7	27.8
Orestimba Creek	7,412	0.4	2,188	0.3	29.5
MID Lateral 4	7,381	0.4	3,534	0.4	47.9
MID Miller Lake	10,363	0.6	5,109	0.6	49.3
TID Lateral	4,192	0.2	3,550	0.4	84.7
TID Westport Drain	25,383	1.5	14,213	1.8	56.0
TID Harding Drain	32,525	1.9	20,005	2.5	61.5
TID Lateral 6 & 7	10,203	0.6	5,873	0.7	57.6
Hospital Creek	2,949	0.2	2,049	0.3	69.5
Ingram Creek	5,103	0.3	4,425	0.6	86.7
Westley Wasteway	1,706	0.1	1,108	0.1	64.9
Del Puerto Creek	15,549	0.9	10,462	1.3	67.3
Marshall Road Drain	2,508	0.1	1,664	0.2	66.3
Patterson Irrigation District Diversion	-56,215	-3.3	-46,797	-5.9	83.2
West Stanislaus Irrigation District Diversion	-60,117	-3.6	-49,977	-6.3	83.1
El Solyo Pumping Station	-19,745	-1.2	-17,834	-2.2	90.3
Ramona Lake Drain	5,225	0.3	3,577	0.4	68.5
Moran Drain	2,330	0.1	2,151	0.3	92.3
Spanish Grant Drain	6,387	0.4	5,491	0.7	86.0

Load Summary	Total (10^6 L)	Proportion of Vernalis (%)	Total (10^6 L)	Proportion of Vernalis (%)	Proportion of Annual (%)
Surface Water	1,543,723	91.5	690,931	86.6	44.8
Groundwater	184,762	11.0	139,942	17.5	75.7
Evaportranspiration/Precipitation	-42,029	-2.5	-33,234	-4.2	79.1

Table 5. Load estimate comparisons for total dissolved solids (TDS).

Site Name	Mean-Load Method	True-Load Method		Beale Ratio Load Method		
	TDS Load (kg)	TDS Load (kg)	Difference (%)[2]	TDS Load (kg)	Difference (%)[2]	Achieved Error Rate[1] (%)
SJR at Vernalis	641,841,254	604,303,582	-6	634,865,321	-1.1	8.7
SJR at Maze Road	592,605,804	588,848,000	-0.6	554,537,725	-6.6	7.3
SJR at Crows Landing	445,387,799	440,463,379	-1.1	452,880,301	1.7	6.2
Tuolumne River	38,858,040	28,032,837	-32.4	40,829,268	4.9	10.2
Merced River	29,129,937	21,123,802	-31.9	33,161,512	12.9	15.1
Mud Slough	134,348,857	125,492,748	-6.8	139,013,936	3.4	12.7
Salt Slough	130,312,243	106,161,699	-20.4	119,128,798	-9	6.3
Los Banos Creek	22,035,746	20,428,643	-7.6	21,097,148	-4.4	15.2
Orestimba Creek	3,747,134	3,515,718	-6.4	3,907,569	4.2	14.3
Ingram Creek	3,639,298	3,577,689	-1.7	3,630,195	-0.3	11.4
Westley Wasteway	685,667	898,594	26.9	663,685	-3.3	30.3
Del Puerto Creek	12,000,558	10,919,747	-9.4	11,660,095	-2.9	10.4
Marshall Road Drain	1,763,166	1,587,089	-10.5	1,533,223	-14	66.9

[1]Achieved error rate is calculated by dividing the root mean square error by the annual load and multiplying by 100 (Baun 1982).

[2] Difference (%) $=100 * \frac{\text{QA-load} - \text{mean-load}}{0.5*(\text{QA-load} + \text{mean-load})}$ where QA-load is either the True-Load or the Beale Ratio Load.

Table 6. Load summary by sample site for total dissolved solids (TDS) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual TDS Load		Irrigation Season TDS Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	641,841,254		275,802,031		43.0
SJR at Maze Road	592,605,804		223,975,558		37.8
SJR at Patterson	422,401,055		174,994,873		41.4
SJR at Crows Landing	445,387,799		193,681,216		43.5
SJR at Lander Avenue	20,662,655	3.2	9,725,563	3.5	47.1
Stanislaus River	32,473,162	5.1	15,616,905	5.7	48.1
Tuolumne River	38,858,040	6.1	19,528,323	7.1	50.3
Merced River	29,129,937	4.5	18,677,043	6.8	64.1
Mud Slough	134,348,857	20.9	37,878,316	13.7	28.2
Salt Slough	130,312,243	20.3	45,498,720	16.5	34.9
Los Banos Creek	22,035,746	3.4	6,390,248	2.3	29.0
Orestimba Creek	3,747,134	0.6	1,532,110	0.6	40.9
MID Lateral 4	376,424	0.1	180,228	0.1	47.9
MID Miller Lake	2,027,955	0.3	992,468	0.4	48.9
TID Lateral	478,154	0.1	407,467	0.1	85.2
TID Westport Drain	10,475,708	1.6	5,541,164	2.0	52.9
TID Harding Drain	16,125,608	2.5	8,692,337	3.2	53.9
TID Lateral 6 & 7	4,361,987	0.7	2,233,932	0.8	51.2
Hospital Creek	1,565,152	0.2	1,102,898	0.4	70.5
Ingram Creek	3,639,298	0.6	3,131,478	1.1	86.0
Westley Wasteway	685,667	0.1	444,712	0.2	64.9
Del Puerto Creek	12,000,558	1.9	7,989,278	2.9	66.6
Marshall Road Drain	1,763,166	0.3	1,227,881	0.4	69.6
Patterson Irrigation District Diversion	-31,232,148	-4.9	-22,734,982	-8.2	72.8
West Stanislaus Irrigation District Diversion	-33,184,606	-5.2	-24,304,131	-8.8	73.2
El Solyo Pumping Station	-7,860,545	-1.2	-5,960,727	-2.2	75.8
Ramona Lake Drain	5,215,756	0.8	3,545,938	1.3	68.0
Moran Drain	1,374,702	0.2	1,265,966	0.5	92.1
Spanish Grant Drain	4,804,601	0.7	4,073,910	1.5	84.8
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	404,185,211	63.0	142,677,044	51.7	35.3
Groundwater	237,656,043	37.0	133,124,987	48.3	56.0

Table 7. Load summary by sample site for total suspended solids (TSS) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The term "in-stream processes" is used to describe TSS load that originates from in-stream bank erosion, sediment resuspension, and algal biomass growth.

	Annual TSS Load		Irrigation Season TSS Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	70,538,122		37,419,181		53.0
SJR at Maze Road	45,972,888		22,967,878		50.0
SJR at Patterson	35,031,172		17,305,916		49.4
SJR at Crows Landing	32,079,712		15,474,594		48.2
SJR at Lander Avenue	1,401,213	2.0	471,027	1.3	33.6
Stanislaus River	7,332,963	10.4	4,072,529	10.9	55.5
Tuolumne River	4,326,670	6.1	1,818,915	4.9	42.0
Merced River	5,627,728	8.0	1,896,739	5.1	33.7
Mud Slough	3,834,899	5.4	1,016,185	2.7	26.5
Salt Slough	13,335,903	18.9	7,197,343	19.2	54.0
Los Banos Creek	1,199,714	1.7	361,194	1.0	30.1
Orestimba Creek	640,746	0.9	408,053	1.1	63.7
MID Lateral 4	62,710	0.1	30,025	0.1	47.9
MID Miller Lake	378,018	0.5	199,771	0.5	52.8
TID Lateral	235,893	0.3	193,618	0.5	82.1
TID Westport Drain	421,165	0.6	232,300	0.6	55.2
TID Harding Drain	927,167	1.3	658,173	1.8	71.0
TID Lateral 6 & 7	117,495	0.2	90,944	0.2	77.4
Hospital Creek	2,725,644	3.9	2,034,707	5.4	74.7
Ingram Creek	3,075,062	4.4	2,960,715	7.9	96.3
Westley Wasteway	976,592	1.4	637,101	1.7	65.2
Del Puerto Creek	1,319,478	1.9	1,159,752	3.1	87.9
Marshall Road Drain	1,263,702	1.8	1,052,575	2.8	83.3
Patterson Irrigation District Diversion	-2,603,694	-3.7	-2,529,244	-6.8	97.1
West Stanislaus Irrigation District Diversion	-2,855,460	-4.0	-2,818,129	-7.5	98.7
El Solyo Pumping Station	-808,928	-1.1	-874,827	-2.3	108.1
Ramona Lake Drain	440,726	0.6	316,305	0.8	71.8
Moran Drain	158,293	0.2	148,791	0.4	94.0
Spanish Grant Drain	2,221,435	3.1	2,040,073	5.5	91.8
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	45,755,133	64.9	22,774,635	60.9	49.8
Groundwater	24,782,989	35.1	14,644,546	39.1	59.1

Table 8. Load summary by sample site for volatile suspended solids (VSS) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The term "in-stream processes" is used to describe VSS load that originates from in-stream algal biomass growth, bank erosion, and other processes.

	Annual VSS Load		Irrigation Season VSS Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	12,402,757		6,036,010		48.7
SJR at Maze Road	7,581,533		4,256,177		56.1
SJR at Patterson	5,296,283		3,203,547		60.5
SJR at Crows Landing	4,817,255		2,561,455		53.2
SJR at Lander Avenue	396,453	3.2	176,839	2.9	44.6
Stanislaus River	1,075,767	8.7	592,683	9.8	55.1
Tuolumne River	831,436	6.7	367,742	6.1	44.2
Merced River	673,983	5.4	322,832	5.3	47.9
Mud Slough	800,293	6.5	266,193	4.4	33.3
Salt Slough	1,532,469	12.4	813,650	13.5	53.1
Los Banos Creek	258,087	2.1	80,441	1.3	31.2
Orestimba Creek	80,383	0.6	38,017	0.6	47.3
MID Lateral 4	11,627	0.1	5,567	0.1	47.9
MID Miller Lake	78,575	0.6	41,159	0.7	52.4
TID Lateral	26,518	0.2	21,870	0.4	82.5
TID Westport Drain	61,679	0.5	32,640	0.5	52.9
TID Harding Drain	134,882	1.1	89,749	1.5	66.5
TID Lateral 6 & 7	17,398	0.1	11,447	0.2	65.8
Hospital Creek	169,863	1.4	125,246	2.1	73.7
Ingram Creek	225,685	1.8	215,207	3.6	95.4
Westley Wasteway	59,985	0.5	39,109	0.6	65.2
Del Puerto Creek	132,665	1.1	111,425	1.8	84.0
Marshall Road Drain	99,451	0.8	81,182	1.3	81.6
Patterson Irrigation District Diversion	-357,257	-2.9	-341,616	-5.7	95.6
West Stanislaus Irrigation District Diversion	-380,536	-3.1	-363,162	-6.0	95.4
El Solyo Pumping Station	-105,317	-0.8	-105,140	-1.7	99.8
Ramona Lake Drain	109,205	0.9	77,337	1.3	70.8
Moran Drain	17,534	0.1	16,863	0.3	96.2
Spanish Grant Drain	156,611	1.3	140,237	2.3	89.5
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	6,107,439	49.2	2,857,518	47.3	46.8
Groundwater	6,295,318	50.8	3,178,492	52.7	50.5

Table 9. Load summary by sample site for biochemical oxygen demand (BOD) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The term "other" is used to describe BOD load that originates from non-point sources and in-stream algal biomass growth.

	Annual BOD Load		Irrigation Season BOD Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	5,489,323		3,638,423		66.3
SJR at Maze Road	4,295,545		2,633,403		61.3
SJR at Patterson	2,961,712		1,978,908		66.8
SJR at Crows Landing	2,656,873		1,647,919		62.0
SJR at Lander Avenue	314,857	5.7	165,417	4.5	52.5
Stanislaus River	618,326	11.3	380,654	10.5	61.6
Tuolumne River	525,694	9.6	251,885	6.9	47.9
Merced River	372,264	6.8	193,048	5.3	51.9
Mud Slough	554,178	10.1	178,253	4.9	32.2
Salt Slough	502,029	9.1	277,042	7.6	55.2
Los Banos Creek	272,427	5.0	129,428	3.6	47.5
Orestimba Creek	31,287	0.6	8,874	0.2	28.4
MID Lateral 4	15,426	0.3	7,386	0.2	47.9
MID Miller Lake	63,781	1.2	32,768	0.9	51.4
TID Lateral	5,696	0.1	4,824	0.1	84.7
TID Westport Drain	63,668	1.2	34,302	0.9	53.9
TID Harding Drain	123,492	2.2	83,141	2.3	67.3
TID Lateral 6 & 7	26,574	0.5	16,232	0.4	61.1
Hospital Creek	39,909	0.7	28,839	0.8	72.3
Ingram Creek	53,061	1.0	48,839	1.3	92.0
Westley Wasteway	11,096	0.2	7,215	0.2	65.0
Del Puerto Creek	88,838	1.6	64,189	1.8	72.3
Marshall Road Drain	37,697	0.7	26,995	0.7	71.6
Patterson Irrigation District Diversion	-200,958	-3.7	-195,811	-5.4	97.4
West Stanislaus Irrigation District Diversion	-215,078	-3.9	-206,876	-5.7	96.2
El Solyo Pumping Station	-58,152	-1.1	-56,749	-1.6	97.6
Ramona Lake Drain	94,733	1.7	66,464	1.8	70.2
Moran Drain	12,891	0.2	12,543	0.3	97.3
Spanish Grant Drain	63,259	1.2	54,740	1.5	86.5
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	3,416,995	62.2	1,613,642	44.4	47.2
Groundwater	2,072,328	37.8	2,024,781	55.6	97.7

Table 10. Load summary by sample site for carbonaceous biochemical oxygen demand (CBOD) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The term "other" is used to describe CBOD load that originates from non-point sources and in-stream algal biomass growth.

	Annual CBOD Load		Irrigation Season CBOD Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	3,118,103		2,095,216		67.2
SJR at Maze Road	2,521,686		1,591,591		63.1
SJR at Patterson	1,887,913		1,298,754		68.8
SJR at Crows Landing	1,645,719		1,051,123		63.9
SJR at Lander Avenue	228,659	7.3	125,319	6.0	54.8
Stanislaus River	356,339	11.4	214,261	10.2	60.1
Tuolumne River	304,813	9.8	144,437	6.9	47.4
Merced River	236,716	7.6	127,270	6.1	53.8
Mud Slough	362,605	11.6	124,615	5.9	34.4
Salt Slough	263,790	8.5	149,480	7.1	56.7
Los Banos Creek	186,869	6.0	93,778	4.5	50.2
Orestimba Creek	19,875	0.6	4,868	0.2	24.5
MID Lateral 4	7,455	0.2	3,569	0.2	47.9
MID Miller Lake	34,786	1.1	18,152	0.9	52.2
TID Lateral	4,338	0.1	3,673	0.2	84.7
TID Westport Drain	29,903	1.0	17,393	0.8	58.2
TID Harding Drain	72,070	2.3	48,057	2.3	66.7
TID Lateral 6 & 7	14,627	0.5	9,391	0.4	64.2
Hospital Creek	24,124	0.8	17,430	0.8	72.3
Ingram Creek	25,148	0.8	23,338	1.1	92.8
Westley Wasteway	7,710	0.2	5,017	0.2	65.1
Del Puerto Creek	37,567	1.2	27,066	1.3	72.0
Marshall Road Drain	25,471	0.8	17,595	0.8	69.1
Patterson Irrigation District Diversion	-127,620	-4.1	-127,987	-6.1	100.3
West Stanislaus Irrigation District Diversion	-134,050	-4.3	-131,714	-6.3	98.3
El Solyo Pumping Station	-35,543	-1.1	-34,968	-1.7	98.4
Ramona Lake Drain	66,527	2.1	47,402	2.3	71.3
Moran Drain	10,682	0.3	10,433	0.5	97.7
Spanish Grant Drain	39,853	1.3	34,104	1.6	85.6

Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	2,062,713	66.2	971,977	46.4	47.1
Groundwater	1,055,390	33.8	1,123,239	53.6	106.4

Table 11. Load summary by sample site for nitrogenous biochemical oxygen demand (NBOD) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007). The term “other” is used to describe NBOD load that originates from non-point sources and in-stream algal biomass growth.

	Annual NBOD Load		Irrigation Season NBOD Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	2,371,220		1,543,206		65.1
SJR at Maze Road	1,773,859		1,041,812		58.7
SJR at Patterson	1,073,799		680,153		63.3
SJR at Crows Landing	1,011,154		596,796		59.0
SJR at Lander Avenue	86,197	3.6	40,098	2.6	46.5
Stanislaus River	261,987	11.0	166,393	10.8	63.5
Tuolumne River	220,882	9.3	107,449	7.0	48.6
Merced River	135,548	5.7	65,778	4.3	48.5
Mud Slough	191,573	8.1	53,638	3.5	28.0
Salt Slough	238,239	10.0	127,562	8.3	53.5
Los Banos Creek	85,558	3.6	35,651	2.3	41.7
Orestimba Creek	11,412	0.5	4,006	0.3	35.1
MID Lateral 4	7,971	0.3	3,817	0.2	47.9
MID Miller Lake	28,996	1.2	14,617	0.9	50.4
TID Lateral	1,359	0.1	1,151	0.1	84.7
TID Westport Drain	33,765	1.4	16,909	1.1	50.1
TID Harding Drain	51,423	2.2	35,085	2.3	68.2
TID Lateral 6 & 7	11,947	0.5	6,841	0.4	57.3
Hospital Creek	15,785	0.7	11,409	0.7	72.3
Ingram Creek	27,913	1.2	25,501	1.7	91.4
Westley Wasteway	3,386	0.1	2,198	0.1	64.9
Del Puerto Creek	51,271	2.2	37,124	2.4	72.4
Marshall Road Drain	12,226	0.5	9,400	0.6	76.9
Patterson Irrigation District Diversion	-73,339	-3.1	-67,824	-4.4	92.5
West Stanislaus Irrigation District Diversion	-81,028	-3.4	-75,162	-4.9	92.8
El Solyo Pumping Station	-22,609	-1.0	-21,781	-1.4	96.3
Ramona Lake Drain	28,206	1.2	19,062	1.2	67.6
Moran Drain	2,209	0.1	2,110	0.1	95.5
Spanish Grant Drain	23,406	1.0	20,637	1.3	88.2
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	1,354,283	57.1	641,666	41.6	47.4
Groundwater	1,016,937	42.9	901,540	58.4	88.7

Table 12. Load summary by sample site for chlorophyll-a for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Chlorophyll-a Load		Irrigation Season Chlorophyll-a Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	49,976		38,448		76.9
SJR at Maze Road	36,117		25,728		71.2
SJR at Patterson	25,266		18,258		72.3
SJR at Crows Landing	22,571		14,934		66.2
SJR at Lander Avenue	2,097	4.2	710	1.8	33.9
Stanislaus River	704	1.4	32	0.1	4.5
Tuolumne River	719	1.4	132	0.3	18.4
Merced River	745	1.5	614	1.6	82.4
Mud Slough	3,476	7.0	1,492	3.9	42.9
Salt Slough	2,381	4.8	1,316	3.4	55.3
Los Banos Creek	1,076	2.2	296	0.8	27.5
Orestimba Creek	333	0.7	26	0.1	7.8
MID Lateral 4	0	0.0	0	0.0	0.0
MID Miller Lake	267	0.5	132	0.3	49.4
TID Lateral	0	0.0	0	0.0	0.0
TID Westport Drain	22	0.0	9	0.0	40.9
TID Harding Drain	110	0.2	76	0.2	69.1
TID Lateral 6 & 7	61	0.1	25	0.1	41.0
Hospital Creek	182	0.4	131	0.3	72.0
Ingram Creek	309	0.6	294	0.8	95.1
Westley Wasteway	40	0.1	26	0.1	65.0
Del Puerto Creek	224	0.4	173	0.4	77.2
Marshall Road Drain	146	0.3	108	0.3	74.0
Patterson Irrigation District Diversion	-927	-1.9	-835	-2.2	90.1
West Stanislaus Irrigation District Diversion	-947	-1.9	-834	-2.2	88.1
El Solyo Pumping Station	-223	-0.4	-193	-0.5	86.3
Ramona Lake Drain	465	0.9	329	0.9	70.8
Moran Drain	29	0.1	28	0.1	96.6
Spanish Grant Drain	174	0.3	151	0.4	86.8
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	11,463	22.9	4,238	11.0	37.0
Groundwater	38,513	77.1	34,210	89.0	88.8

Table 13. Load summary by sample site for total nitrogen for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Total Nitrogen Load		Irrigation Season Total Nitrogen Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	3,340,064		1,498,044		44.9
SJR at Maze Road	3,100,094		1,264,569		40.8
SJR at Patterson	2,044,720		1,038,419		50.8
SJR at Crows Landing	1,812,623		980,453		54.1
SJR at Lander Avenue	94,035	2.8	40,325	2.7	42.9
Stanislaus River	225,508	6.8	100,893	6.7	44.7
Tuolumne River	566,632	17.0	270,836	18.1	47.8
Merced River	963,309	28.8	741,761	49.5	77.0
Mud Slough	406,114	12.2	150,528	10.0	37.1
Salt Slough	282,934	8.5	146,221	9.8	51.7
Los Banos Creek	42,798	1.3	16,475	1.1	38.5
Orestimba Creek	28,726	0.9	18,618	1.2	64.8
MID Lateral 4	5,176	0.2	2,478	0.2	47.9
MID Miller Lake	37,443	1.1	17,160	1.1	45.8
TID Lateral	10,062	0.3	8,647	0.6	85.9
TID Westport Drain	319,611	9.6	167,307	11.2	52.3
TID Harding Drain	385,641	11.5	207,109	13.8	53.7
TID Lateral 6 & 7	194,311	5.8	93,968	6.3	48.4
Hospital Creek	13,907	0.4	10,059	0.7	72.3
Ingram Creek	36,208	1.1	32,667	2.2	90.2
Westley Wasteway	3,075	0.1	1,995	0.1	64.9
Del Puerto Creek	95,654	2.9	61,591	4.1	64.4
Marshall Road Drain	19,552	0.6	12,168	0.8	62.2
Patterson Irrigation District Diversion	-209,956	-6.3	-243,218	-16.2	115.8
West Stanislaus Irrigation District Diversion	-247,496	-7.4	-275,733	-18.4	111.4
El Solyo Pumping Station	-64,673	-1.9	-69,630	-4.6	107.7
Ramona Lake Drain	21,441	0.6	14,556	1.0	67.9
Moran Drain	14,132	0.4	12,996	0.9	92.0
Spanish Grant Drain	60,410	1.8	50,929	3.4	84.3
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	3,304,554	98.9	1,590,706	106.2	48.1
Groundwater	35,510	1.1	0	0.0	N/A

Table 14. Load summary by sample site for nitrate-nitrite-nitrogen (nitrate; nitrite-nitrogen is only present in appreciably small amounts in reduced environments and is assumed to be zero) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Nitrate Load		Irrigation Season Total Nitrate Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	2,598,139		1,124,729		43.3
SJR at Maze Road	2,520,002		1,023,355		40.6
SJR at Patterson	1,681,611		846,688		50.3
SJR at Crows Landing	1,426,846		810,132		56.8
SJR at Lander Avenue	56,254	2.2	22,321	2.0	39.7
Stanislaus River	130,510	5.0	53,597	4.8	41.1
Tuolumne River	468,935	18.0	233,141	20.7	49.7
Merced River	879,581	33.9	683,772	60.8	77.7
Mud Slough	292,811	11.3	123,047	10.9	42.0
Salt Slough	186,828	7.2	96,303	8.6	51.5
Los Banos Creek	11,014	0.4	5,577	0.5	50.6
Orestimba Creek	22,345	0.9	15,718	1.4	70.3
MID Lateral 4	3,965	0.2	1,899	0.2	47.9
MID Miller Lake	29,428	1.1	13,089	1.2	44.5
TID Lateral	8,863	0.3	7,620	0.7	86.0
TID Westport Drain	286,218	11.0	140,674	12.5	49.1
TID Harding Drain	352,955	13.6	181,140	16.1	51.3
TID Lateral 6 & 7	178,911	6.9	84,719	7.5	47.4
Hospital Creek	9,333	0.4	6,723	0.6	72.0
Ingram Creek	27,407	1.1	24,255	2.2	88.5
Westley Wasteway	1,951	0.1	1,265	0.1	64.8
Del Puerto Creek	74,128	2.9	51,332	4.6	69.2
Marshall Road Drain	15,007	0.6	8,631	0.8	57.5
Patterson Irrigation District Diversion	-172,696	-6.6	-206,772	-18.4	119.7
West Stanislaus Irrigation District Diversion	-205,275	-7.9	-233,909	-20.8	113.9
El Solyo Pumping Station	-53,512	-2.1	-58,974	-5.2	110.2
Ramona Lake Drain	11,553	0.4	7,720	0.7	66.8
Moran Drain	12,634	0.5	11,523	1.0	91.2
Spanish Grant Drain	47,460	1.8	39,559	3.5	83.4

Load Summary[1]	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	2,676,609	103.0	1,313,970	116.8	49.1

[1]The complete load summary for inorganic nitrogen (nitrate + ammonia) is available in Table 16.

Table 15. Load summary by sample site for total ammonia nitrogen including nitrogen derived from ammonium and aqueous ammonia (Ammonia) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Ammonia Load		Irrigation Season Ammonia Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	64,897		16,745		25.8
SJR at Maze Road	64,520		15,595		24.2
SJR at Patterson	22,783		4,444		19.5
SJR at Crows Landing	22,154		5,443		24.6
SJR at Lander Avenue	1,593	2.5	515	3.1	32.3
Stanislaus River	14,811	22.8	6,126	36.6	41.4
Tuolumne River	12,801	19.7	5,260	31.4	41.1
Merced River	10,484	16.2	5,575	33.3	53.2
Mud Slough	8,295	12.8	1,232	7.4	14.9
Salt Slough	16,959	26.1	9,002	53.8	53.1
Los Banos Creek	3,317	5.1	1,669	10.0	50.3
Orestimba Creek	1,794	2.8	1,176	7.0	65.6
MID Lateral 4	221	0.3	106	0.6	48.0
MID Miller Lake	763	1.2	335	2.0	43.9
TID Lateral	71	0.1	59	0.4	83.1
TID Westport Drain	1,175	1.8	793	4.7	67.5
TID Harding Drain	5,693	8.8	4,460	26.6	78.3
TID Lateral 6 & 7	586	0.9	271	1.6	46.2
Hospital Creek	389	0.6	277	1.7	71.2
Ingram Creek	2,366	3.6	2,295	13.7	97.0
Westley Wasteway	112	0.2	73	0.4	65.2
Del Puerto Creek	8,189	12.6	3,559	21.3	43.5
Marshall Road Drain	480	0.7	320	1.9	66.7
Patterson Irrigation District Diversion	-4,298	-6.6	-4,204	-25.1	97.8
West Stanislaus Irrigation District Diversion	-5,137	-7.9	-4,829	-28.8	94.0
El Solyo Pumping Station	-1,402	-2.2	-1,328	-7.9	94.7
Ramona Lake Drain	819	1.3	565	3.4	69.0
Moran Drain	94	0.1	86	0.5	91.5
Spanish Grant Drain	1,343	2.1	1,152	6.9	85.8

Load Summary[1]	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	81,517	125.6	34,546	206.3	42.4

[1]The complete load summary for inorganic nitrogen (nitrate + ammonia) is available in Table 16.

Table 16. Load summary for inorganic nitrogen (nitrate-nitrite-nitrogen and total ammonia nitrogen).

	Annual Inorganic Nitrogen Load		Irrigation Season Inorganic Nitrogen Load		
	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	2,758,126	103.6	1,348,516	118.1	48.9
Groundwater	35,510	1.3	0	0.0	N/A
Transformation	-130,600	-4.9	-207,042	-18.1	158.5

Table 17. Load summary by sample site for organic nitrogen for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Organic Nitrogen Load		Irrigation Season Organic Nitrogen Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	677,029		356,570		52.7
SJR at Maze Road	515,573		225,620		43.8
SJR at Patterson	340,326		187,286		55.0
SJR at Crows Landing	363,623		164,879		45.3
SJR at Lander Avenue	36,188	5.3	17,489	4.9	48.3
Stanislaus River	80,186	11.8	41,171	11.5	51.3
Tuolumne River	84,896	12.5	32,435	9.1	38.2
Merced River	73,244	10.8	52,414	14.7	71.6
Mud Slough	105,008	15.5	26,248	7.4	25.0
Salt Slough	79,148	11.7	40,916	11.5	51.7
Los Banos Creek	28,467	4.2	9,229	2.6	32.4
Orestimba Creek	4,586	0.7	1,724	0.5	37.6
MID Lateral 4	990	0.1	474	0.1	47.9
MID Miller Lake	7,252	1.1	3,736	1.0	51.5
TID Lateral	1,129	0.2	968	0.3	85.7
TID Westport Drain	32,217	4.8	25,840	7.2	80.2
TID Harding Drain	26,993	4.0	21,509	6.0	79.7
TID Lateral 6 & 7	14,815	2.2	8,978	2.5	60.6
Hospital Creek	4,185	0.6	3,059	0.9	73.1
Ingram Creek	6,435	1.0	6,117	1.7	95.1
Westley Wasteway	1,012	0.1	657	0.2	64.9
Del Puerto Creek	13,337	2.0	6,699	1.9	50.2
Marshall Road Drain	4,066	0.6	3,217	0.9	79.1
Patterson Irrigation District Diversion	-32,962	-4.9	-32,243	-9.0	97.8
West Stanislaus Irrigation District Diversion	-37,084	-5.5	-36,995	-10.4	99.8
El Solyo Pumping Station	-9,759	-1.4	-9,328	-2.6	95.6
Ramona Lake Drain	9,069	1.3	6,271	1.8	69.1
Moran Drain	1,404	0.2	1,387	0.4	98.8
Spanish Grant Drain	11,606	1.7	10,218	2.9	88.0

Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	546,428	80.7	242,190	67.9	44.3
Transformation	130,601	19.3	114,380	32.1	87.6

Table 18. Load summary by sample site for total phosphorus for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007)

	Annual Total Phosphorus Load		Irrigation Season Total Phosphorus Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	318,406		136,109		42.7
SJR at Maze Road	272,069		104,585		38.4
SJR at Patterson	208,054		98,182		47.2
SJR at Crows Landing	125,068		56,649		45.3
SJR at Lander Avenue	8,859	2.8	2,701	2.0	30.5
Stanislaus River	37,544	11.8	15,269	11.2	40.7
Tuolumne River	33,871	10.6	18,842	13.8	55.6
Merced River	11,885	3.7	7,744	5.7	65.2
Mud Slough	22,652	7.1	2,154	1.6	9.5
Salt Slough	42,435	13.3	18,207	13.4	42.9
Los Banos Creek	12,124	3.8	3,708	2.7	30.6
Orestimba Creek	1,204	0.4	461	0.3	38.3
MID Lateral 4	292	0.1	140	0.1	47.9
MID Miller Lake	2,857	0.9	1,385	1.0	48.5
TID Lateral	145	0.0	125	0.1	86.2
TID Westport Drain	3,945	1.2	2,112	1.6	53.5
TID Harding Drain	74,835	23.5	35,203	25.9	47.0
TID Lateral 6 & 7	6,168	1.9	3,033	2.2	49.2
Hospital Creek	1,290	0.4	893	0.7	69.2
Ingram Creek	1,747	0.5	1,532	1.1	87.7
Westley Wasteway	468	0.1	304	0.2	65.0
Del Puerto Creek	5,873	1.8	4,043	3.0	68.8
Marshall Road Drain	1,478	0.5	980	0.7	66.3
Patterson Irrigation District Diversion	-15,523	-4.9	-12,544	-9.2	80.8
West Stanislaus Irrigation District Diversion	-16,374	-5.1	-13,162	-9.7	80.4
El Solyo Pumping Station	-4,196	-1.3	-3,609	-2.7	86.0
Ramona Lake Drain	1,551	0.5	1,128	0.8	72.7
Moran Drain	455	0.1	438	0.3	96.3
Spanish Grant Drain	2,176	0.7	1,898	1.4	87.2
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	237,761	74.7	92,985	68.3	39.1
Groundwater	80,645	25.3	43,124	31.7	53.5

Table 19. Load summary by sample site for dissolved orthophosphate as phosphorus (Phosphate) for 2007 (January 1, 2007 to December 31, 2007) and the irrigation season of 2007 (April 1, 2007 to September 30, 2007).

	Annual Total Phosphorus Load		Irrigation Season Total Phosphorus Load		
Site Name	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
SJR at Vernalis	183,324		78,887		43.0
SJR at Maze Road	162,149		58,454		36.0
SJR at Patterson	149,194		72,870		48.8
SJR at Crows Landing	53,888		24,882		46.2
SJR at Lander Avenue	3,153	1.7	754	1.0	23.9
Stanislaus River	22,707	12.4	11,014	14.0	48.5
Tuolumne River	22,585	12.3	15,297	19.4	67.7
Merced River	8,132	4.4	4,883	6.2	60.0
Mud Slough	11,466	6.3	298	0.4	2.6
Salt Slough	17,747	9.7	9,922	12.6	55.9
Los Banos Creek	7,863	4.3	2,671	3.4	34.0
Orestimba Creek	502	0.3	343	0.4	68.3
MID Lateral 4	370	0.2	177	0.2	47.8
MID Miller Lake	2,011	1.1	991	1.3	49.3
TID Lateral	49	0.0	42	0.1	85.7
TID Westport Drain	3,999	2.2	2,012	2.6	50.3
TID Harding Drain	71,729	39.1	33,595	42.6	46.8
TID Lateral 6 & 7	5,618	3.1	2,757	3.5	49.1
Hospital Creek	842	0.5	570	0.7	67.7
Ingram Creek	1,045	0.6	896	1.1	85.7
Westley Wasteway	289	0.2	187	0.2	64.7
Del Puerto Creek	4,432	2.4	3,029	3.8	68.3
Marshall Road Drain	941	0.5	535	0.7	56.9
Patterson Irrigation District Diversion	-10,801	-5.9	-9,301	-11.8	86.1
West Stanislaus Irrigation District Diversion	-11,530	-6.3	-9,830	-12.5	85.3
El Solyo Pumping Station	-2,927	-1.6	-2,739	-3.5	93.6
Ramona Lake Drain	550	0.3	409	0.5	74.4
Moran Drain	294	0.2	280	0.4	95.2
Spanish Grant Drain	1,310	0.7	1,132	1.4	86.4
Load Summary	Total (kg)	Proportion of Vernalis (%)	Total (kg)	Proportion of Vernalis (%)	Relative to Annual
Surface Water	162,375	88.6	69,924	88.6	43.1
Groundwater	80,645	44.0	43,124	54.7	53.5
Transformation	-59,696	-32.6	-34,161	-43.3	57.2

Figure 1. The study area is made up of the San Joaquin River and all primary tributaries and diversions beginning at the Lander Avenue flow station near Stevinson and ending at the Vernalis flow station. Station numbers correspond to Table 1.

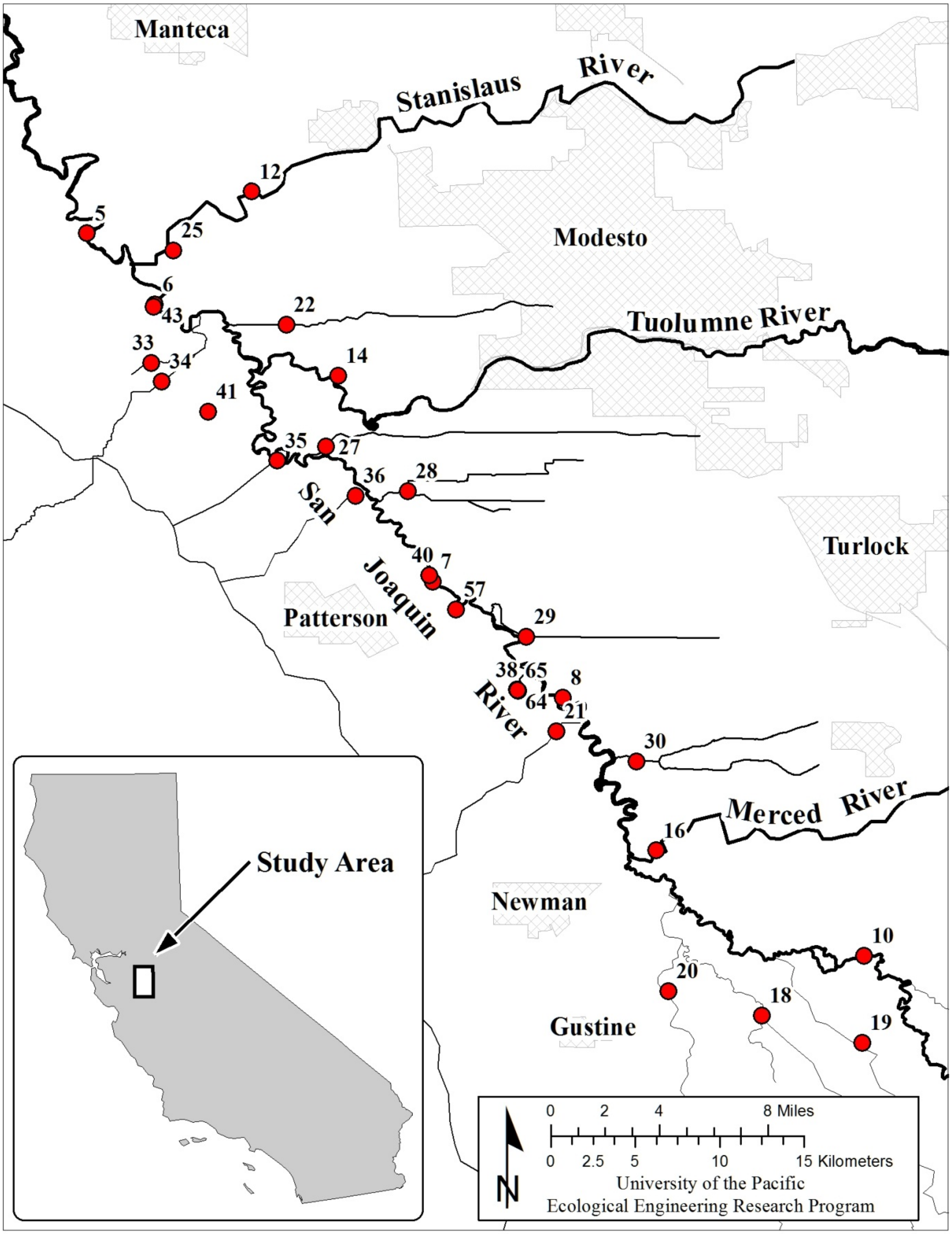

Figure 2. Flow in the San Joaquin River at Maze Road over the year 2007. The flow measurements which were potentially miscalibrated are in red. Applying the rating curve from July 7, 2007 to the questionable flow data produces the modified dataset shown in green.

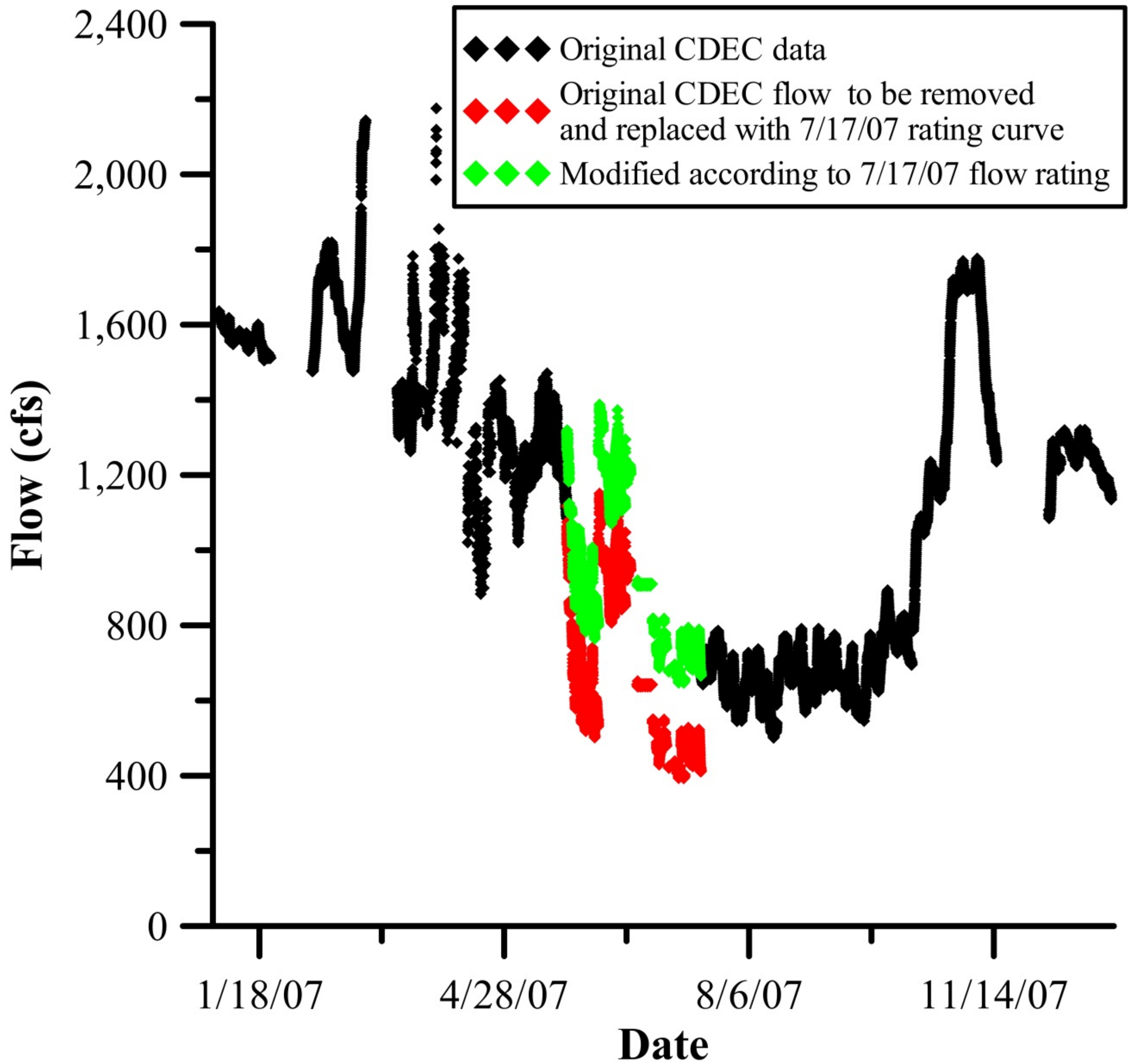

Figure 3. Flow in the San Joaquin River at Patterson over the year 2007. The flow measurements which were possibly miscalibrated are in red. Applying the rating curve from July 7, 2007 to the questionable flow data produces the modified dataset shown in green.

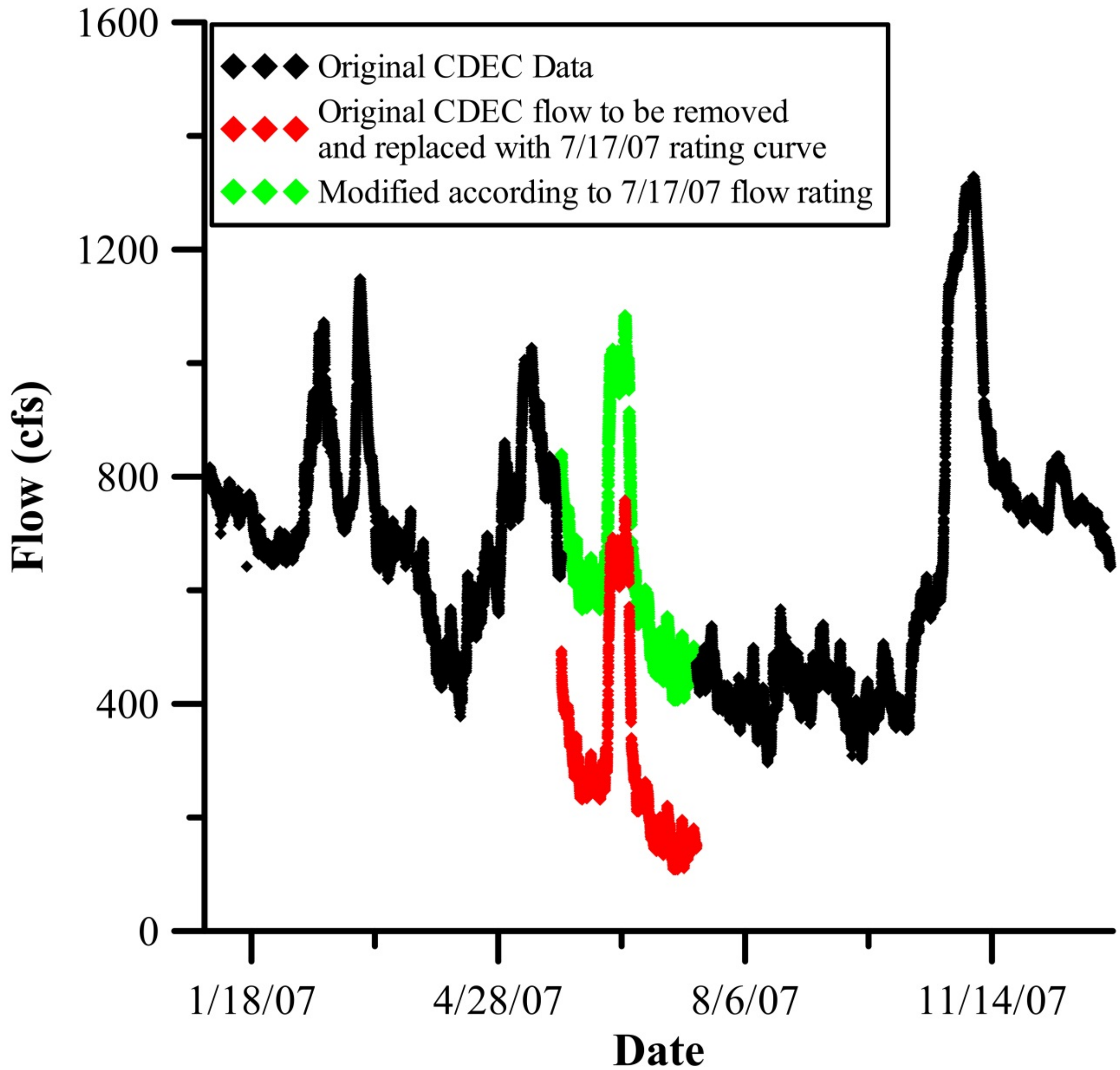

Figure 4. Schematic illustrating the relative location of surface water inputs and diversions which were used in the mass balance. Exact site locations are listed in Table 1.

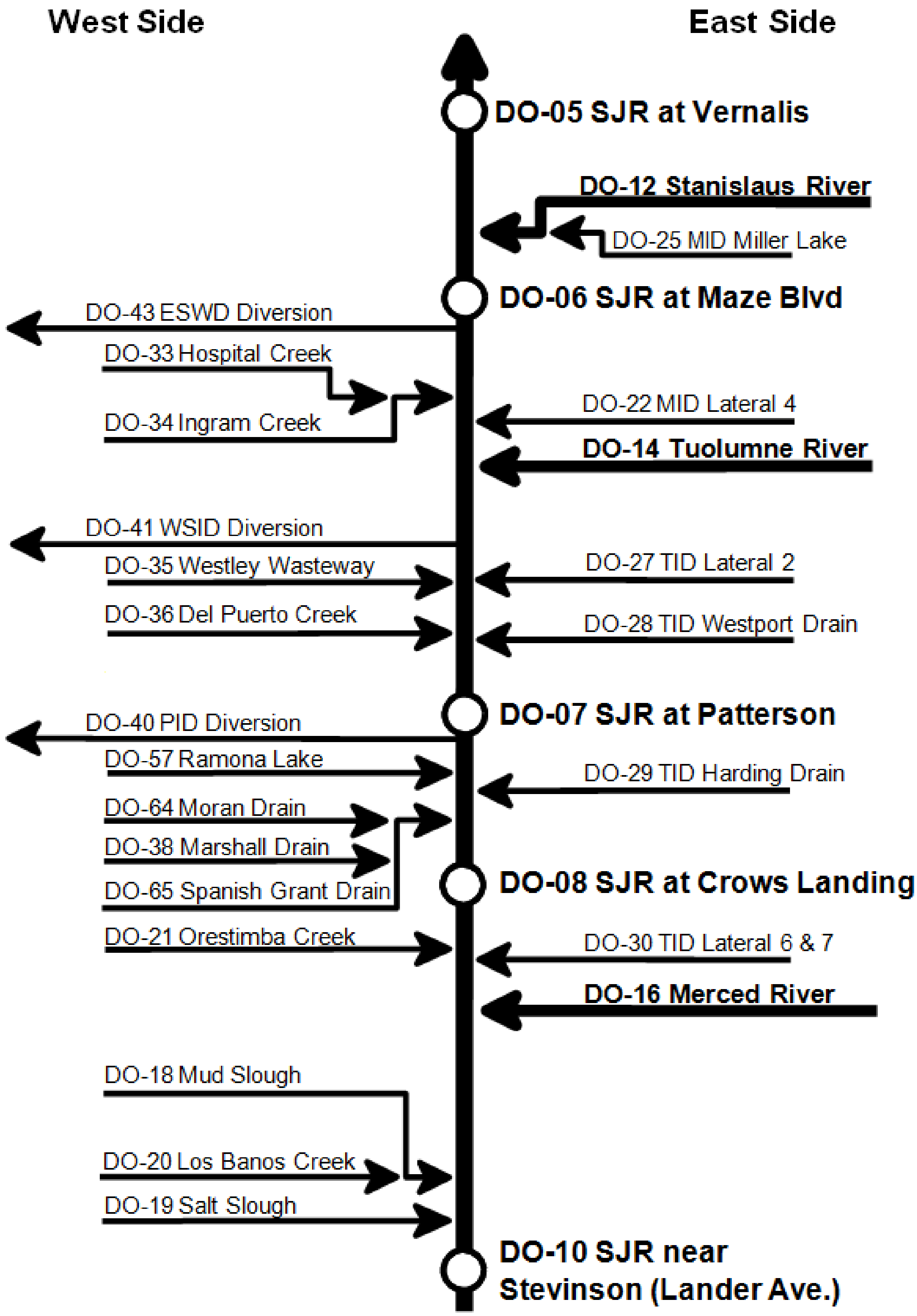

Figure 5. Annual Flow. The following pie chart represents the proportional origins of the total inflow from surface water inputs to the San Joaquin River from January 1, 2007 to December 31, 2007. Flow designated as "other" represents inflow that is not accounted for by surface water inputs.

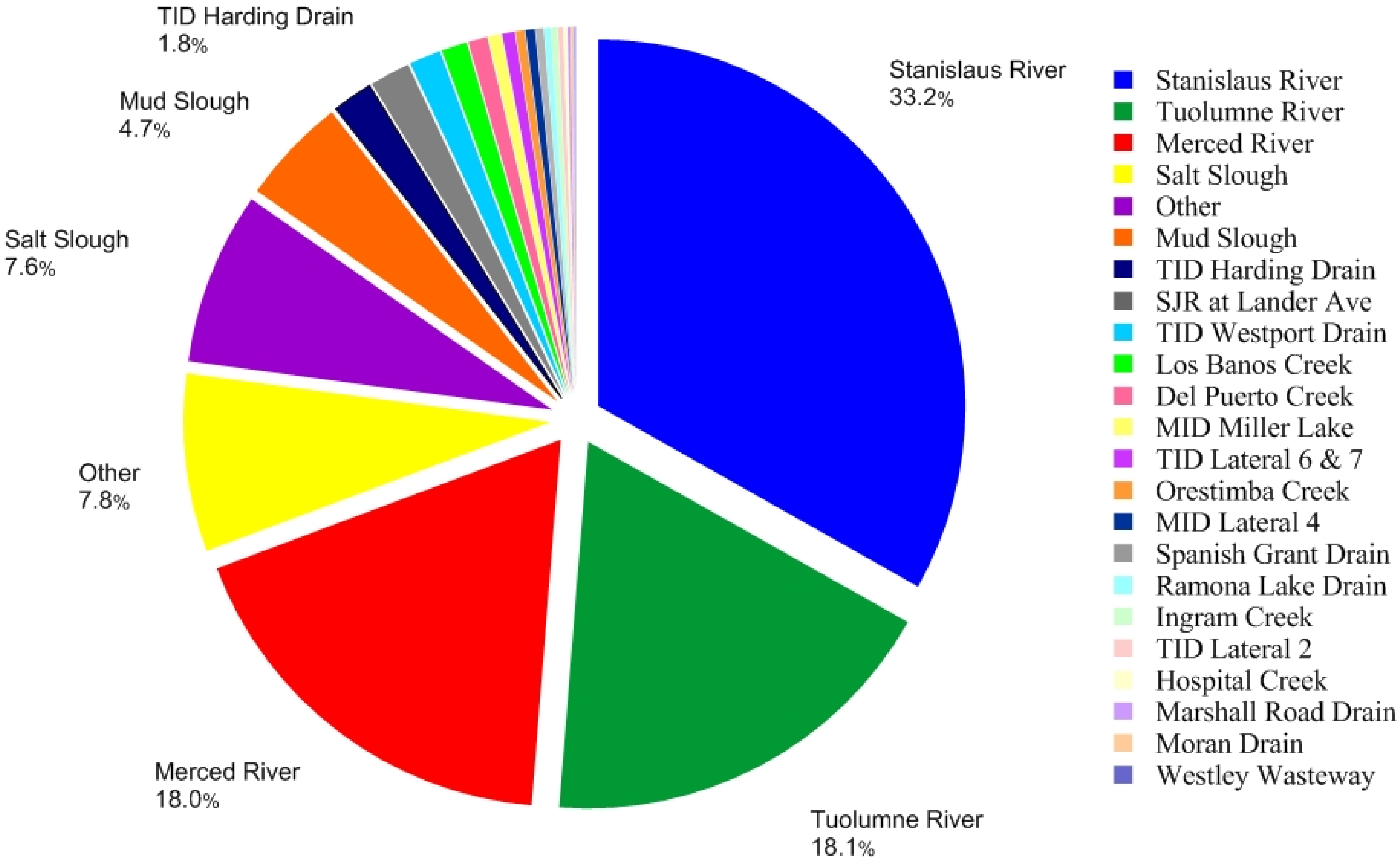

Figure 6. Irrigation Season Flow. The following pie chart represents the proportional origins of the total inflow from surface water inputs to the San Joaquin River from April 1, 2007 to September 30, 2007. Flow designated as "other" represents inflow that was not accounted for by surface water inputs and was likely due to groundwater inputs.

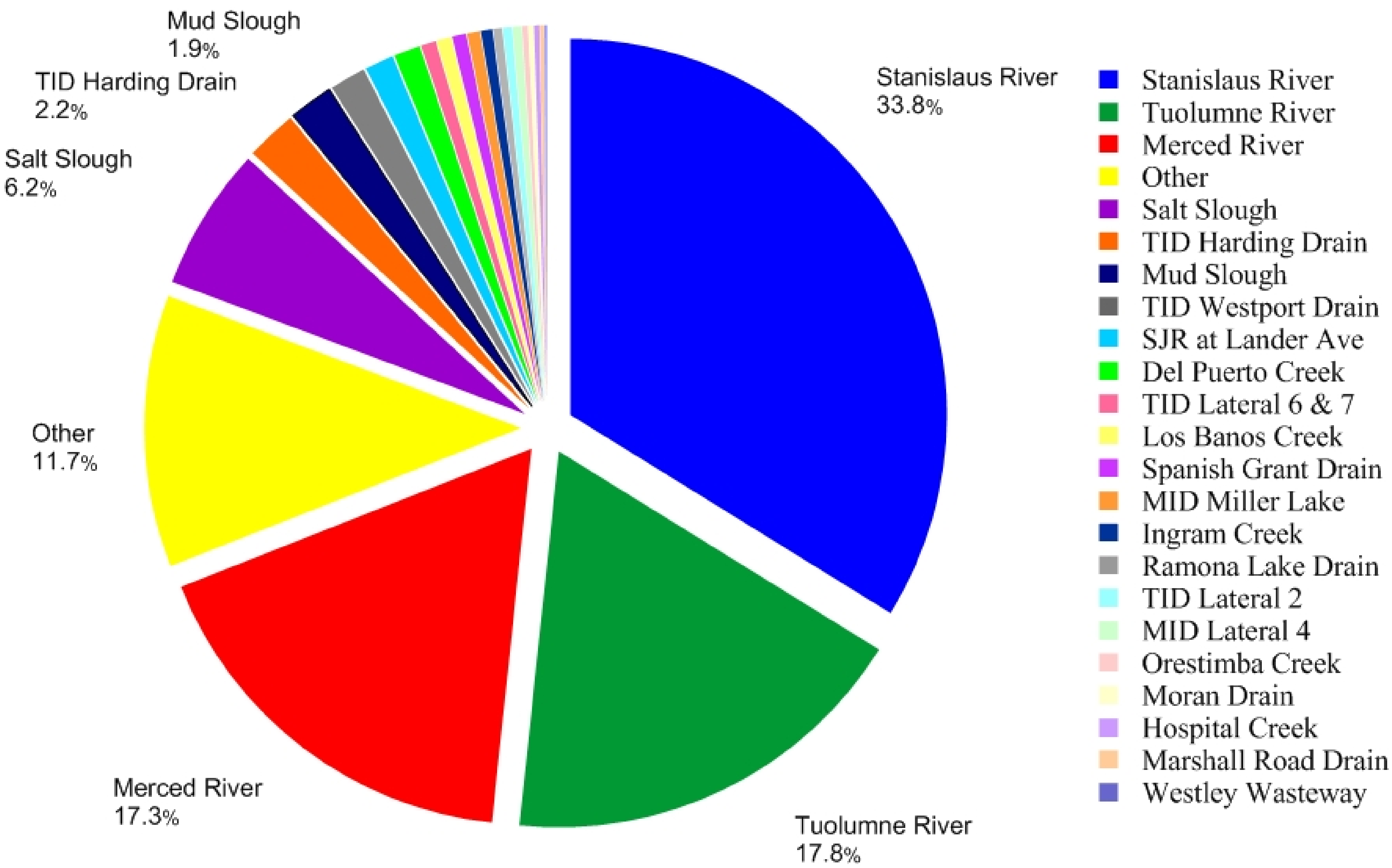

Figure 7. Annual TDS. The following pie chart represents the proportional origins of total dissolved solids (TDS) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. TDS load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to groundwater inputs.

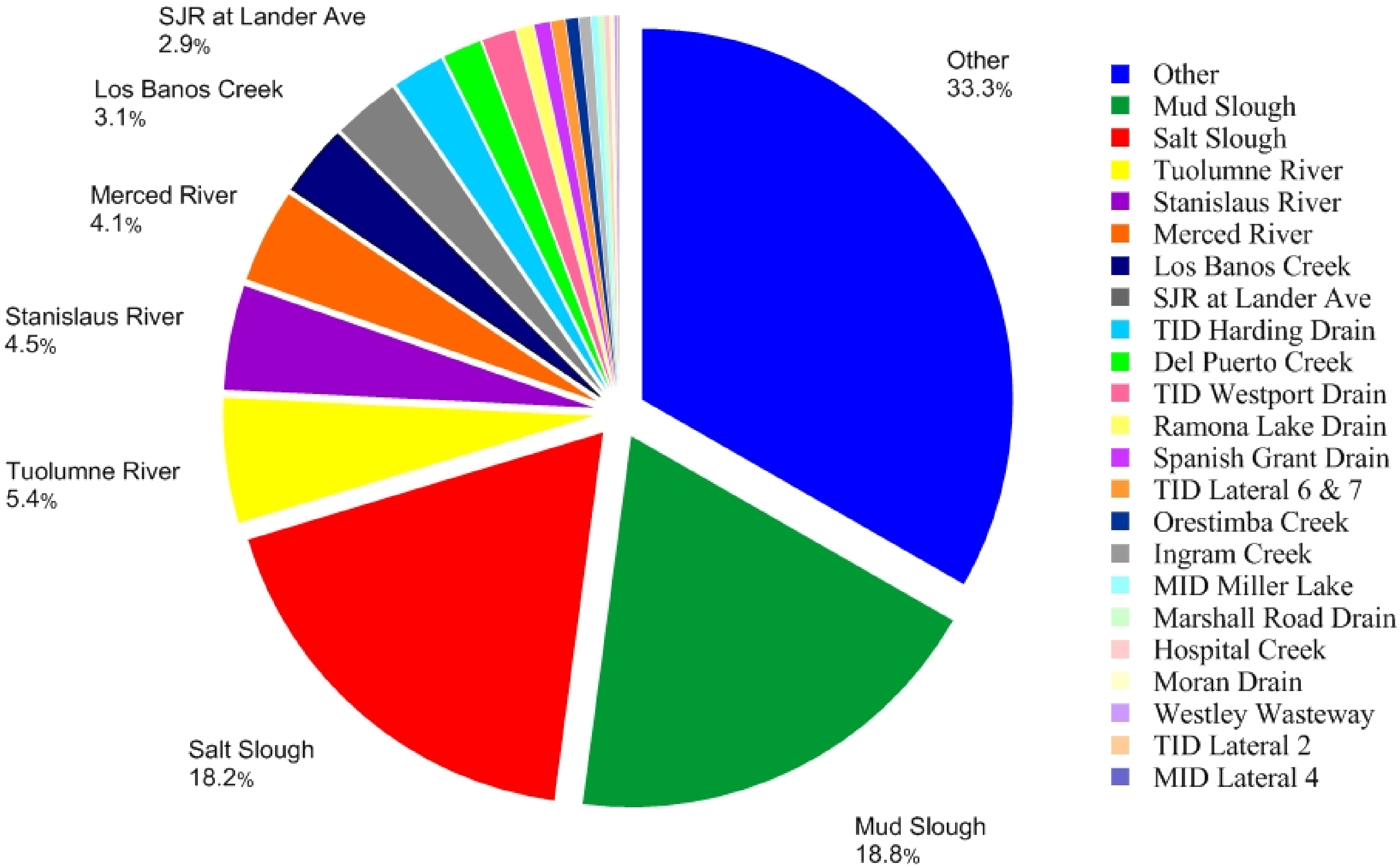

Figure 8. Annual TDS. Quadrant plot of discharged volume versus total dissolved solids (TDS) load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

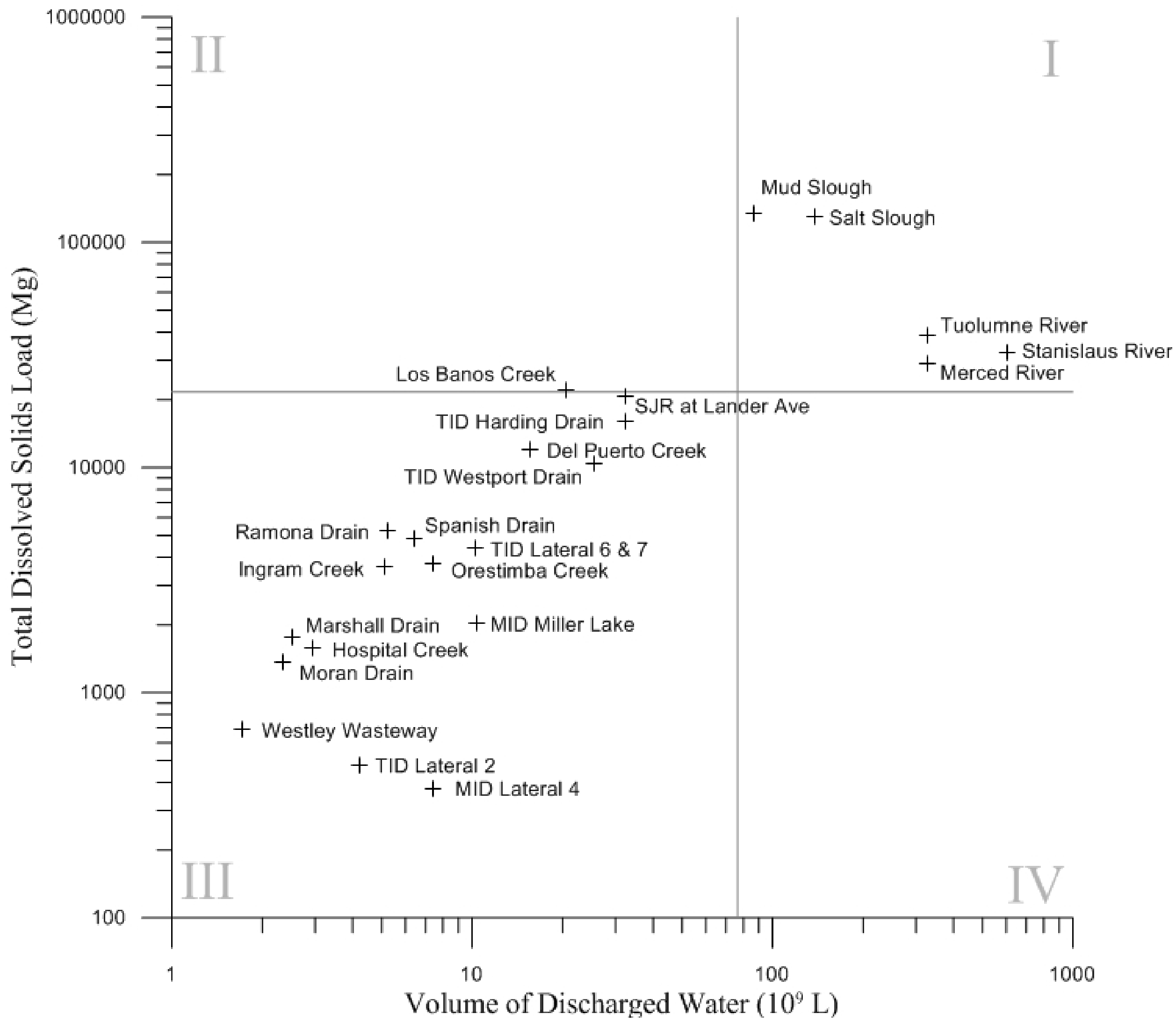

Figure 9. Irrigation Season TDS. The following pie chart represents the proportional origins of total dissolved solids (TDS) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. TDS load designated as “other” represents input load that was not accounted for by surface water loads and was likely due to groundwater inputs.

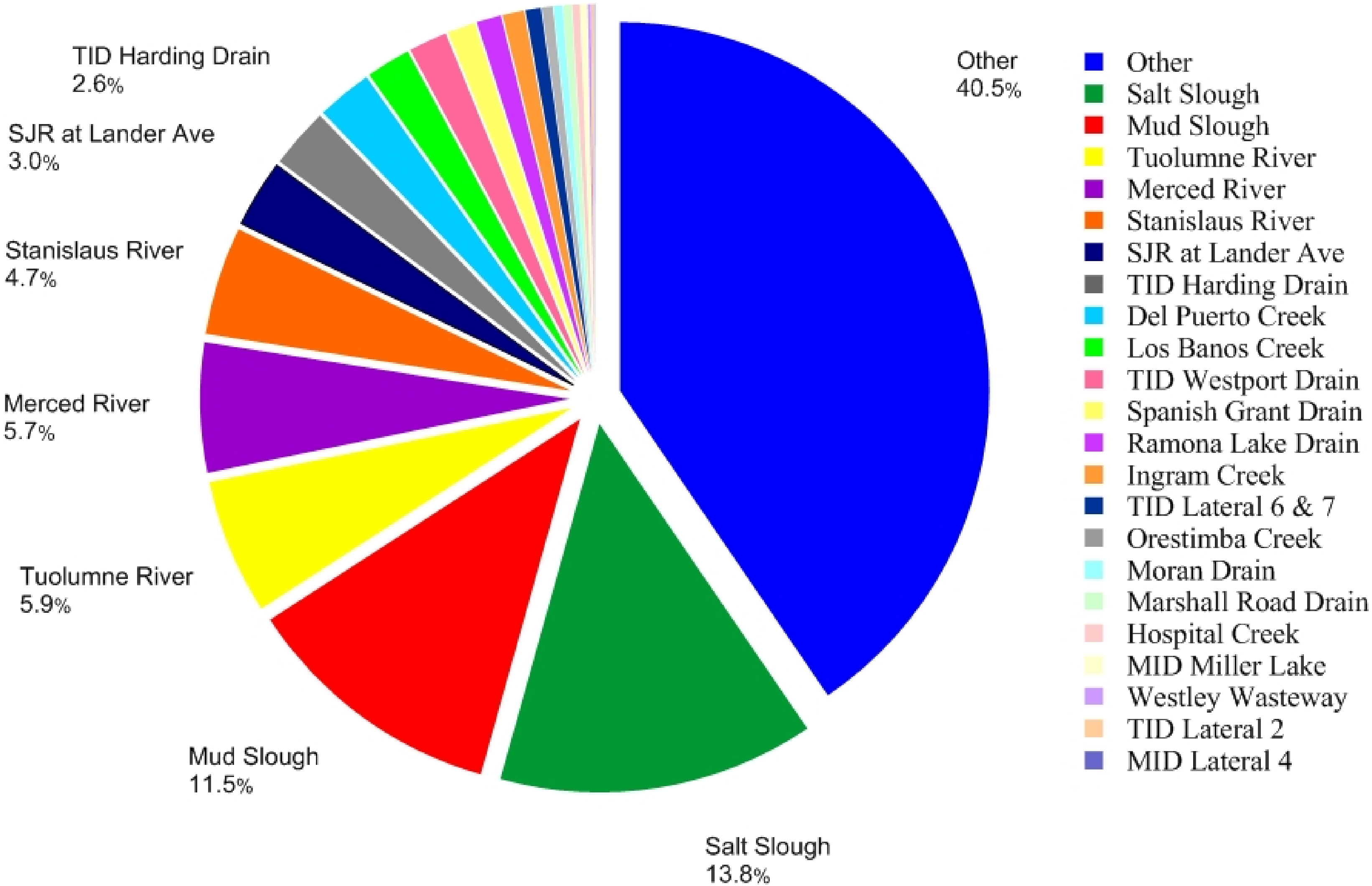

Figure 10. Irrigation Season TDS. Quadrant plot of discharged volume versus total dissolved solids (TDS) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

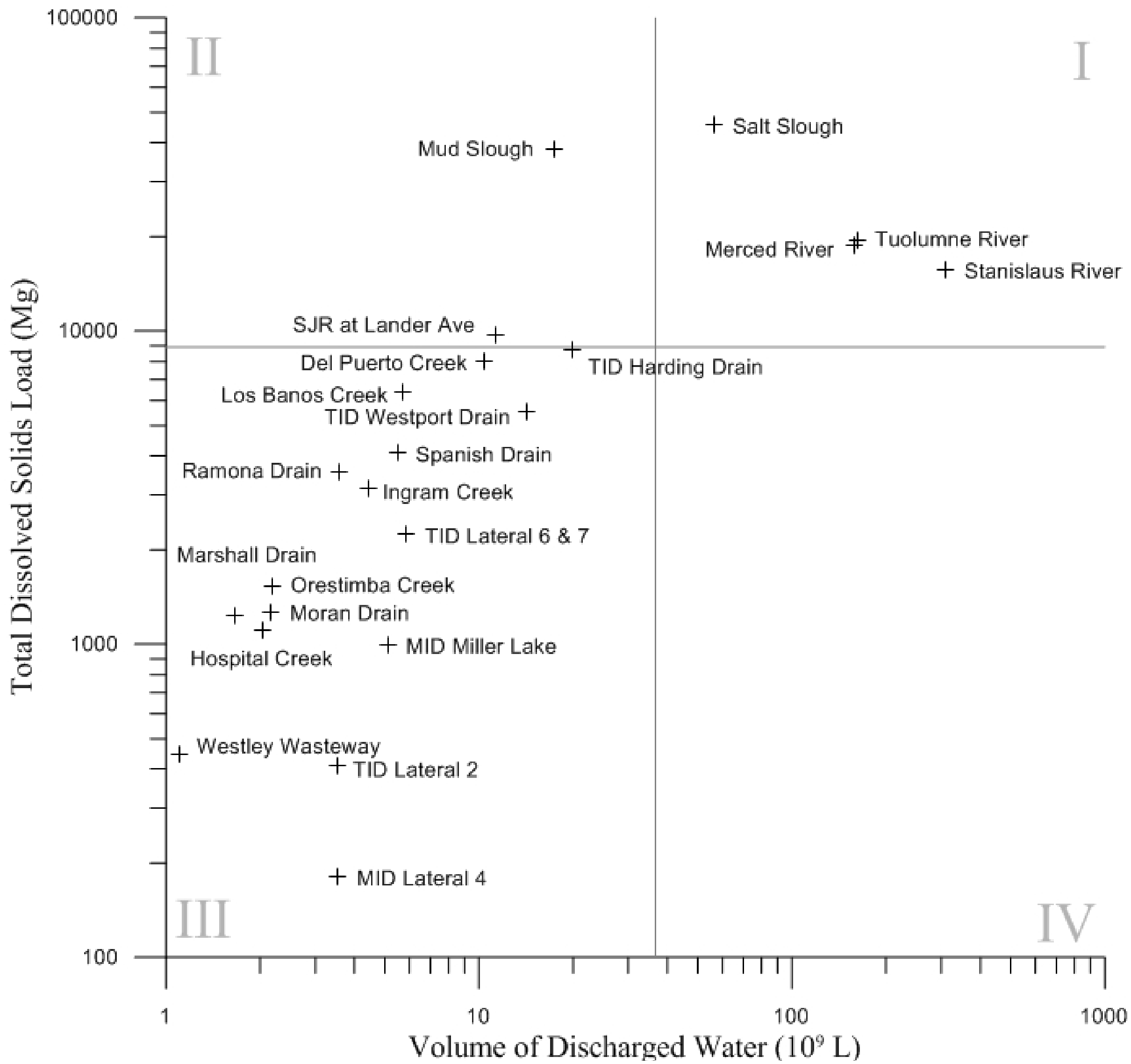

Figure 11. Annual TSS. The following pie chart represents the proportional origins of total suspended solids (TSS) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. TSS load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to in-stream bank erosion, river bed resuspension, and algal biomass growth.

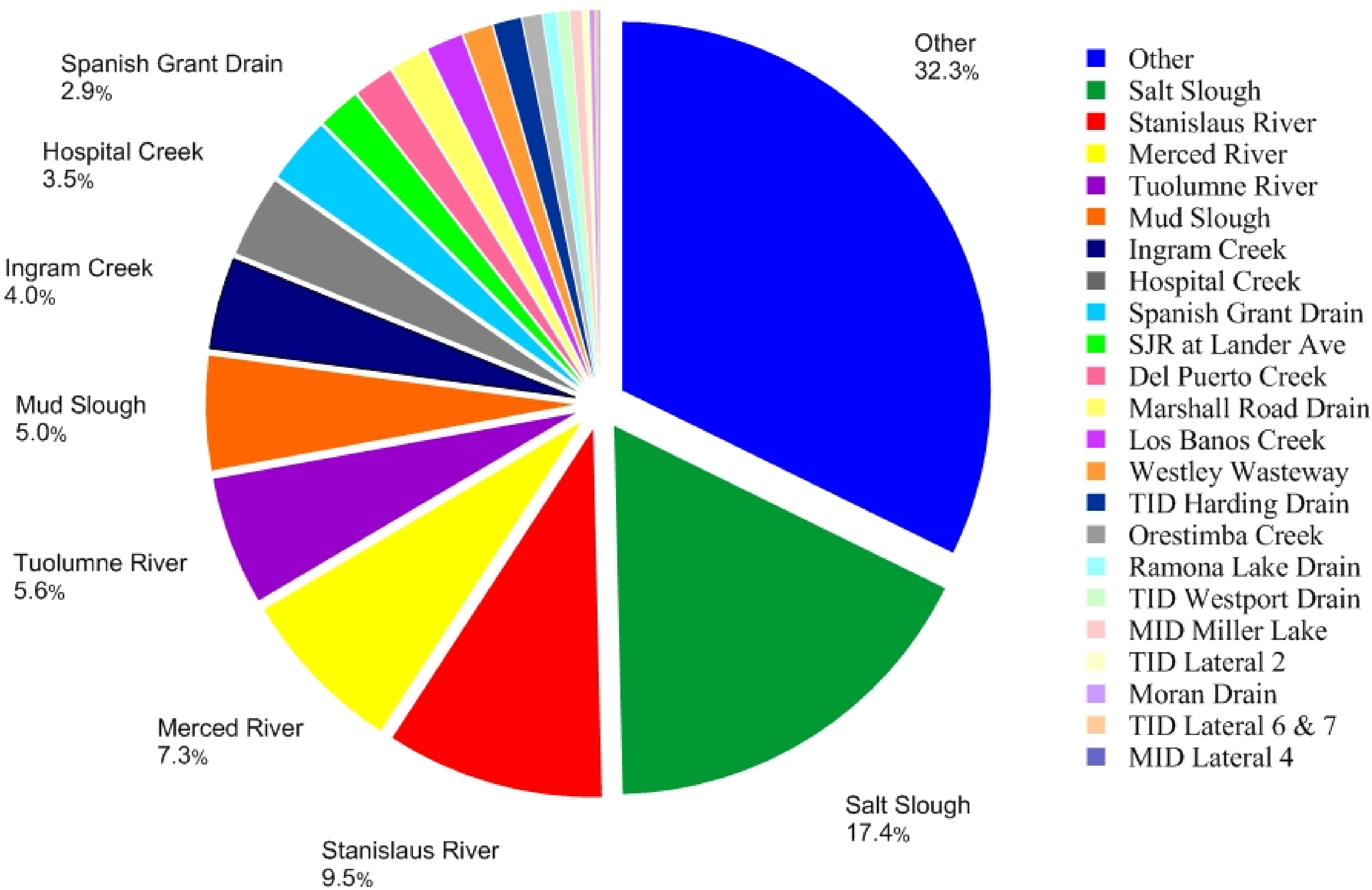

Figure 12. Annual TSS. Quadrant plot of discharged volume versus total suspended solids (TSS) load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

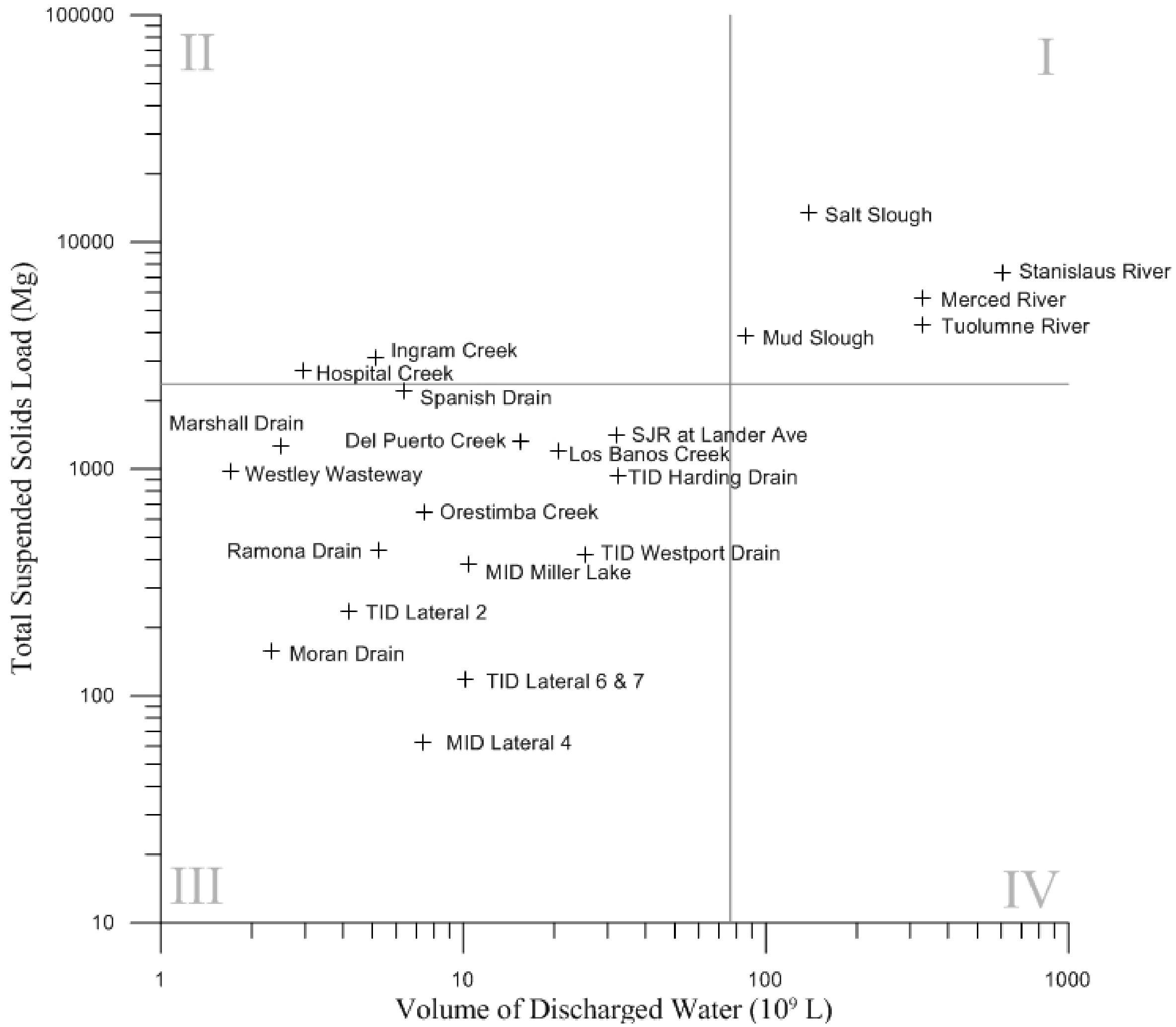

Figure 13. Irrigation Season TSS. The following pie chart represents the proportional origins of total suspended solids (TSS) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. TSS load designated as “other” represents input load that was not accounted for by surface water loads and was likely due to in-stream bank erosion, river bed resuspension, and algal biomass growth.

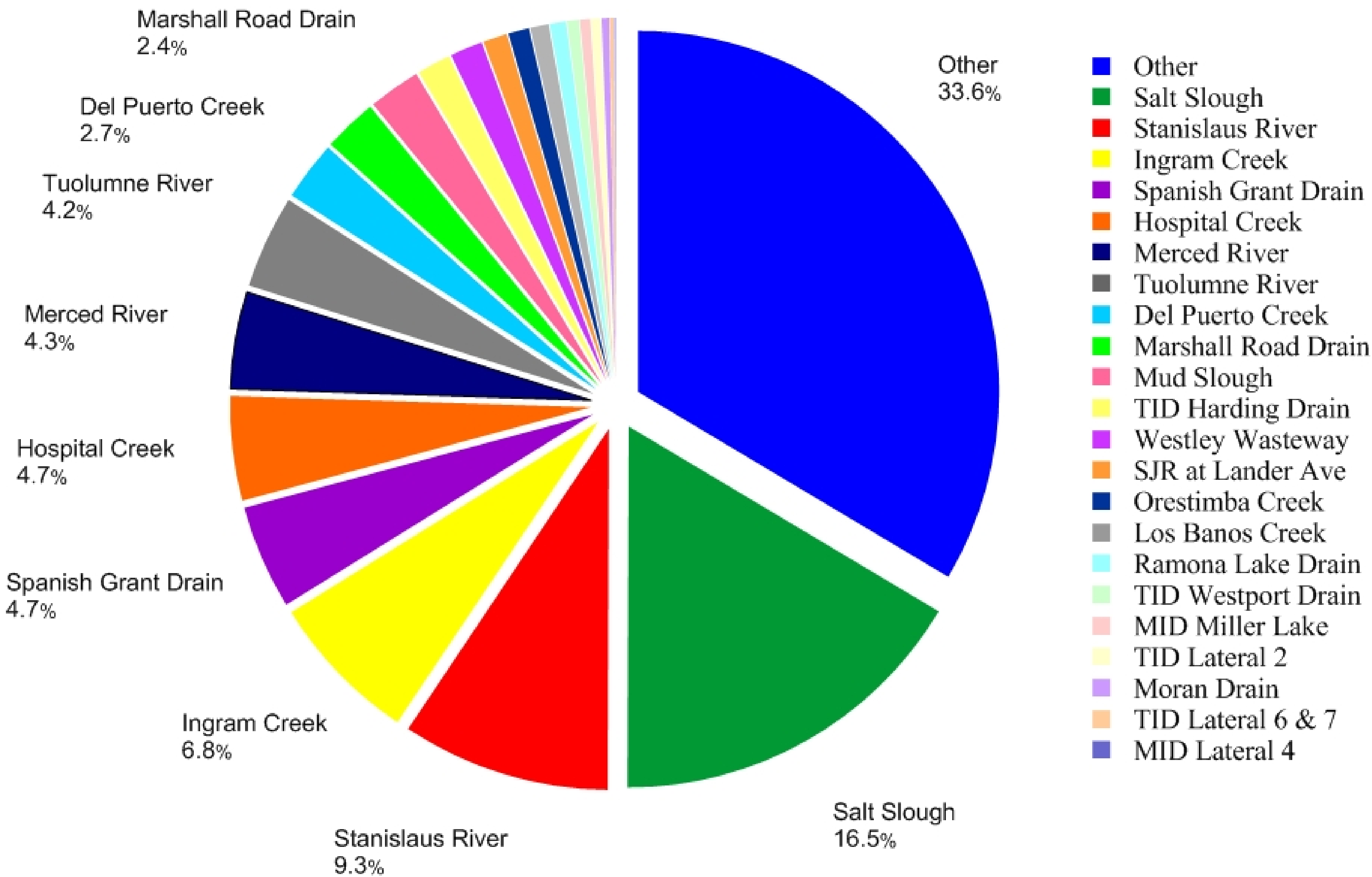

Figure 14. Irrigation Season TSS. Quadrant plot of discharged volume versus total suspended solids (TSS) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

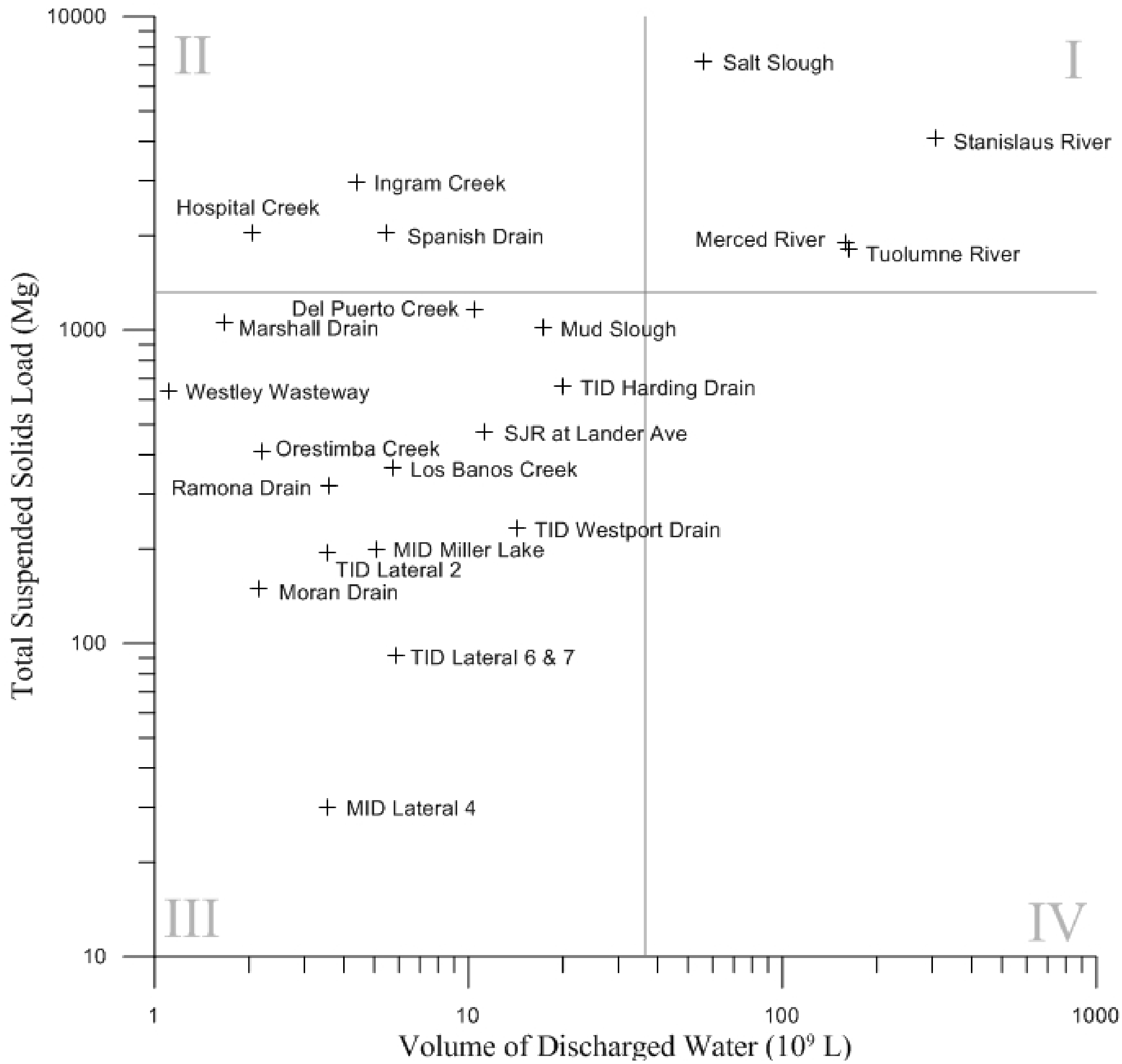

Figure 15. Annual VSS. The following pie chart represents the proportional origins of volatile suspended solids (VSS) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. VSS load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to in-stream algal biomass growth, bank erosion, and other processes.

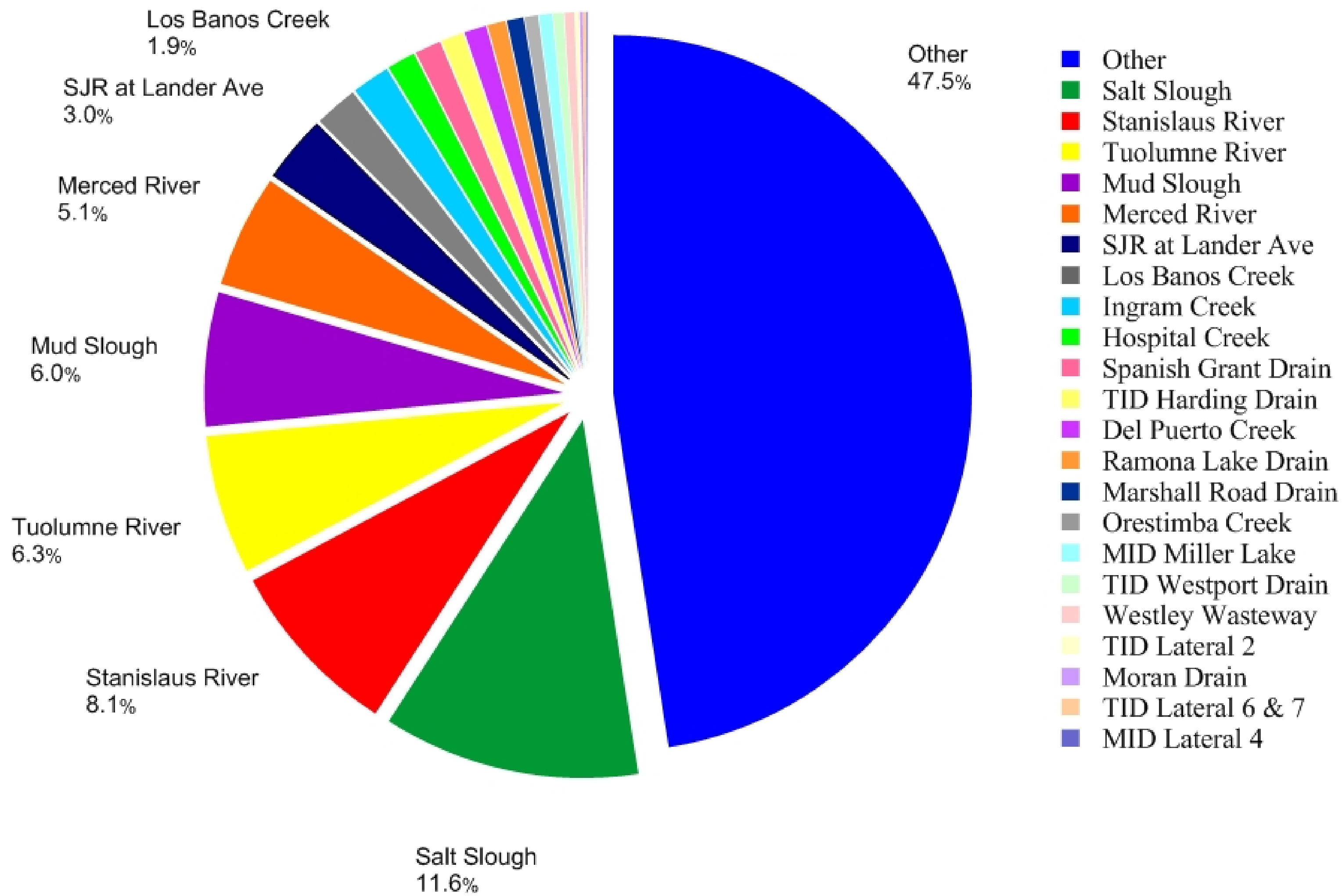

Figure 16. Annual VSS. Quadrant plot of discharged volume versus volatile suspended solids (VSS) load for all San Joaquin River tributaries from January 1, 2007 to December 31, 2007. Quadrants are divided by average load and average volume.

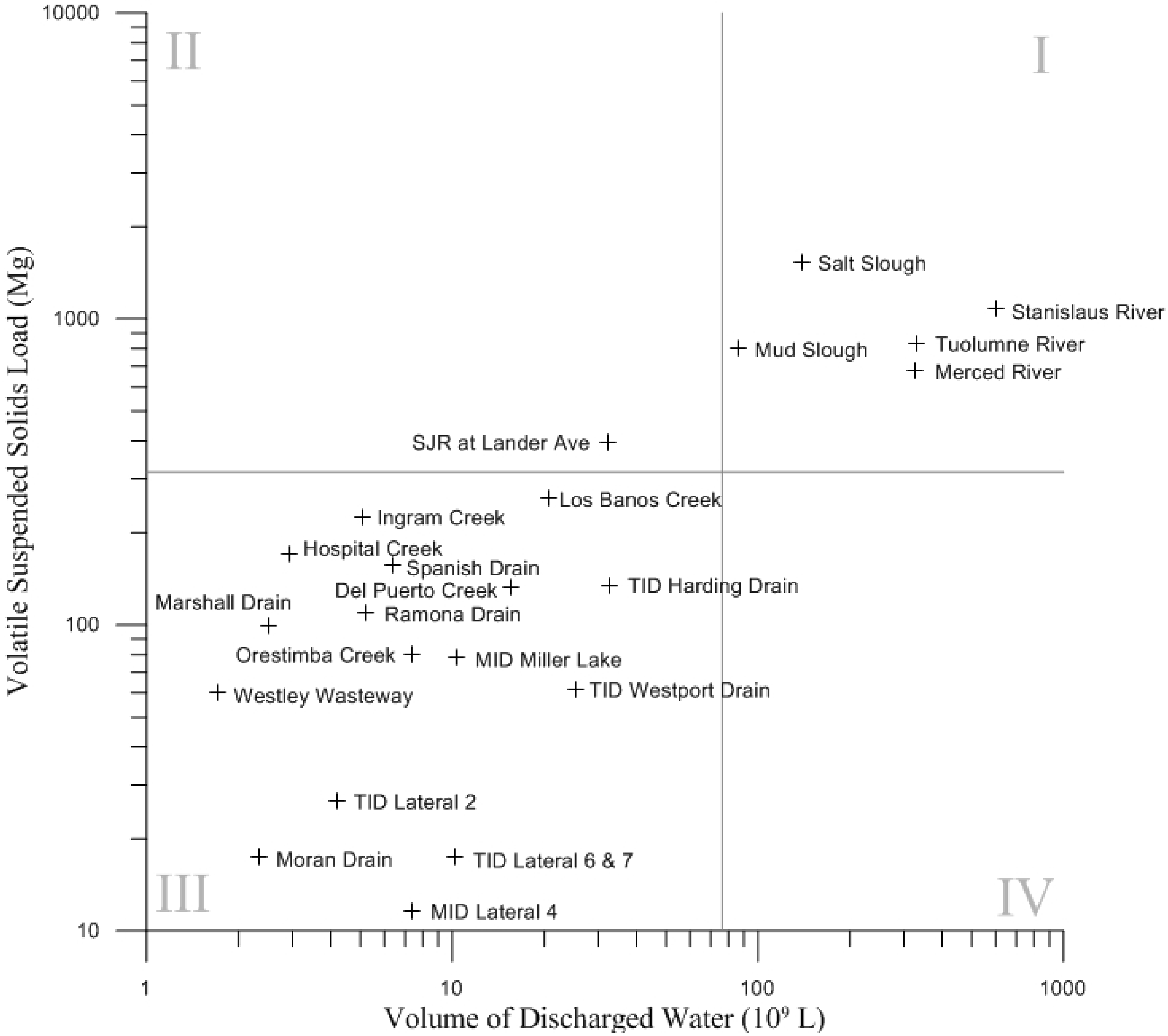

Figure 17. Irrigation Season VSS. The following pie chart represents the proportional origins of volatile suspended solids (VSS) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. VSS load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to in-stream algal biomass growth, bank erosion, and other processes.

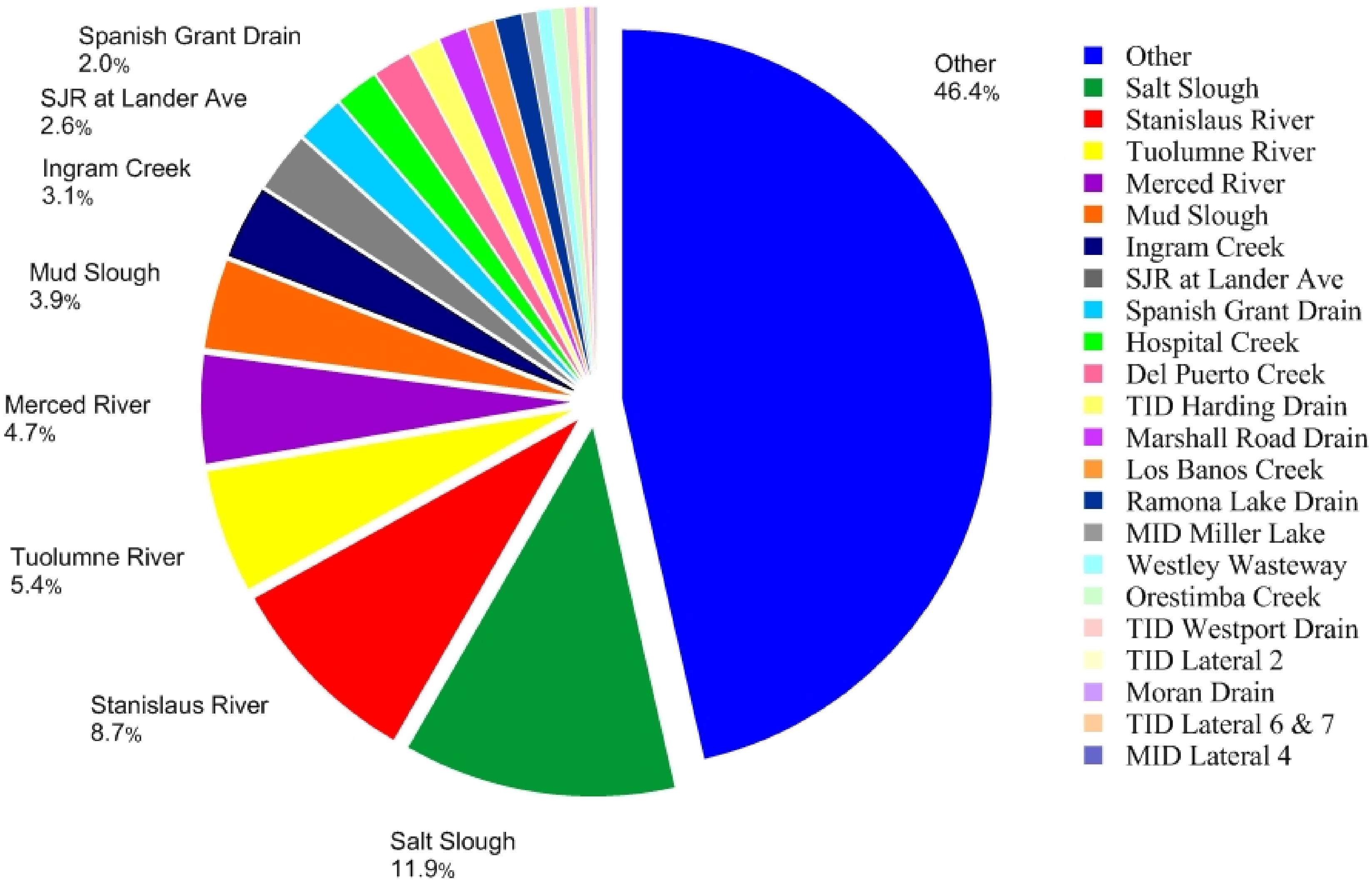

Figure 18. Irrigation Season VSS. Quadrant plot of discharged volume versus volatile suspended solids (VSS) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

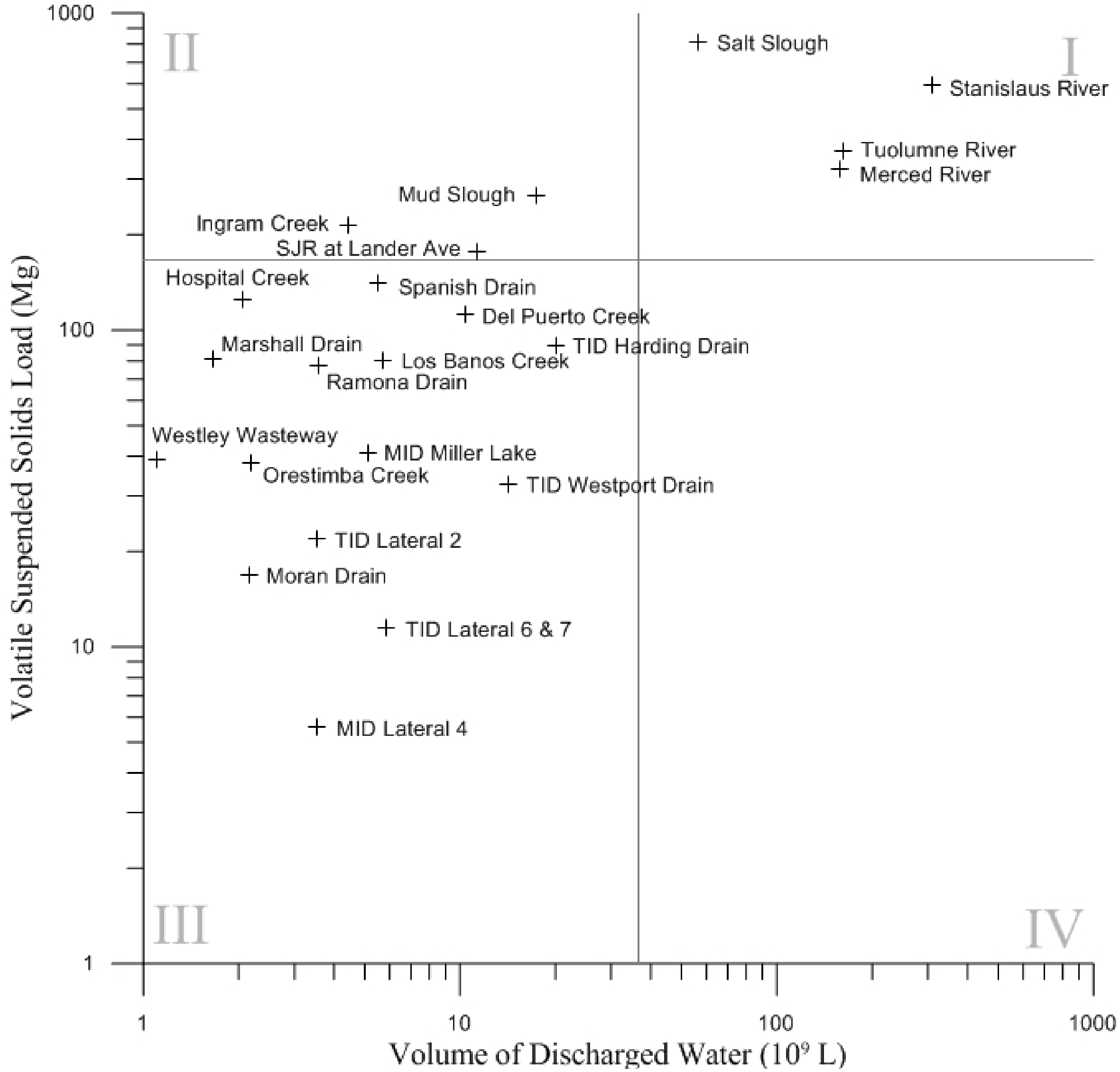

Figure 19. Annual BOD. The following pie chart represents the proportional origins of biochemical oxygen demand (BOD) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. BOD load designated as “other” represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

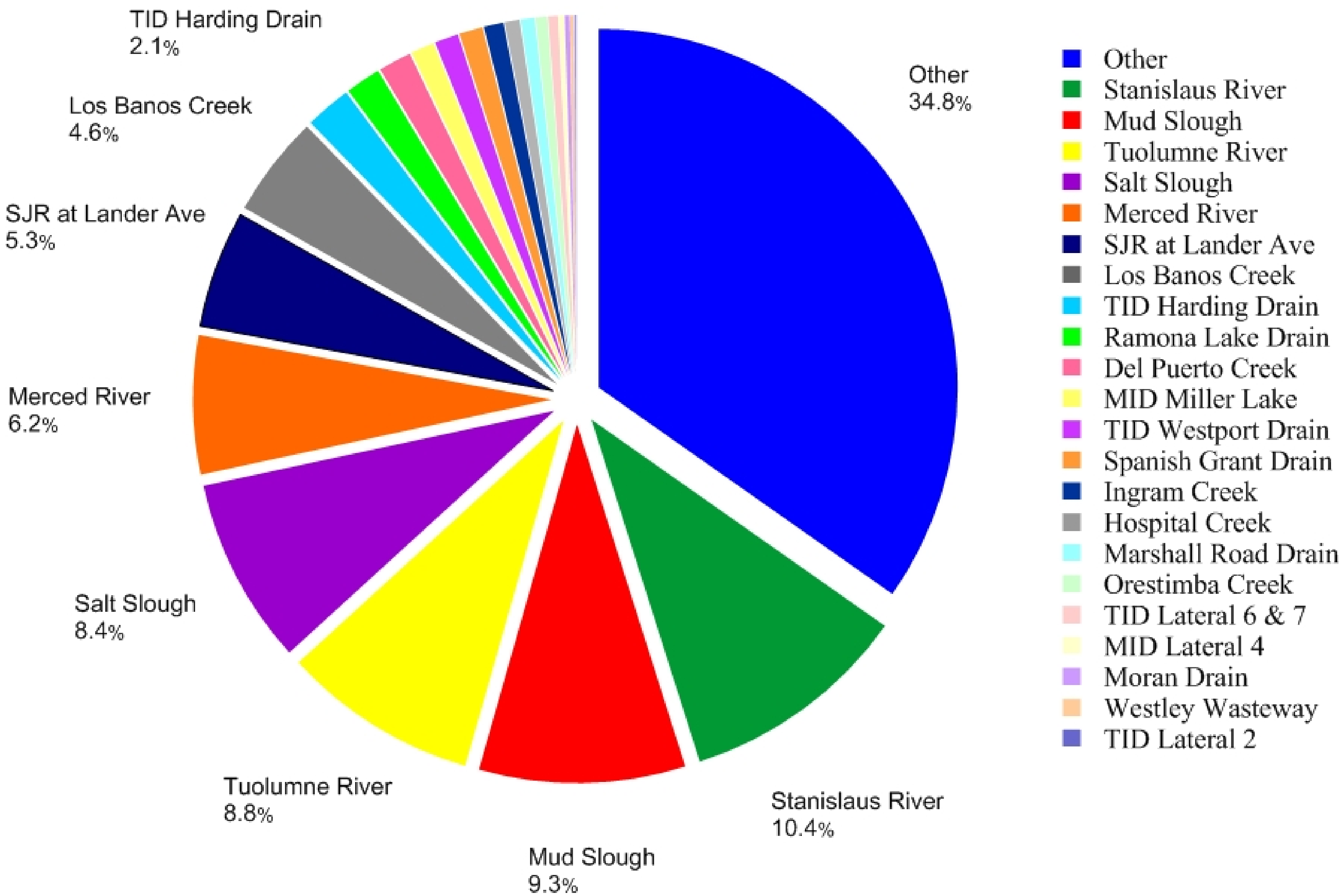

Figure 20. Annual BOD. Quadrant plot of discharged volume versus 10 day biochemical oxygen demand (BOD) load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

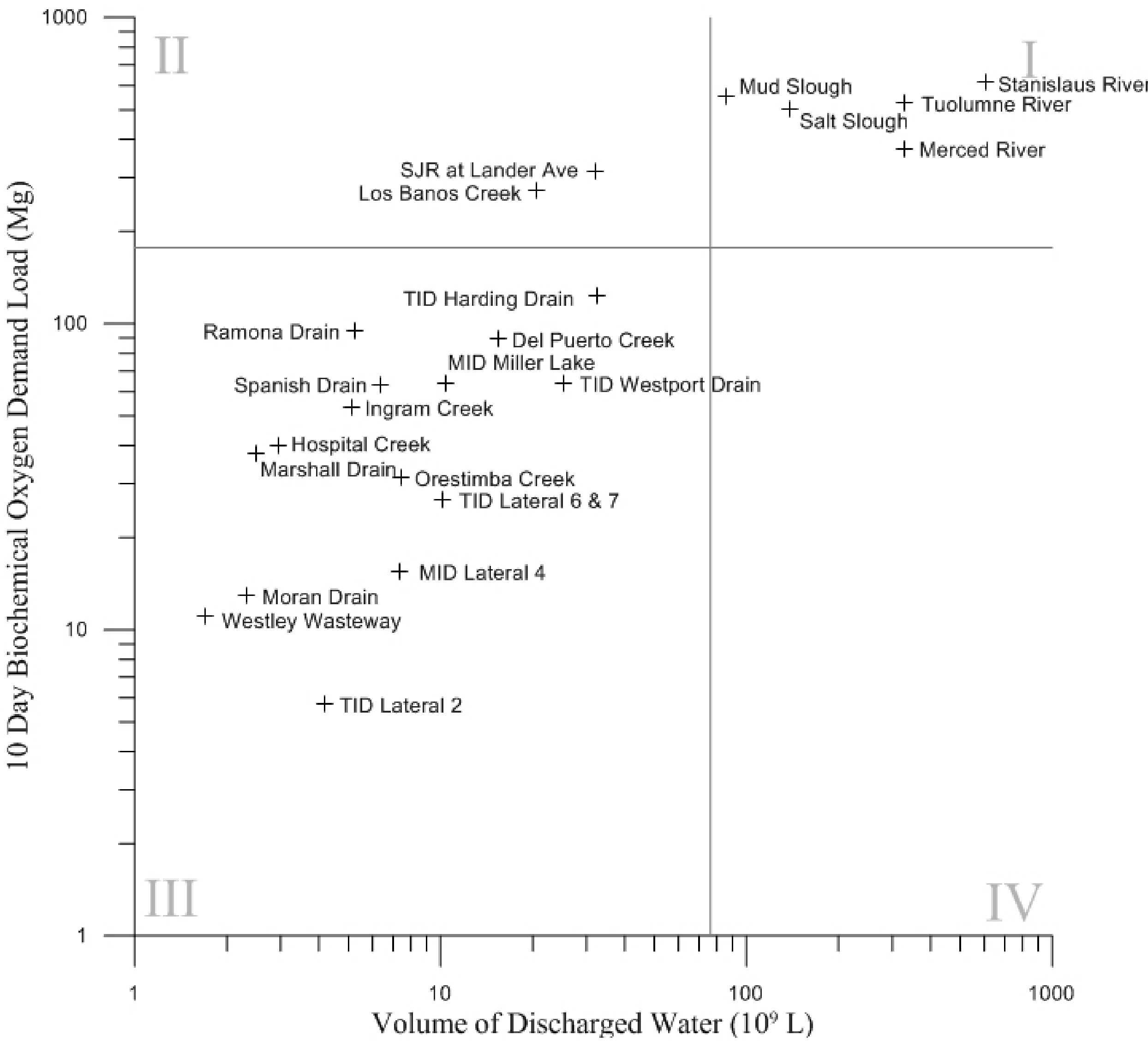

Figure 21. Irrigation Season BOD. The following pie chart represents the proportional origins of biochemical oxygen demand (BOD) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. BOD load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

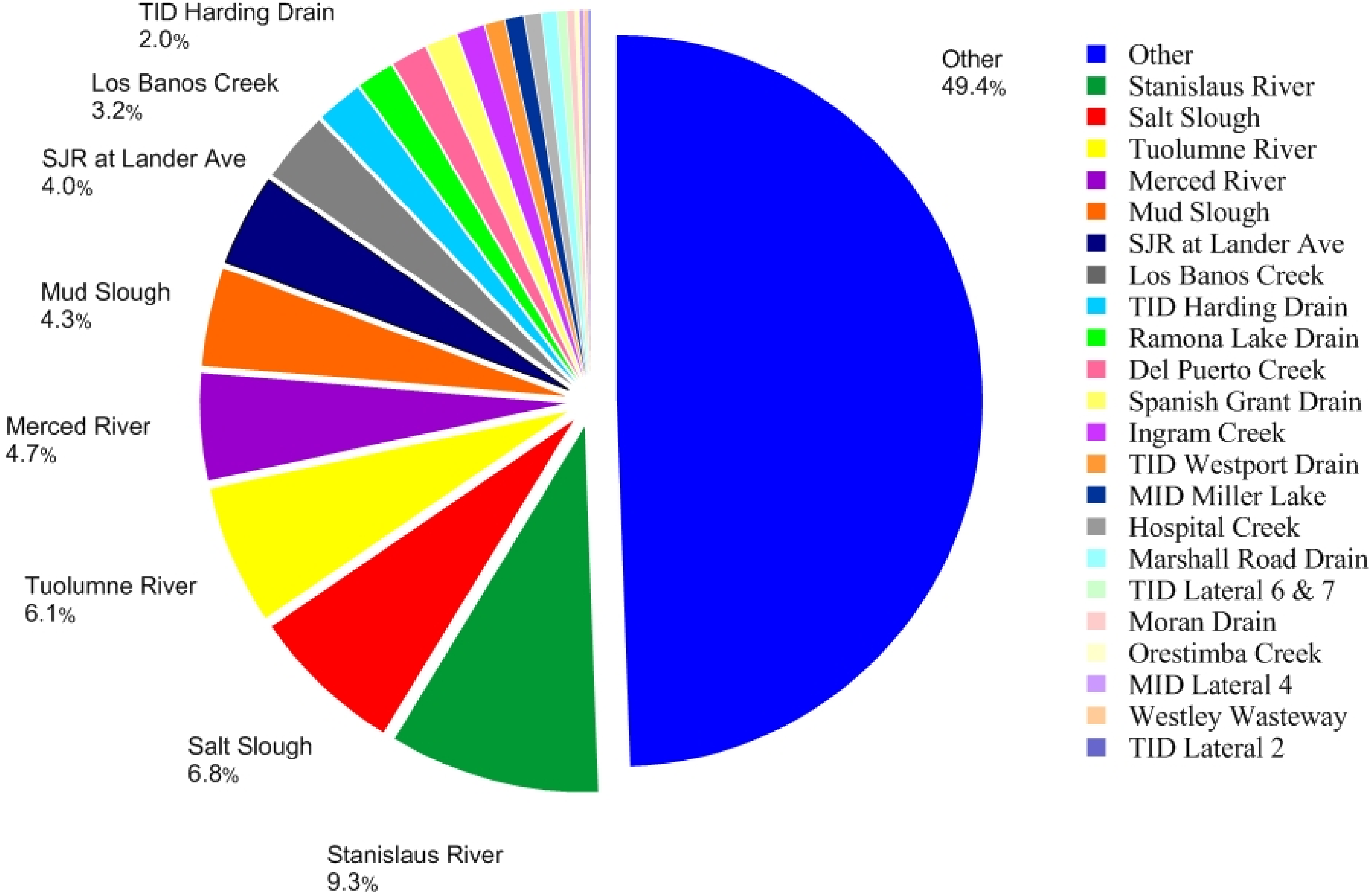

Figure 22. Irrigation Season BOD. Quadrant plot of discharged volume versus 10 day biochemical oxygen demand (BOD) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

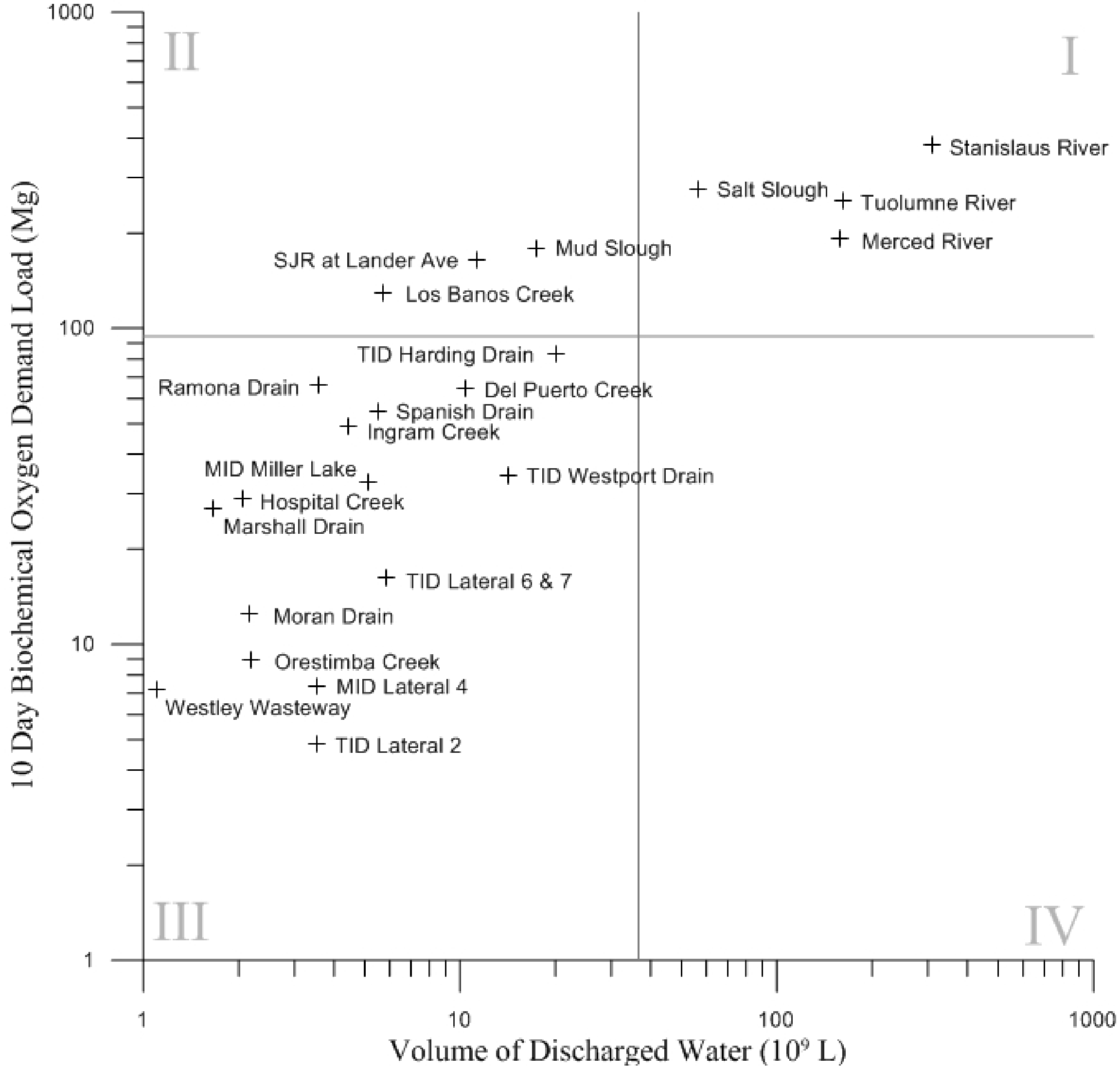

Figure 23. Annual CBOD. The following pie chart represents the proportional origins of carbonaceous biochemical oxygen demand (CBOD) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. CBOD load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

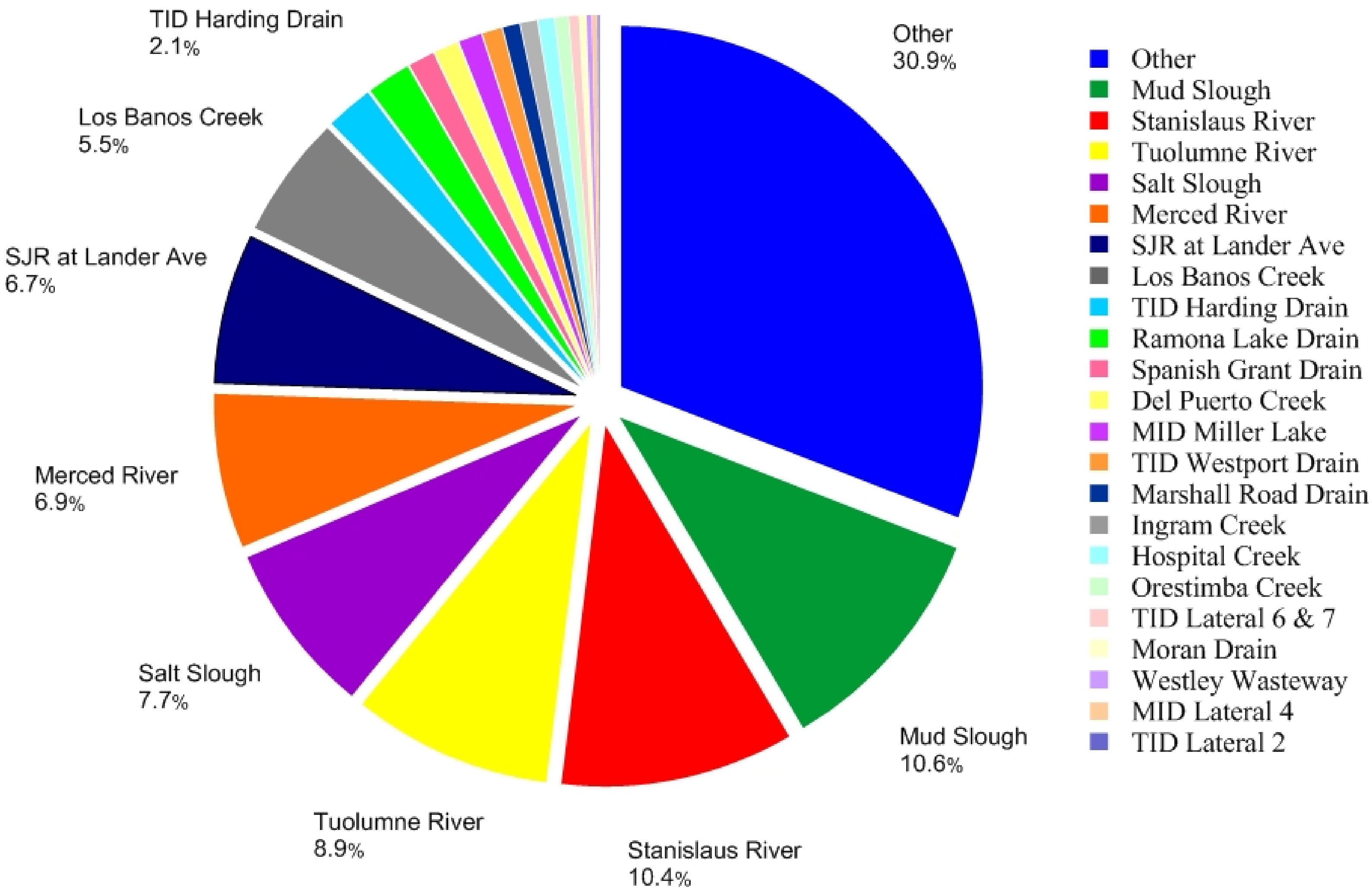

Figure 24. Annual CBOD. Quadrant plot of discharged volume versus 10 day carbonaceous biochemical oxygen demand (CBOD) load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

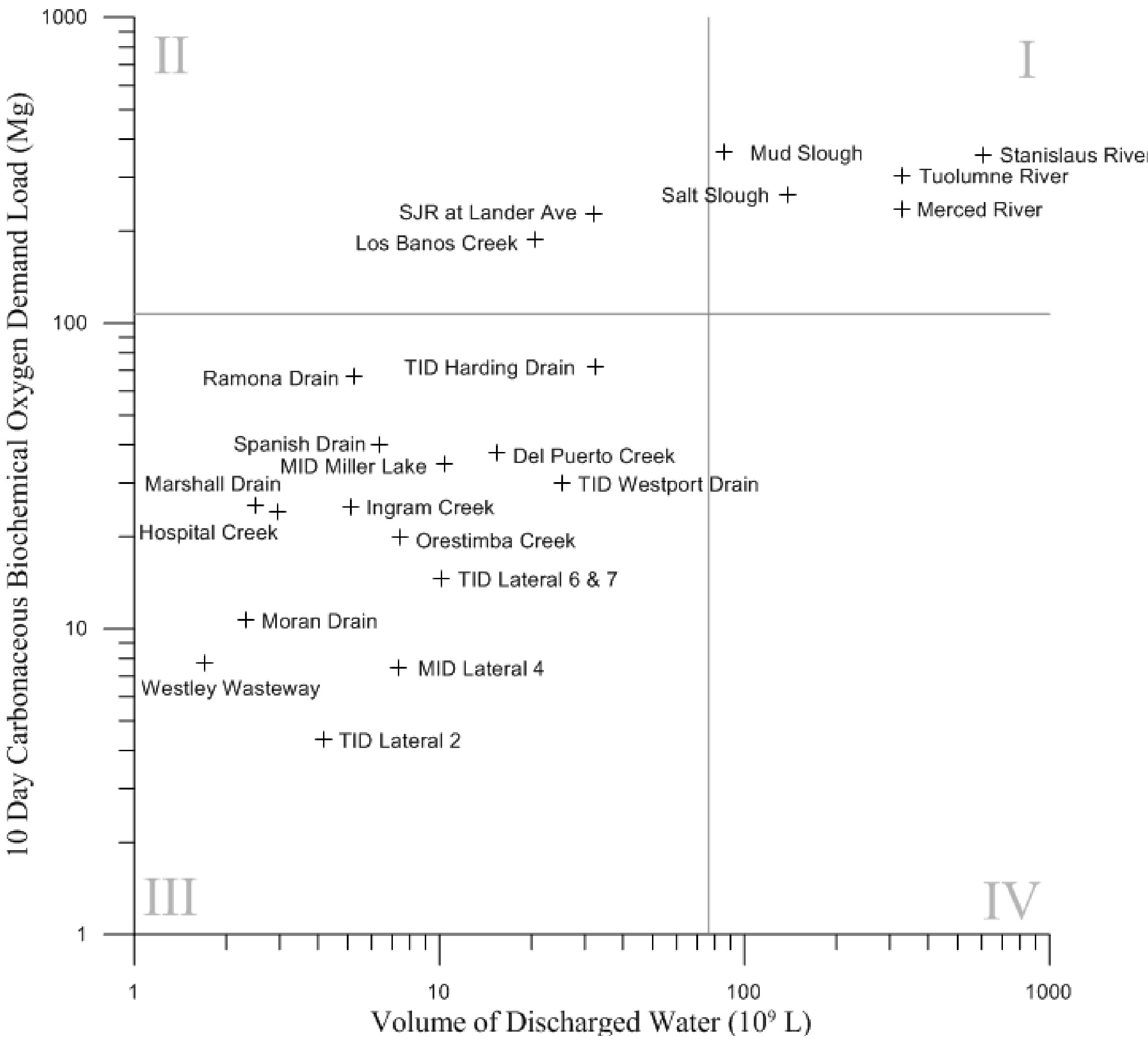

Figure 25. Irrigation Season CBOD. The following pie chart represents the proportional origins of carbonaceous biochemical oxygen demand (CBOD) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. CBOD load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

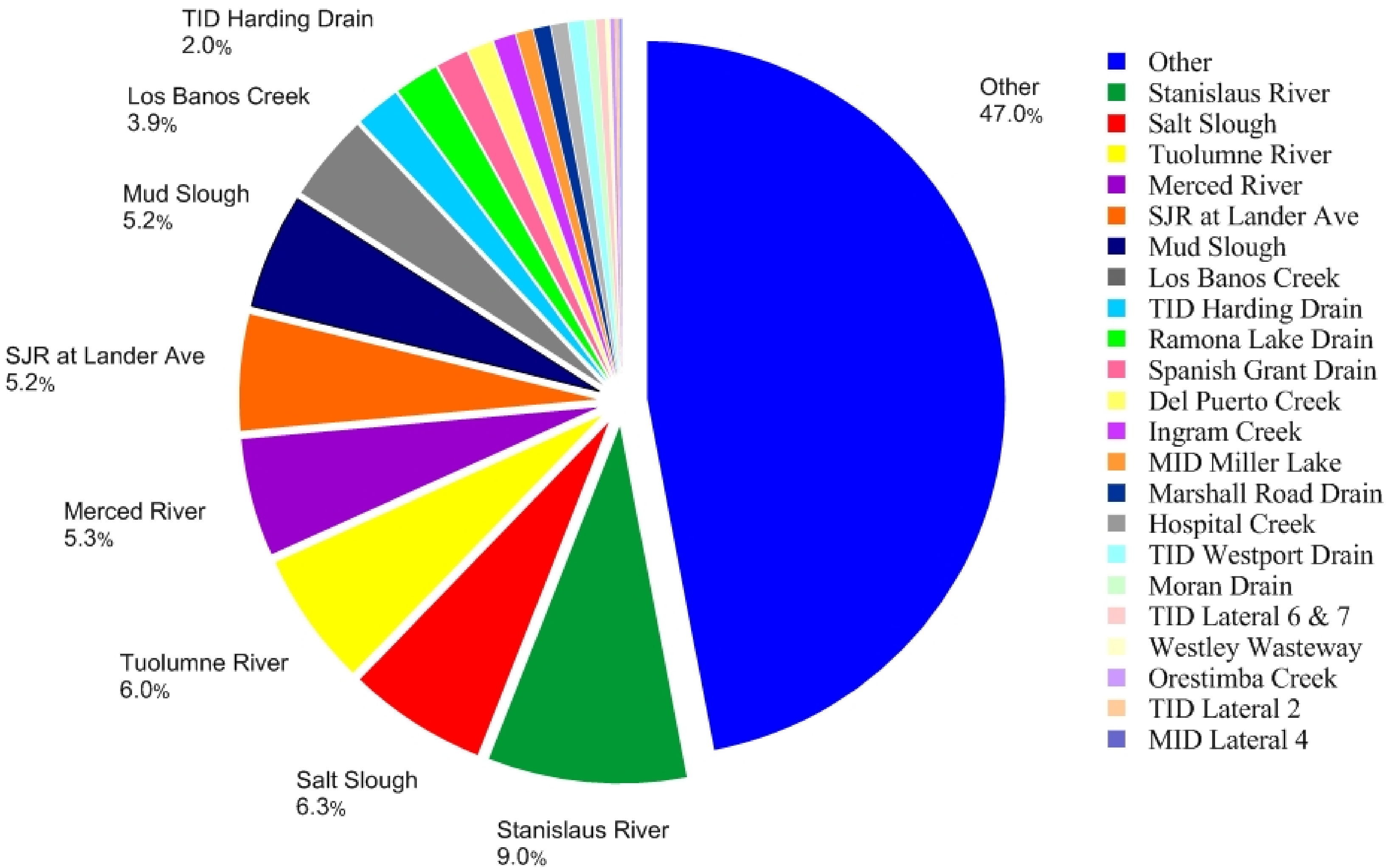

Figure 26. Irrigation Season CBOD. Quadrant plot of discharged volume versus 10 day carbonaceous biochemical oxygen demand (CBOD) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

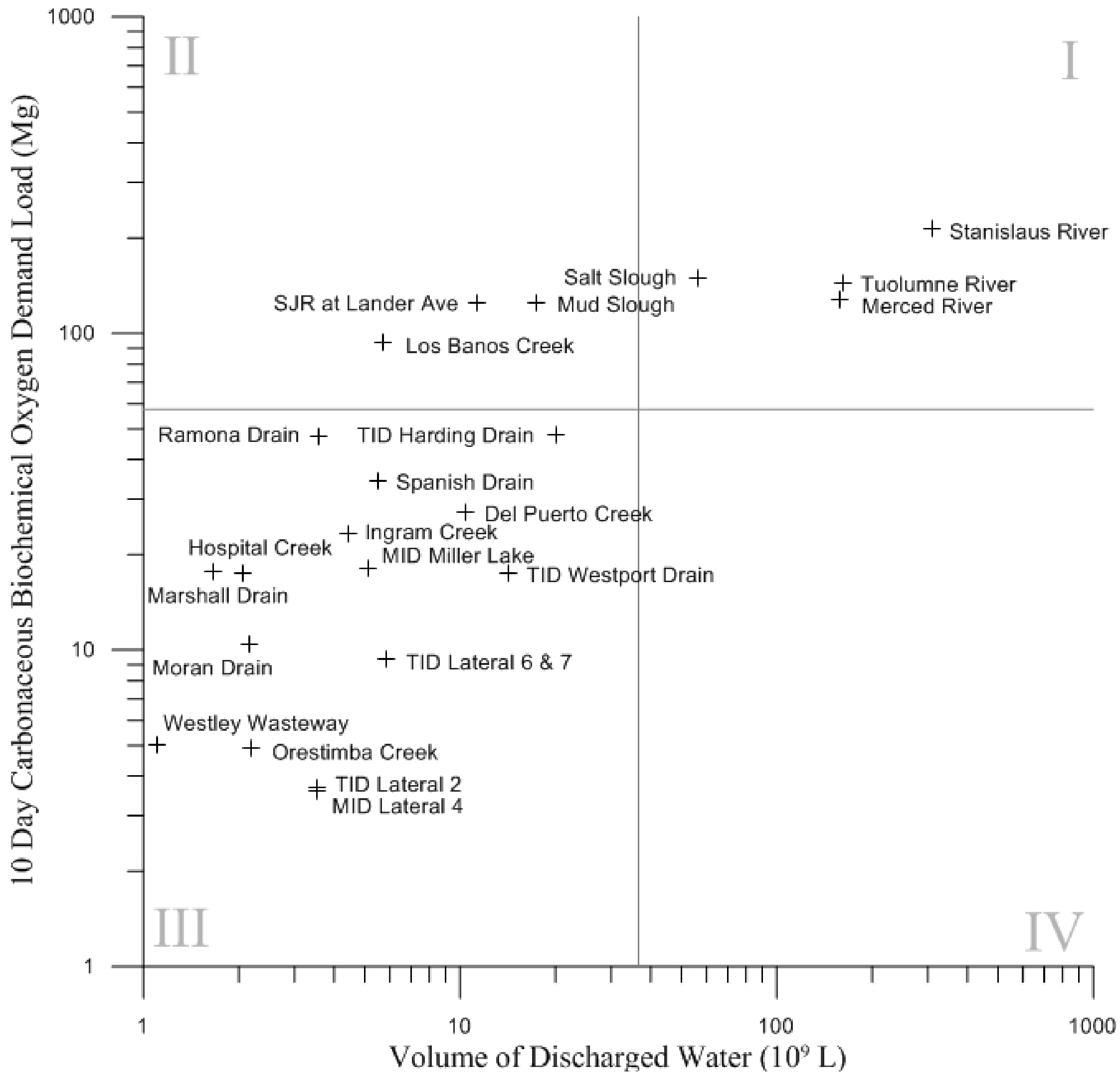

Figure 27. Annual NBOD. The following pie chart represents the proportional origins of nitrogenous biochemical oxygen demand (NBOD) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. NBOD load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

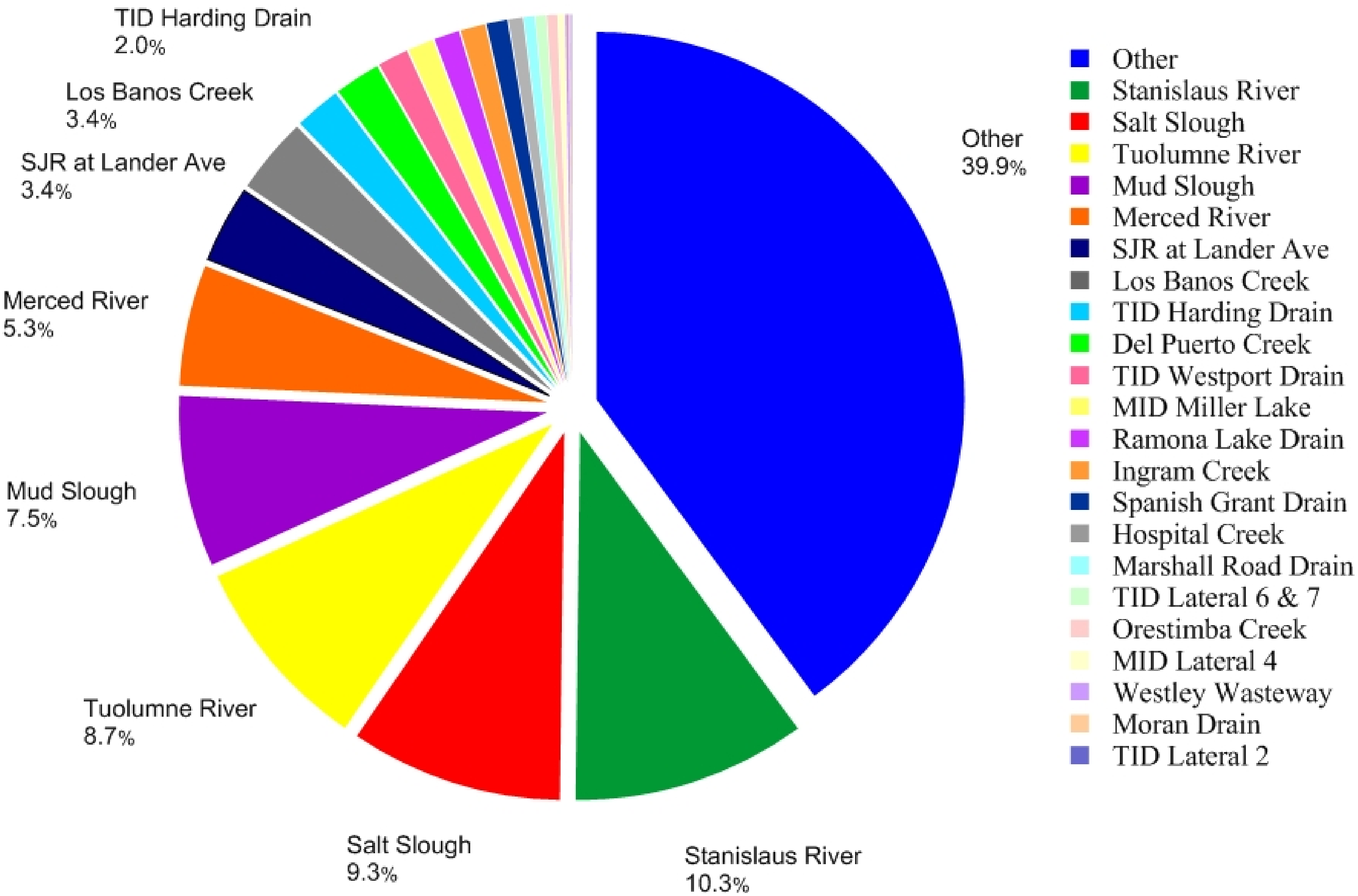

Figure 28. Annual NBOD. Quadrant plot of discharged volume versus 10 day nitrogenous biochemical oxygen demand (NBOD) load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

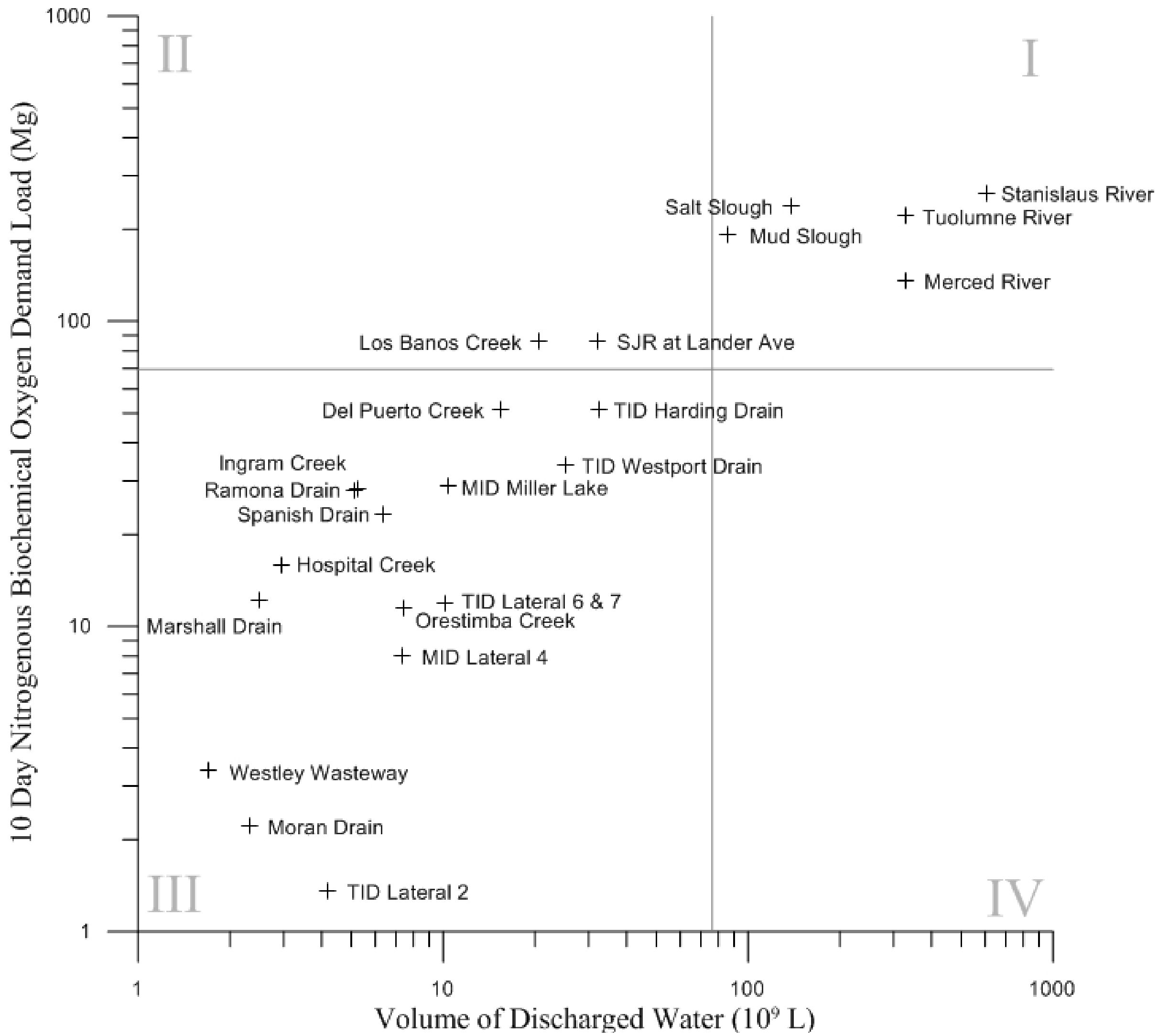

Figure 29. Irrigation Season NBOD. The following pie chart represents the proportional origins of nitrogenous biochemical oxygen demand (NBOD) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. NBOD load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to non-point sources and in-stream algal biomass growth.

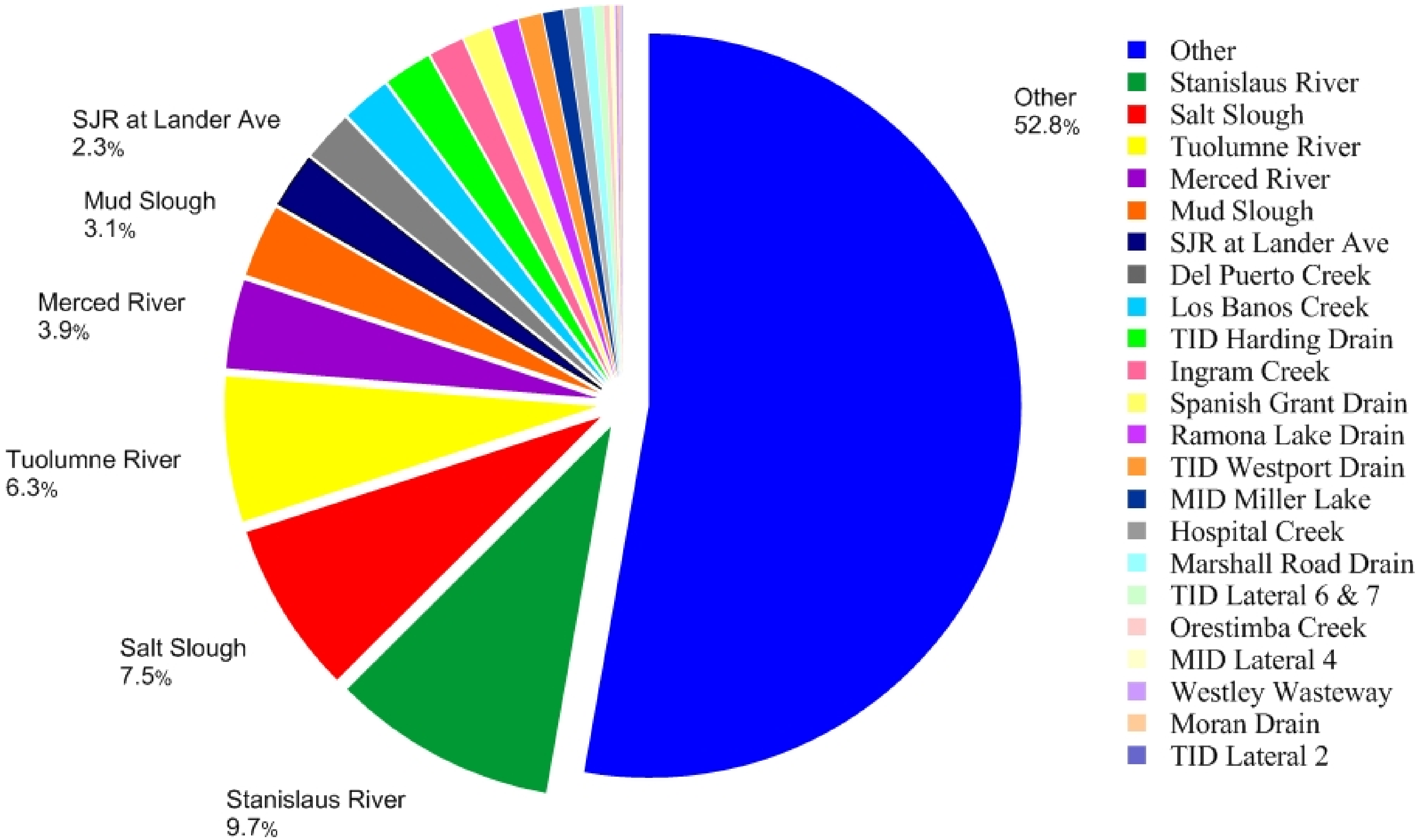

Figure 30. Irrigation Season NBOD. Quadrant plot of discharged volume versus 10 day nitrogenous biochemical oxygen demand (NBOD) load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

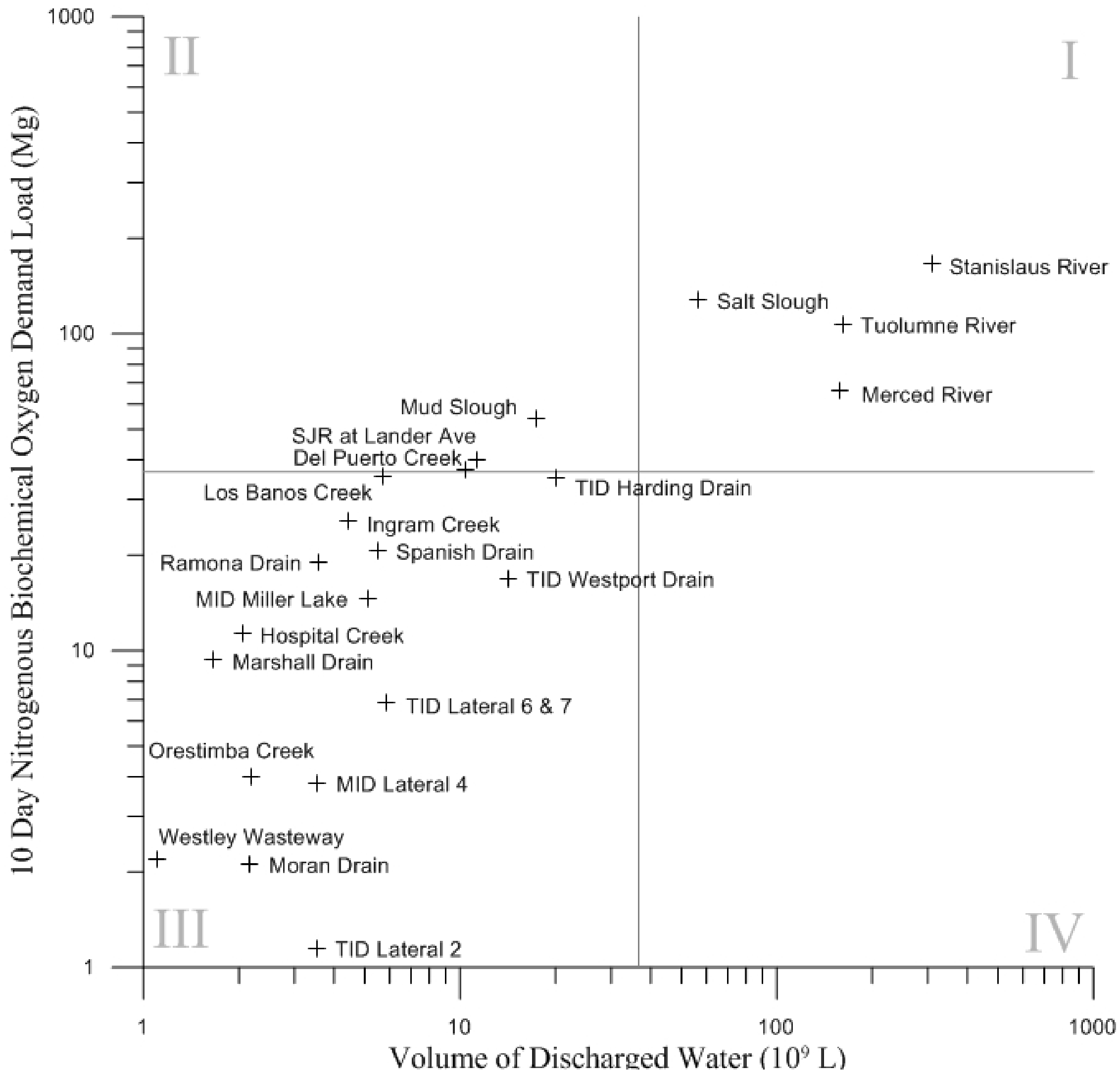

Figure 31. Annual Chlorophyll. The following pie chart represents the proportional origins of chlorophyll-a from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. Chlorophyll-a load d designated as "other" represents input load that was not accounted for by surface water loads and was likely due to in-stream algal biomass growth.

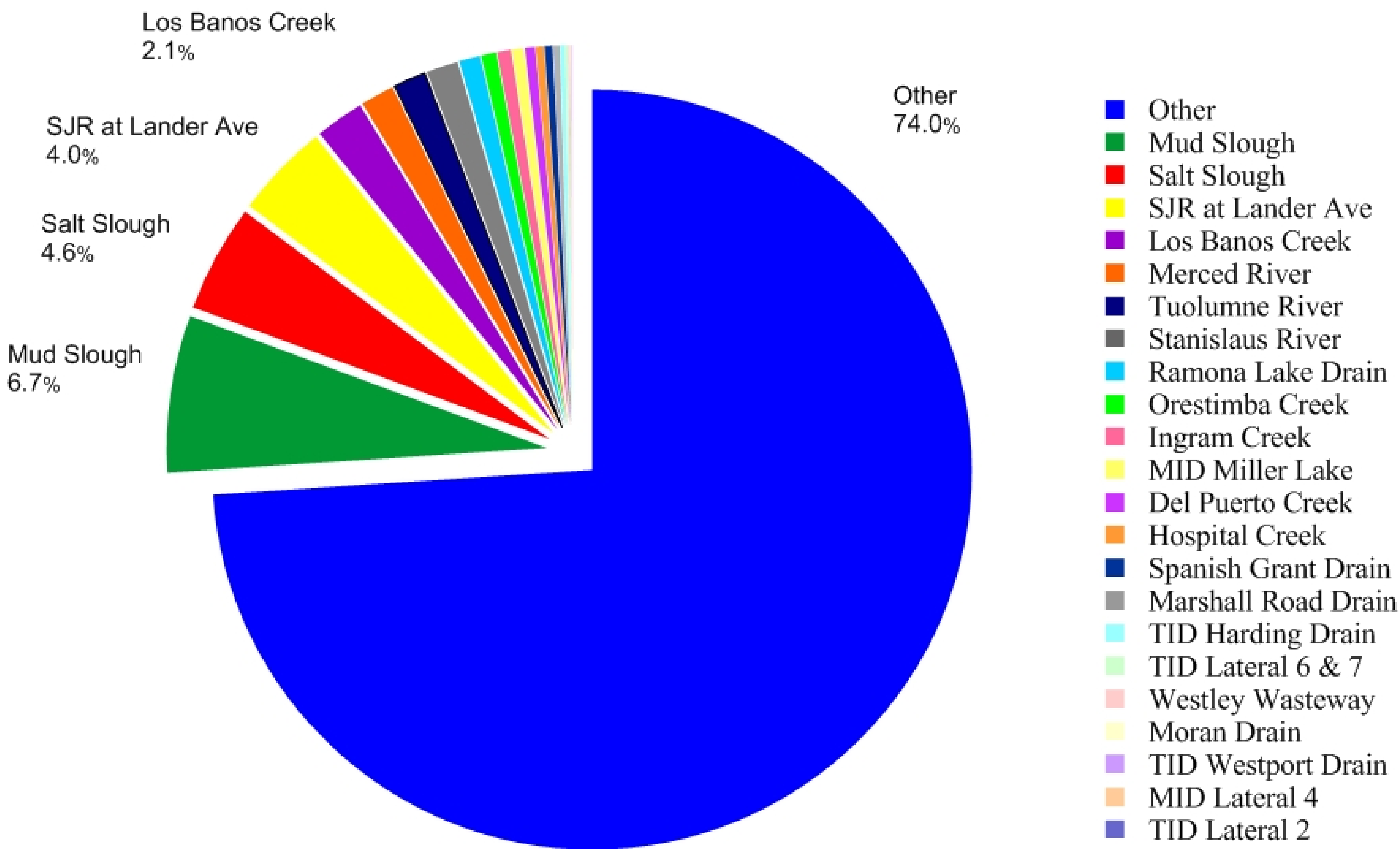

Figure 32. Annual Chlorophyll. Quadrant plot of discharged volume versus chlorophyll-a load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

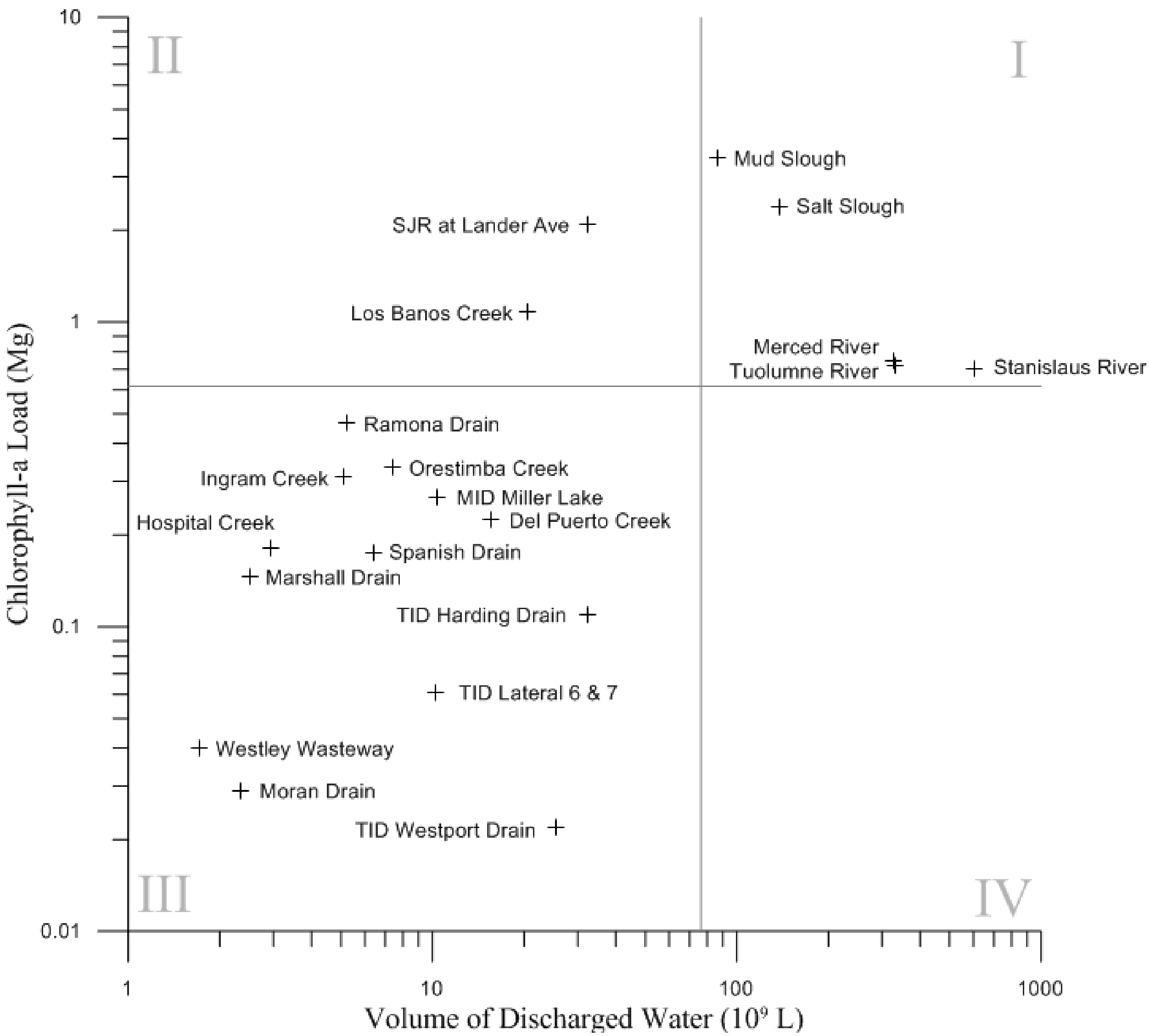

Figure 33. Irrigation Season Chlorophyll. The larger pie chart represents the proportional origins of chlorophyll-a from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The chlorophyll-a load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to in-stream algal biomass growth.

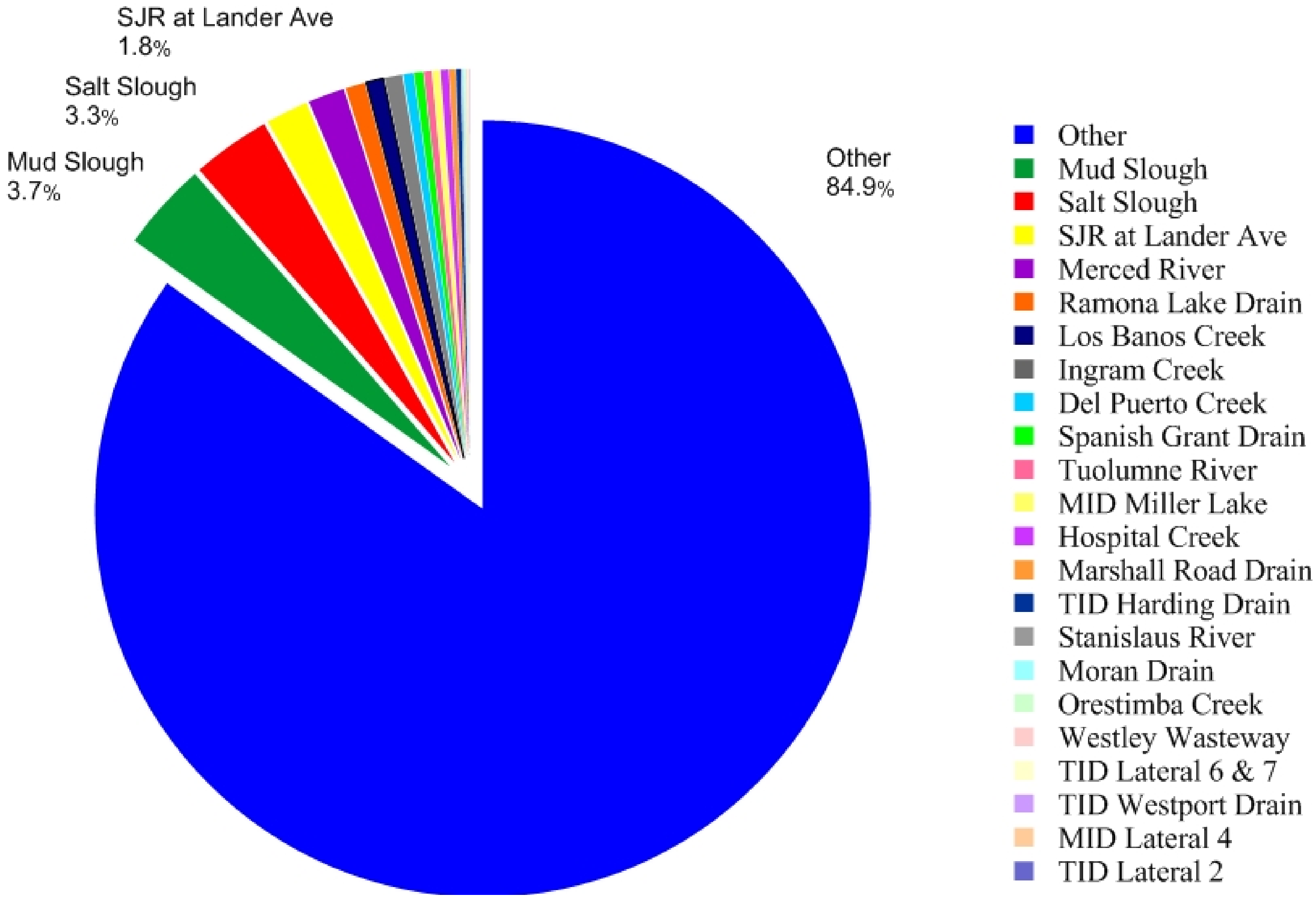

Figure 34. Irrigation Season Chlorophyll. Quadrant plot of discharged volume versus chlorophyll-a load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

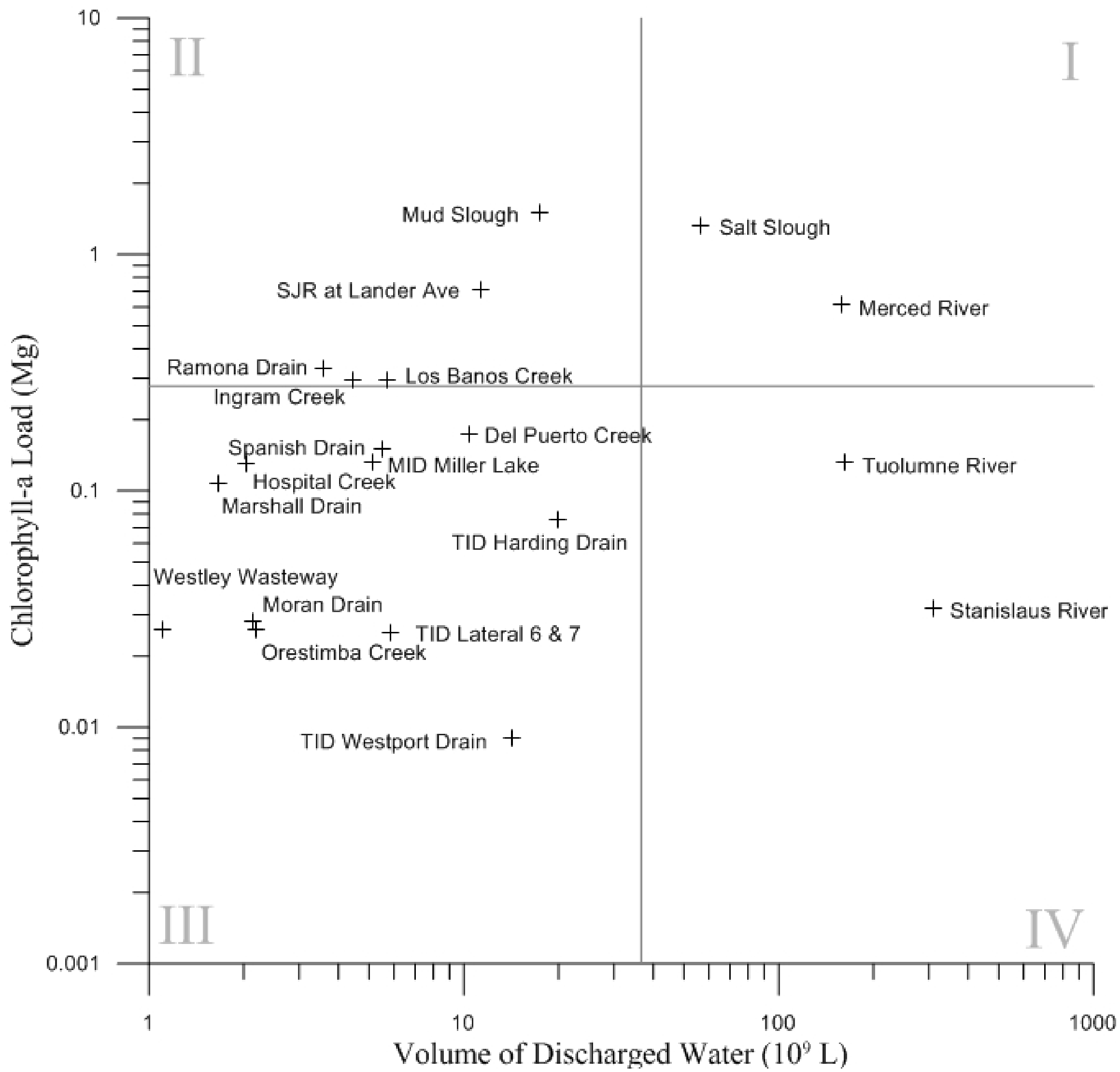

Figure 35. Annual Total Nitrogen. The larger pie chart represents the proportional origins of total nitrogen from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. The total nitrogen load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to groundwater loads.

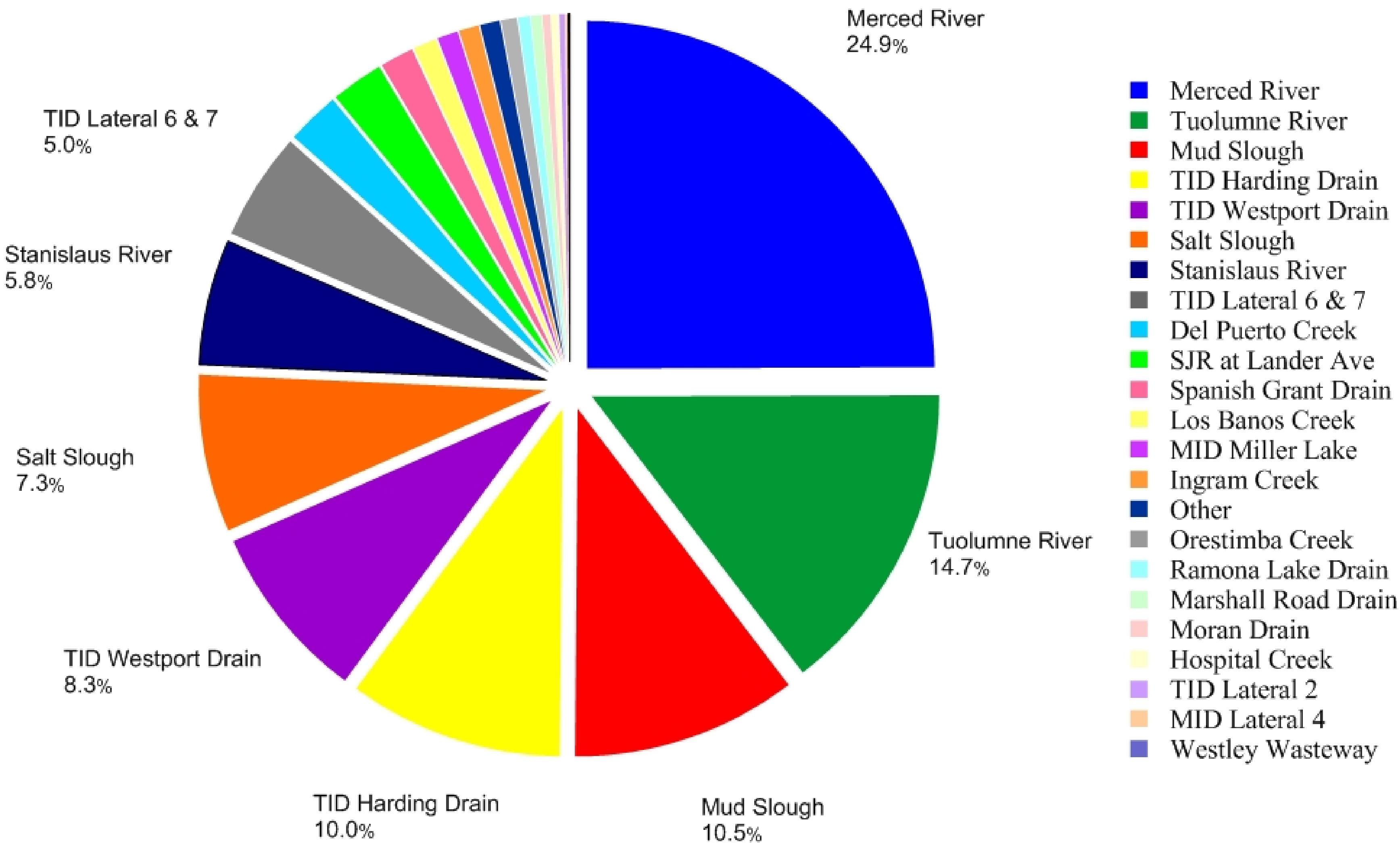

Figure 36. Annual Total Nitrogen. Quadrant plot of discharged volume versus total nitrogen load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

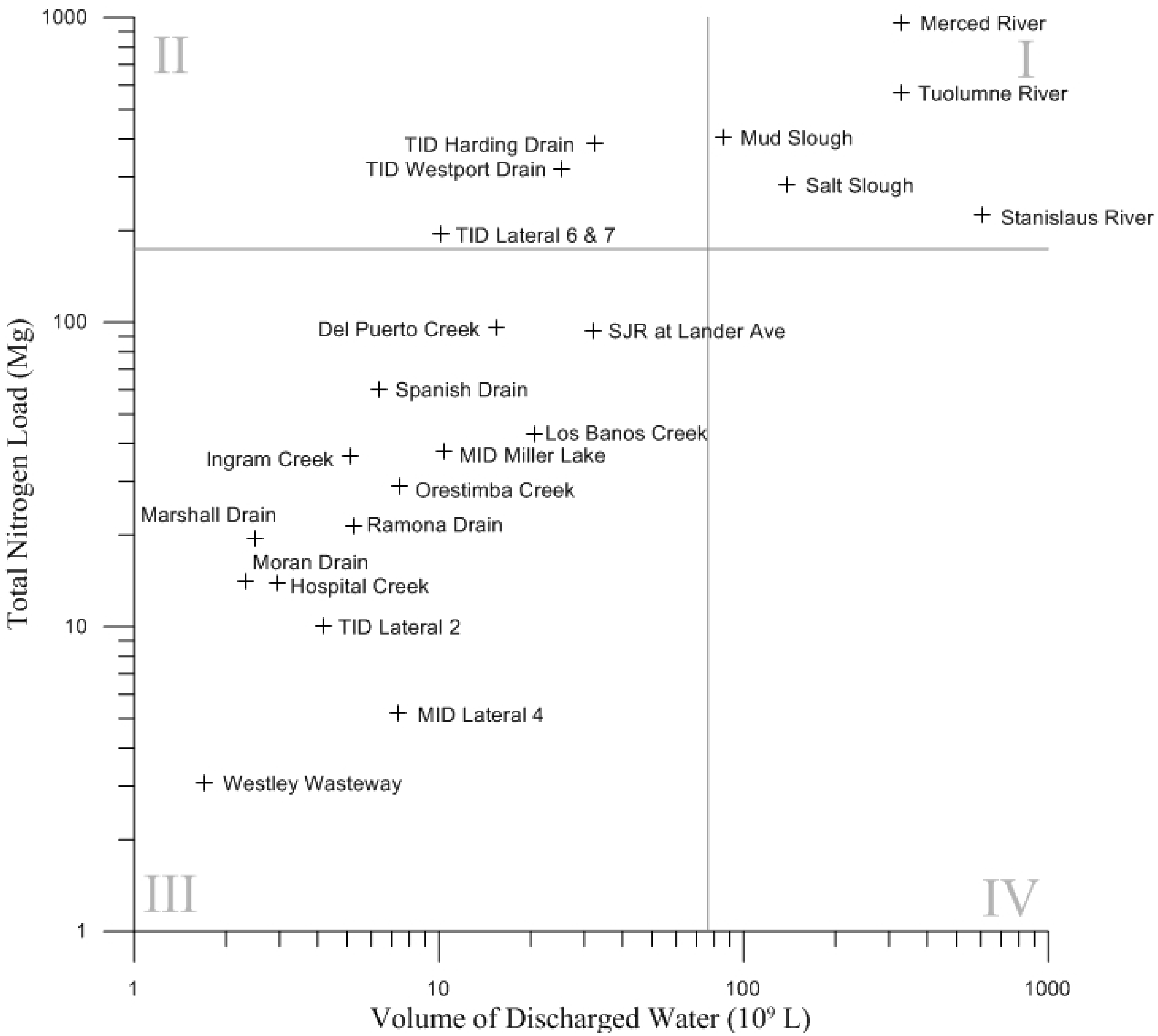

Figure 37. Irrigation Season Total Nitrogen. The larger pie chart represents the proportional origins of total nitrogen from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The smaller pie chart represents the amount of load which was over accounted for by surface water inputs compared to observations at the San Joaquin River at Vernalis flow station.

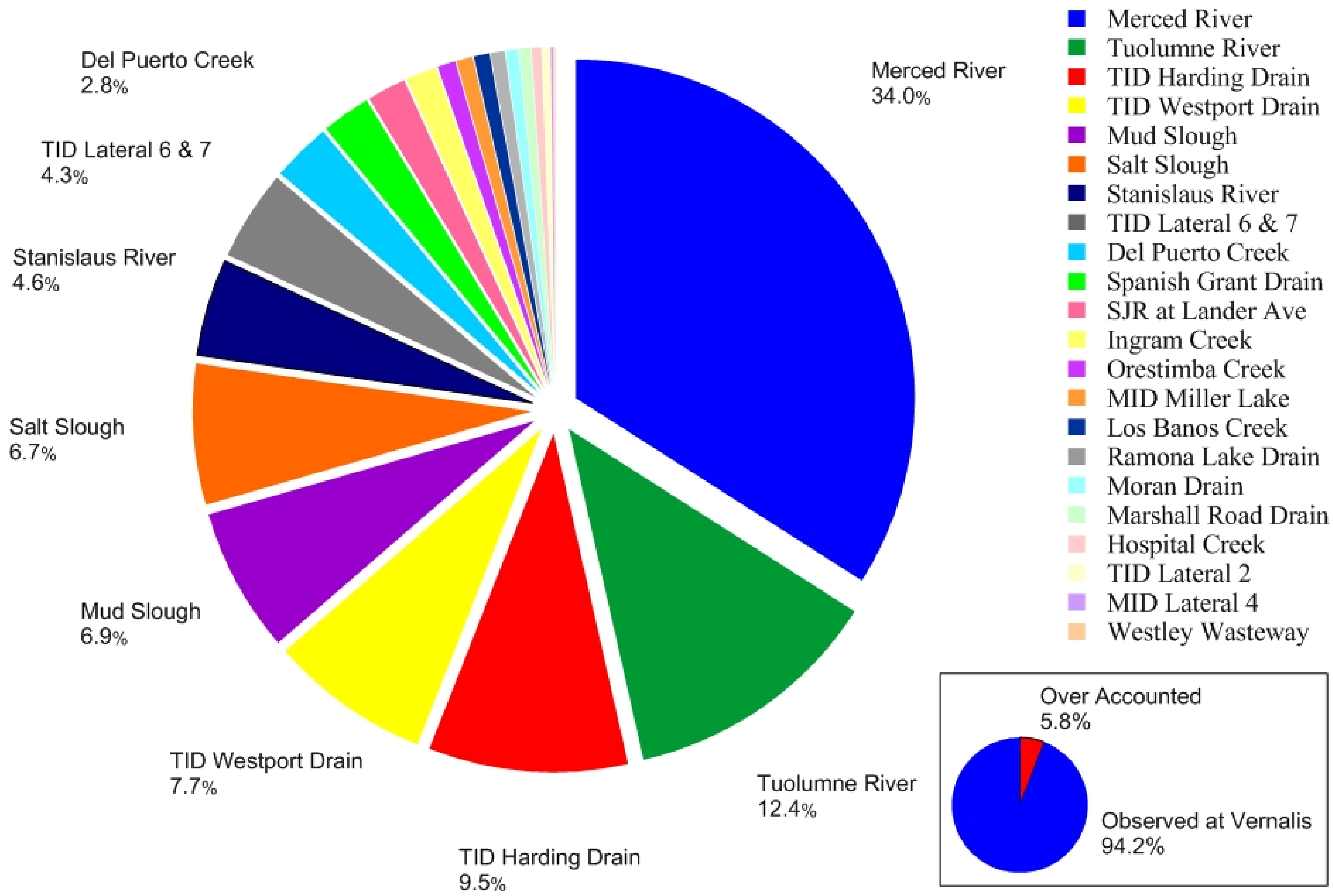

Figure 38. Irrigation Season Total Nitrogen. Quadrant plot of discharged volume versus total nitrogen load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

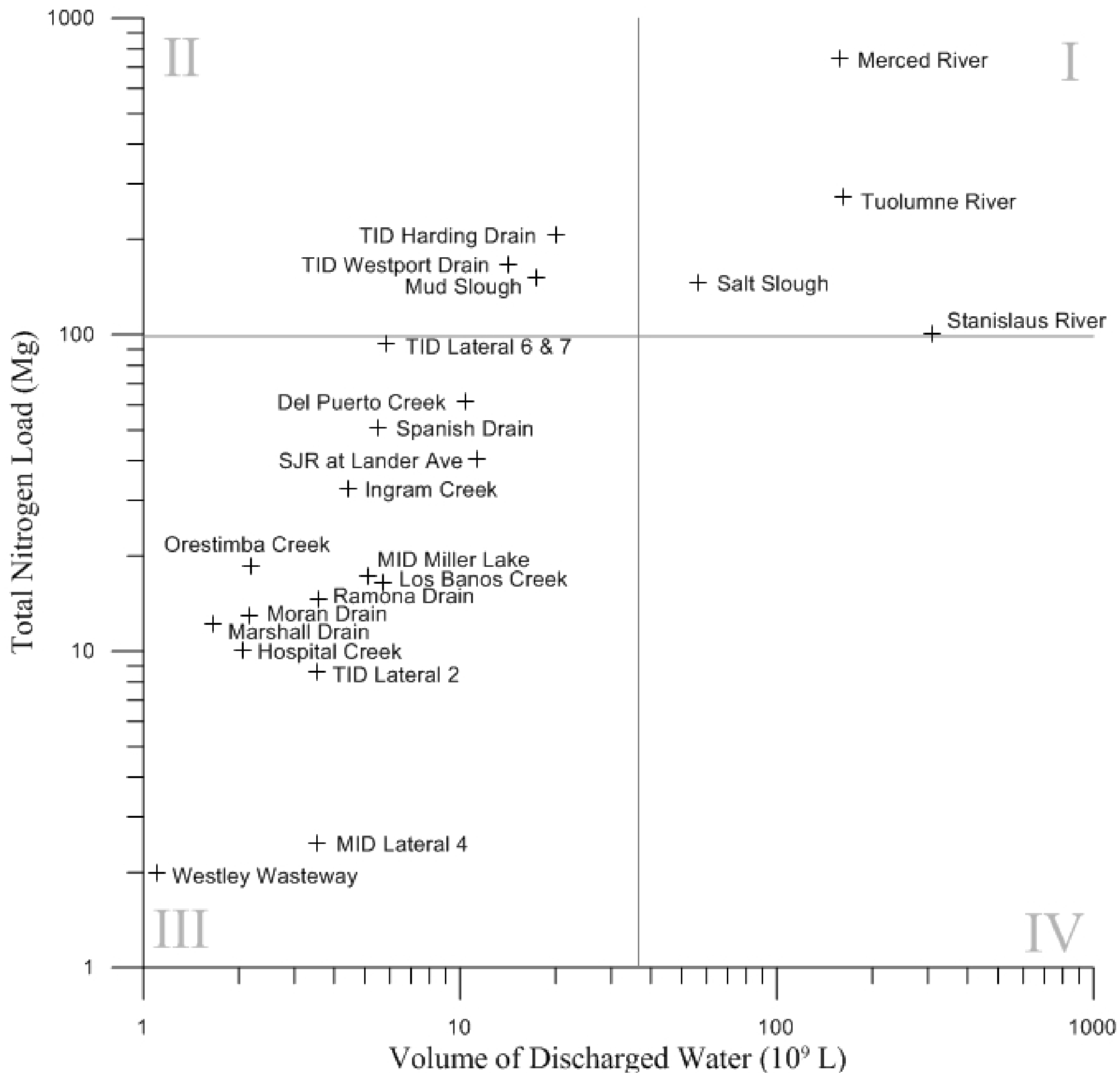

Figure 39. Annual Nitrate. The larger pie chart represents the proportional origins of nitrate-nitrite-nitrogen from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. The smaller pie chart represents the amount of load which was over estimated by surface water inputs compared to observations at the San Joaquin River at Vernalis flow station. The over accounted load was likely due to nitrate transformation to organic nitrogen by algal biomass growth in the SJR in addition to groundwater inputs.

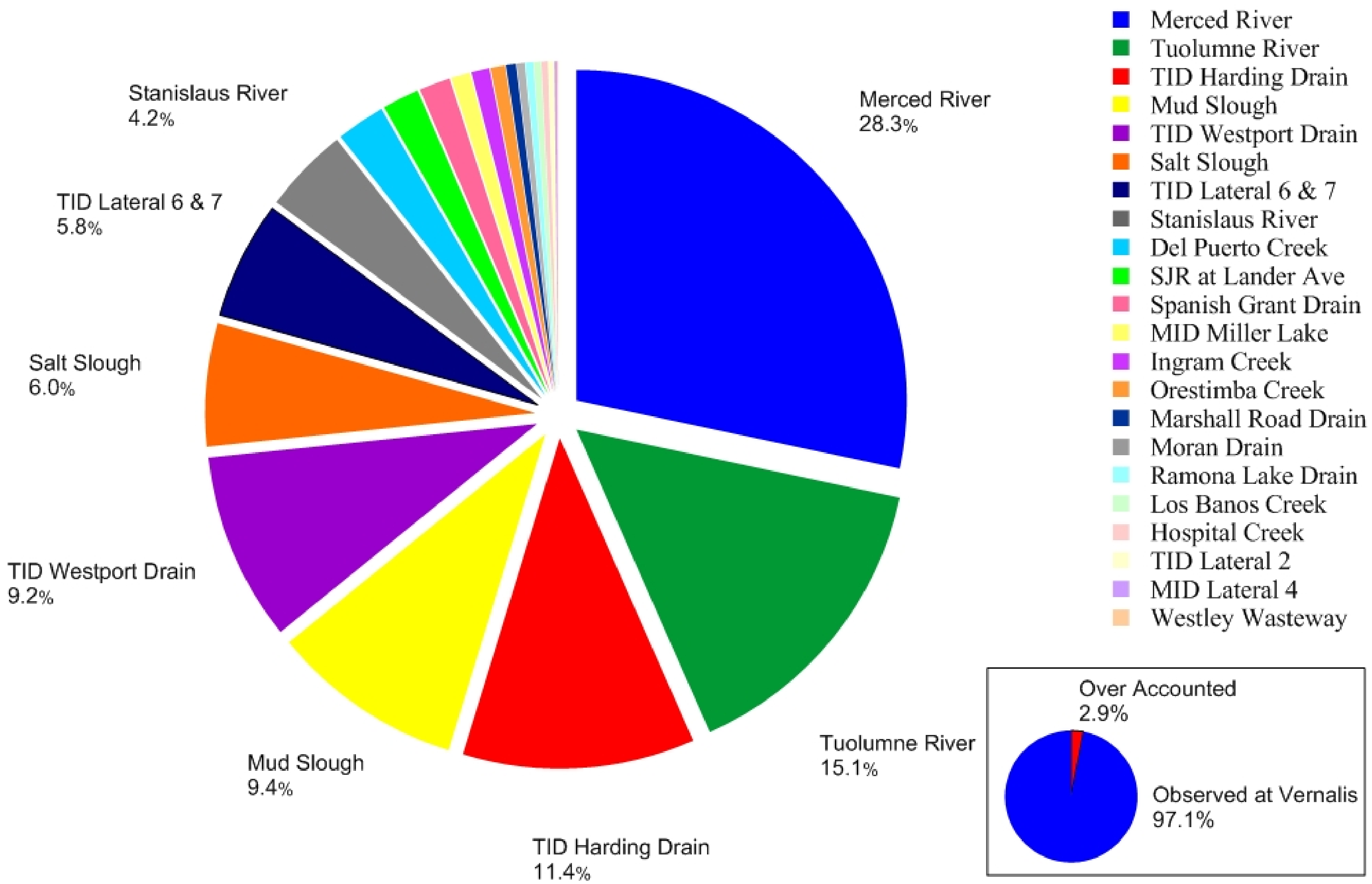

Figure 40. Annual Nitrate. Quadrant plot of discharged volume versus nitrate-nitrite-nitrogen load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

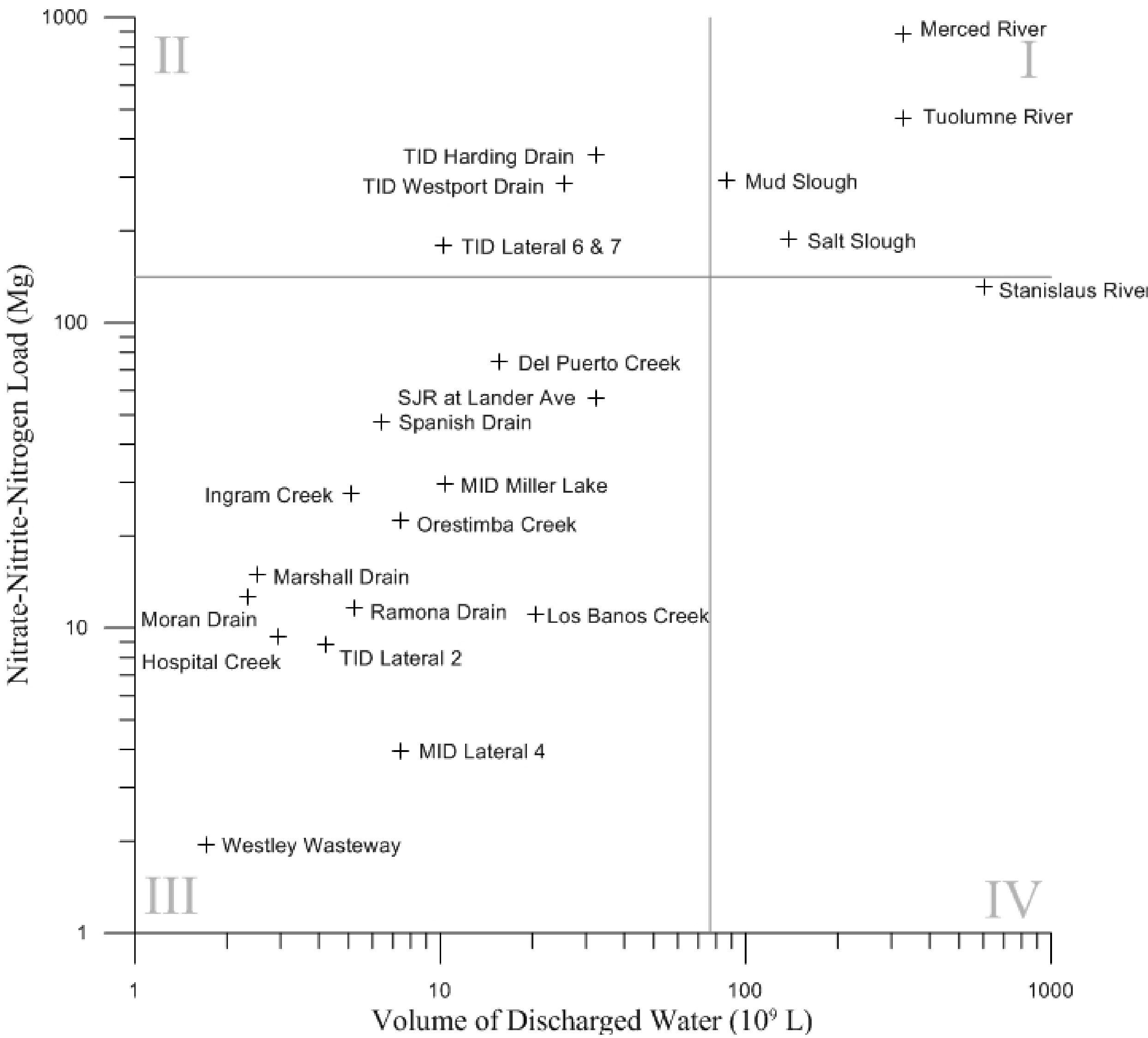

Figure 41. Irrigation Season Nitrate. The larger pie chart represents the proportional origins of nitrate-nitrite-nitrogen from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The smaller pie chart represents the amount of load which was over estimated by surface water inputs compared to observations at the San Joaquin River at Vernalis flow station. The over accounted load was likely due to nitrate transformation to organic nitrogen by algal biomass growth in the SJR in addition to groundwater inputs.

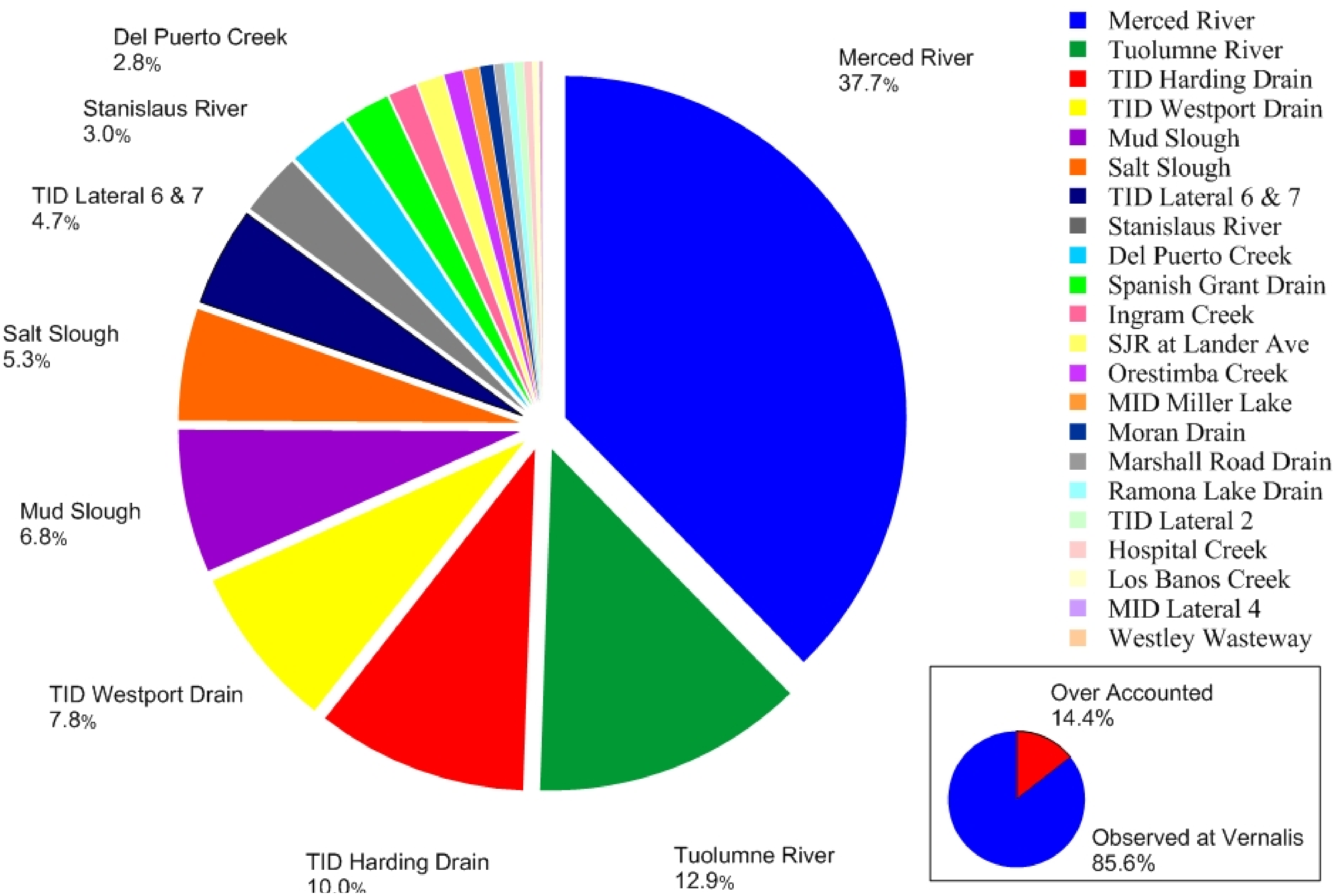

Figure 42. Irrigation Season Nitrate. Quadrant plot of discharged volume versus nitrate-nitrite-nitrogen load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

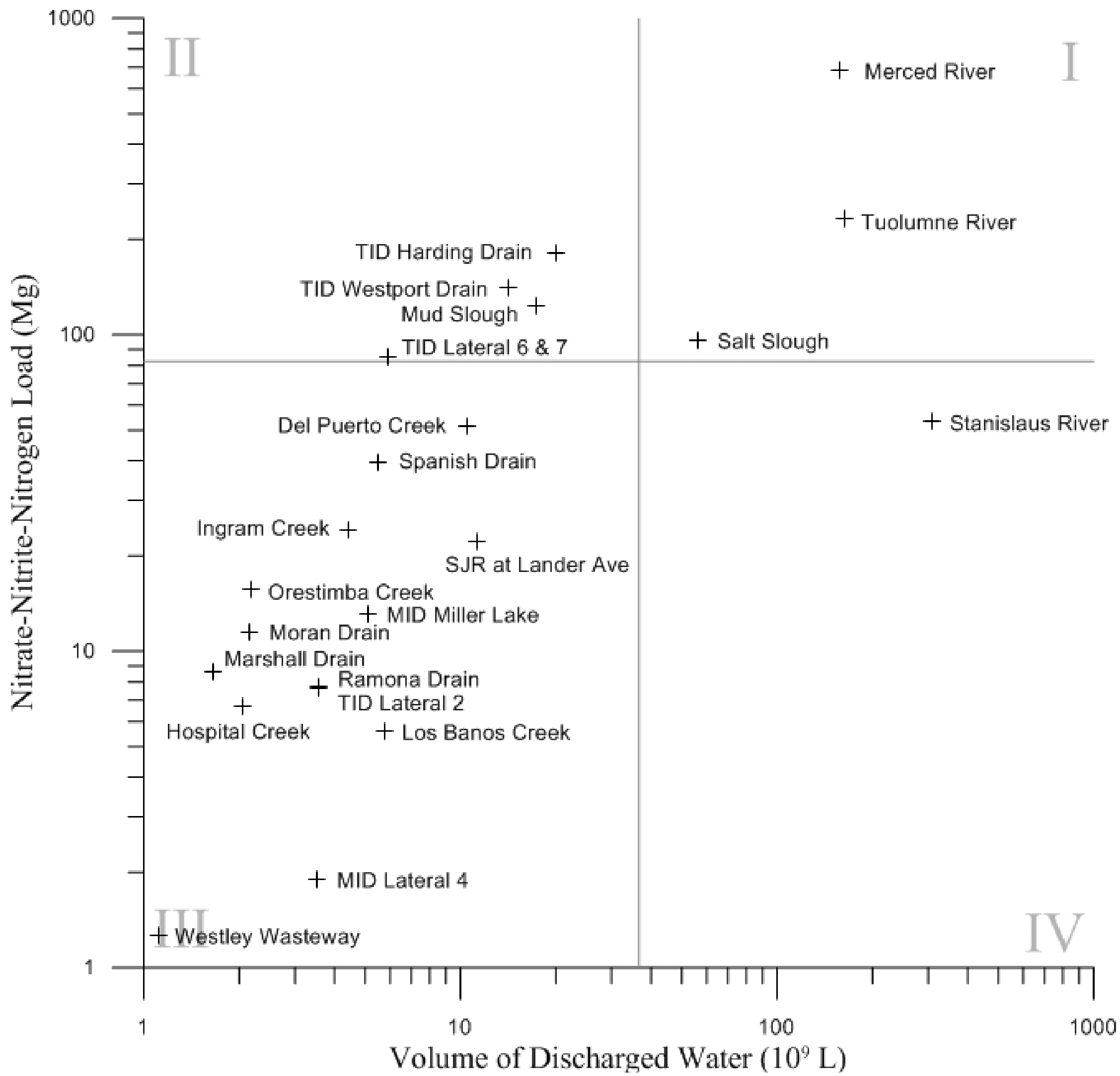

Figure 43. Annual Ammonia. The larger pie chart represents the proportional origins of total ammonia nitrogen from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. The smaller pie chart represents the amount of load which was over estimated by surface water inputs compared to observations at the San Joaquin River at Vernalis flow station. The over accounted load was likely due to ammonia transformation to organic nitrogen by algal biomass growth in the SJR in addition to groundwater inputs.

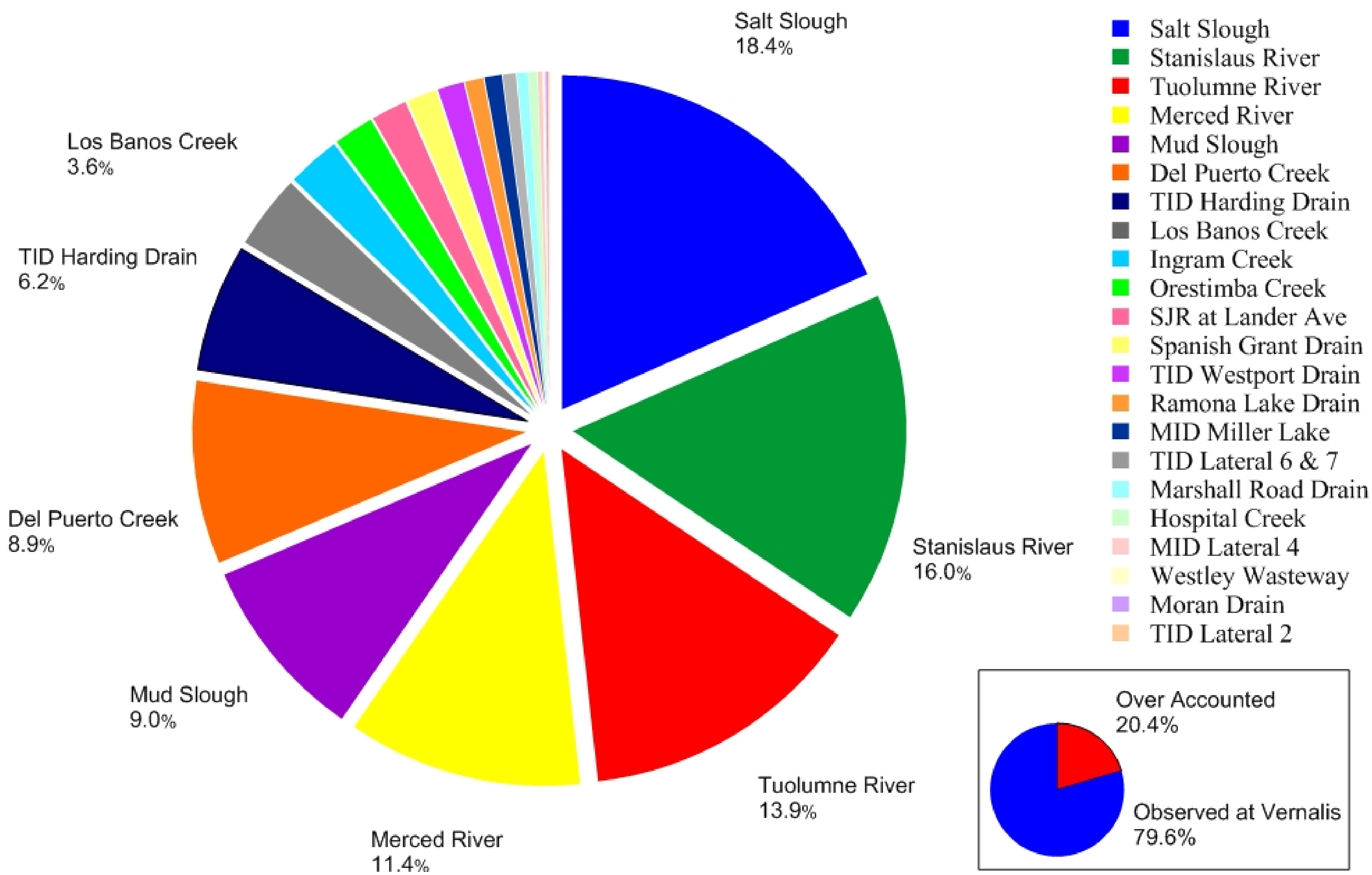

Figure 44. Annual Ammonia. Quadrant plot of discharged volume versus total ammonia nitrogen load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

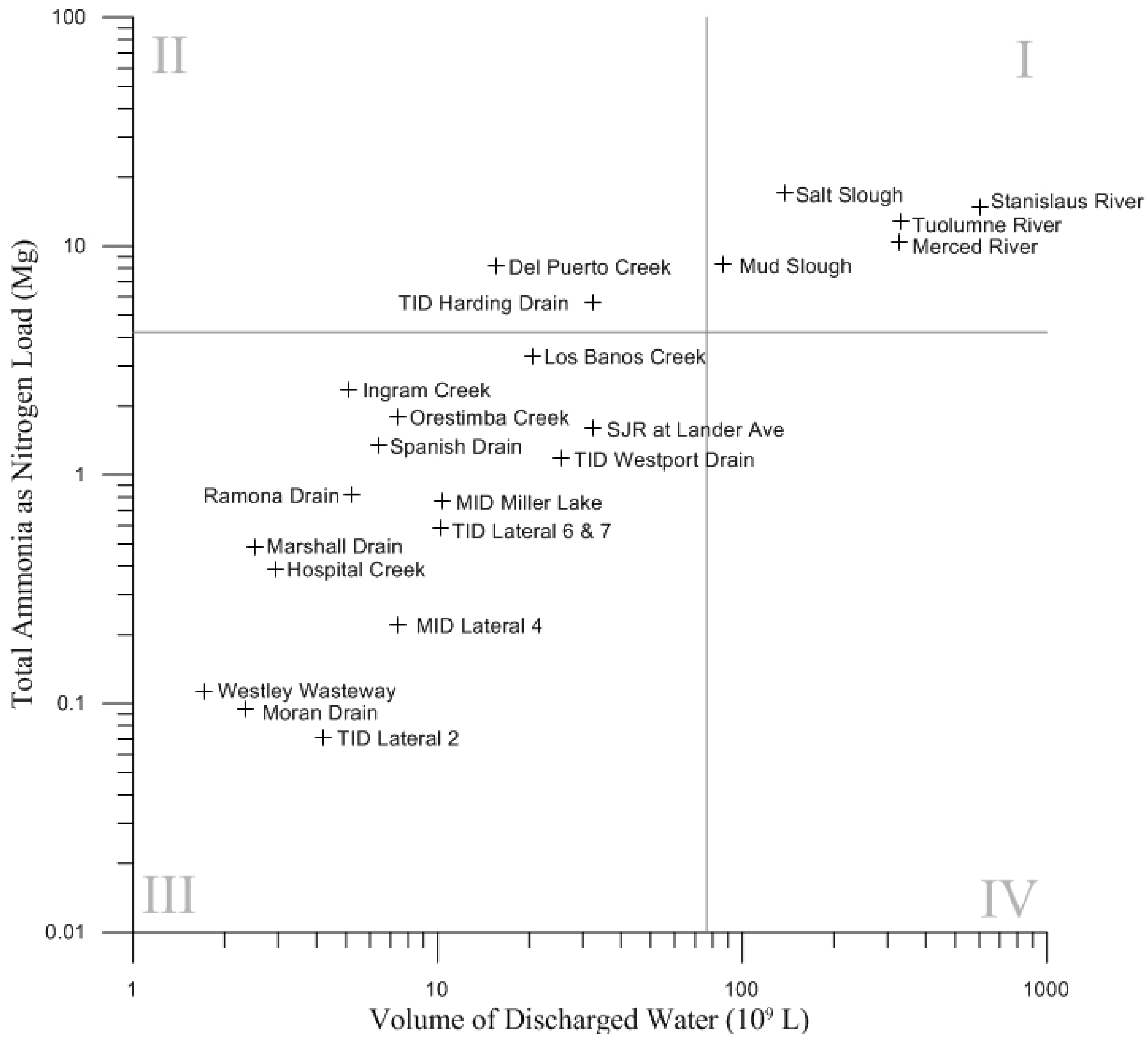

Figure 45. Irrigation Season Ammonia. The larger pie chart represents the proportional origins of total ammonia nitrogen from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The smaller pie chart represents the amount of load which was over estimated by surface water inputs compared to observations at the San Joaquin River at Vernalis flow station. The over accounted load was likely due to ammonia transformation to organic nitrogen by algal biomass growth in the SJR in addition to groundwater inputs.

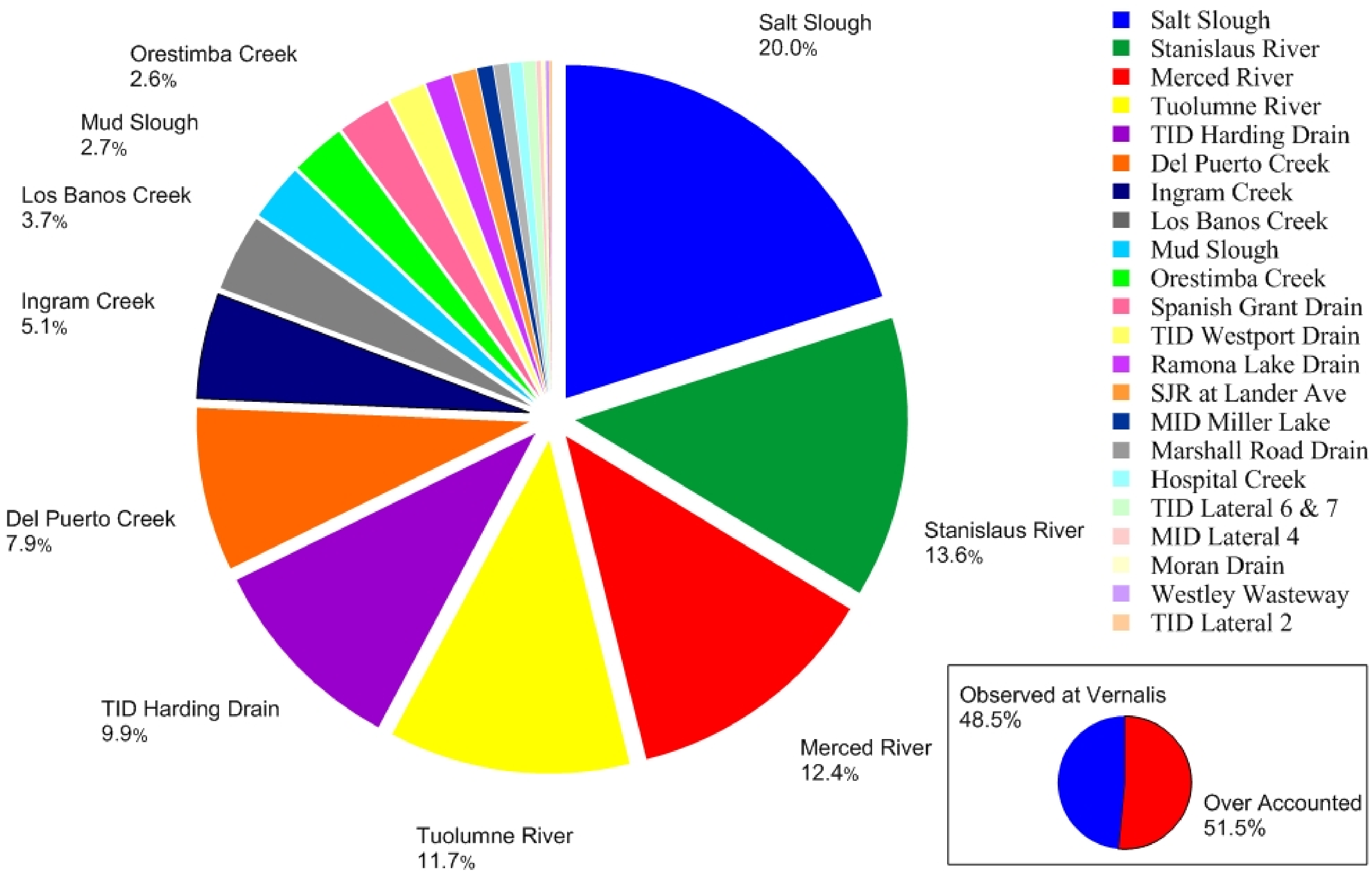

Figure 46. Irrigation Season Ammonia. Quadrant plot of discharged volume versus total ammonia as nitrogen load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

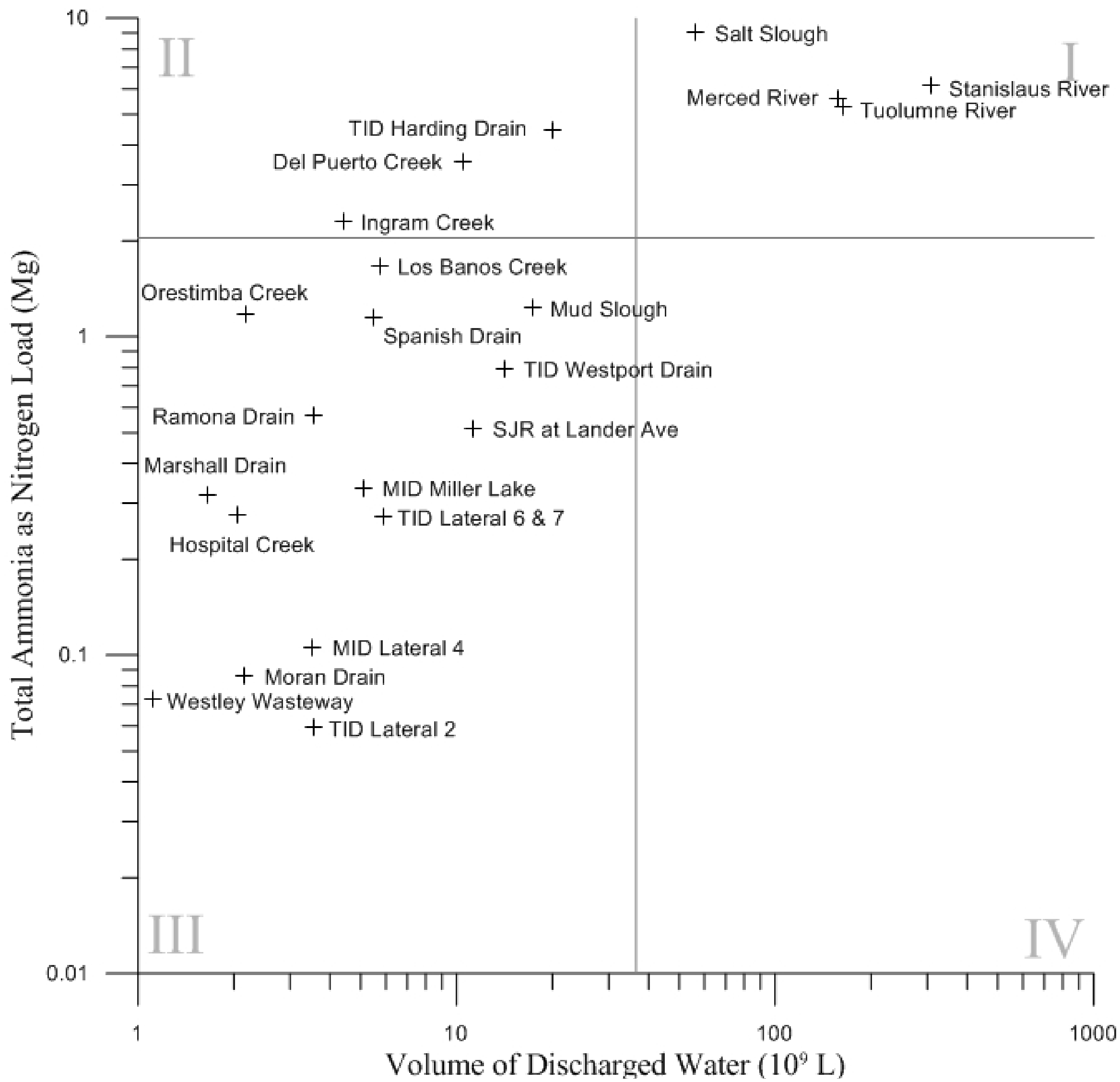

Figure 47. Annual Organic Nitrogen. The larger pie chart represents the proportional origins of organic nitrogen from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. The organic nitrogen load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to inorganic nitrogen transformation to organic nitrogen by algal biomass growth in the SJR.

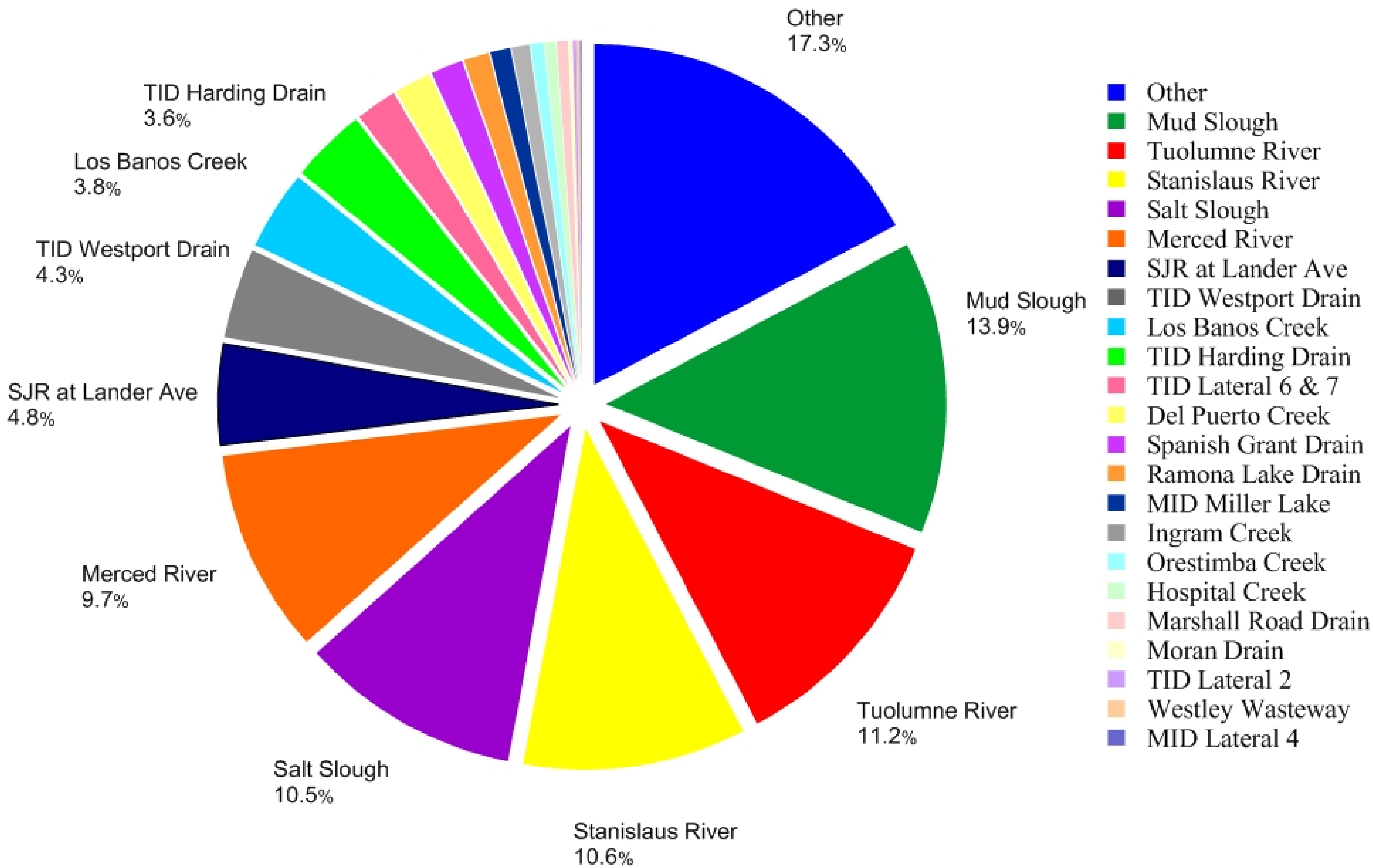

Figure 48. Annual Organic Nitrogen. Quadrant plot of discharged volume versus organic nitrogen load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

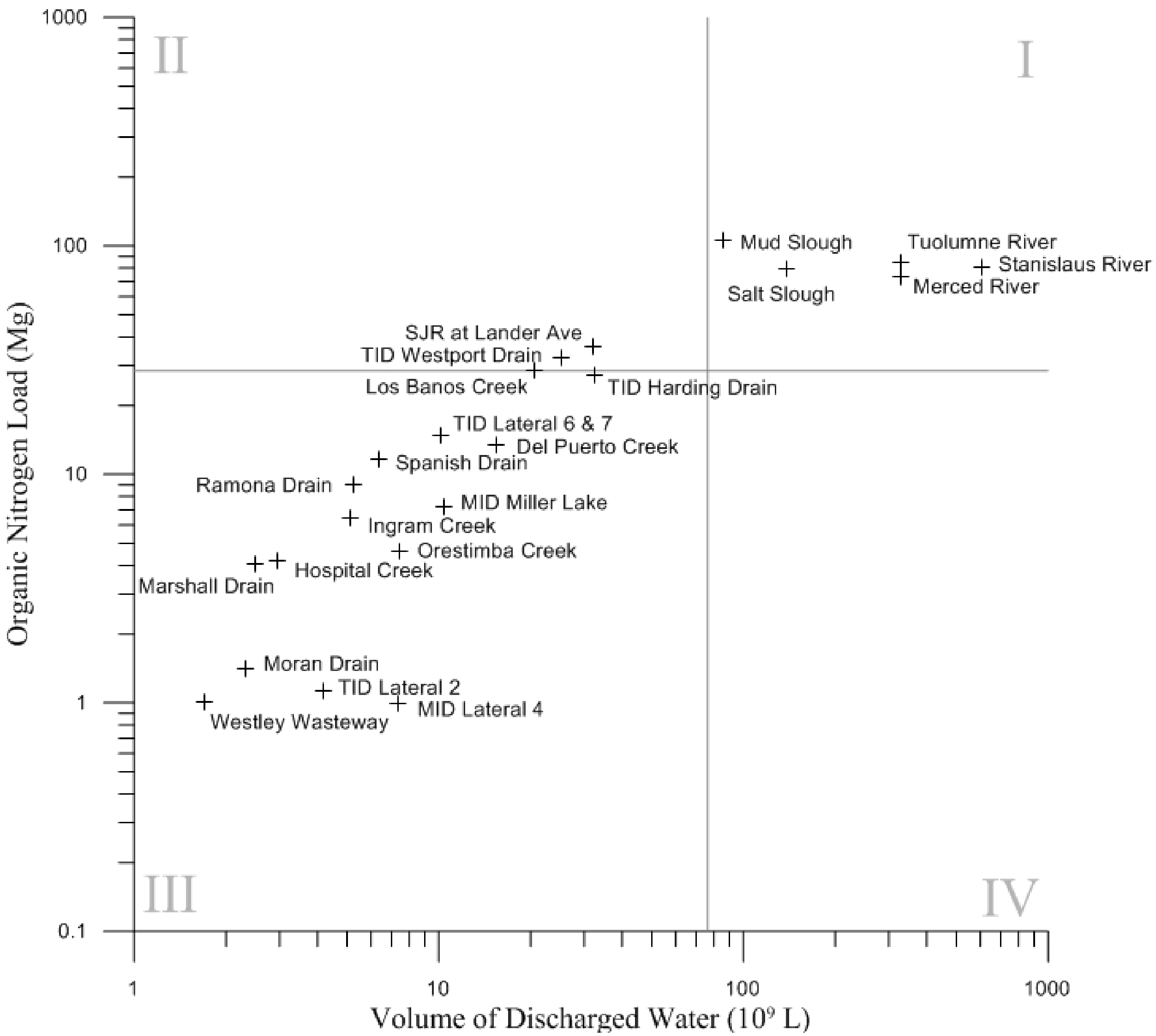

Figure 49. Irrigation Season Organic Nitrogen. The larger pie chart represents the proportional origins of organic nitrogen from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The organic nitrogen load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to inorganic nitrogen transformation to organic nitrogen by algal biomass growth in the SJR.

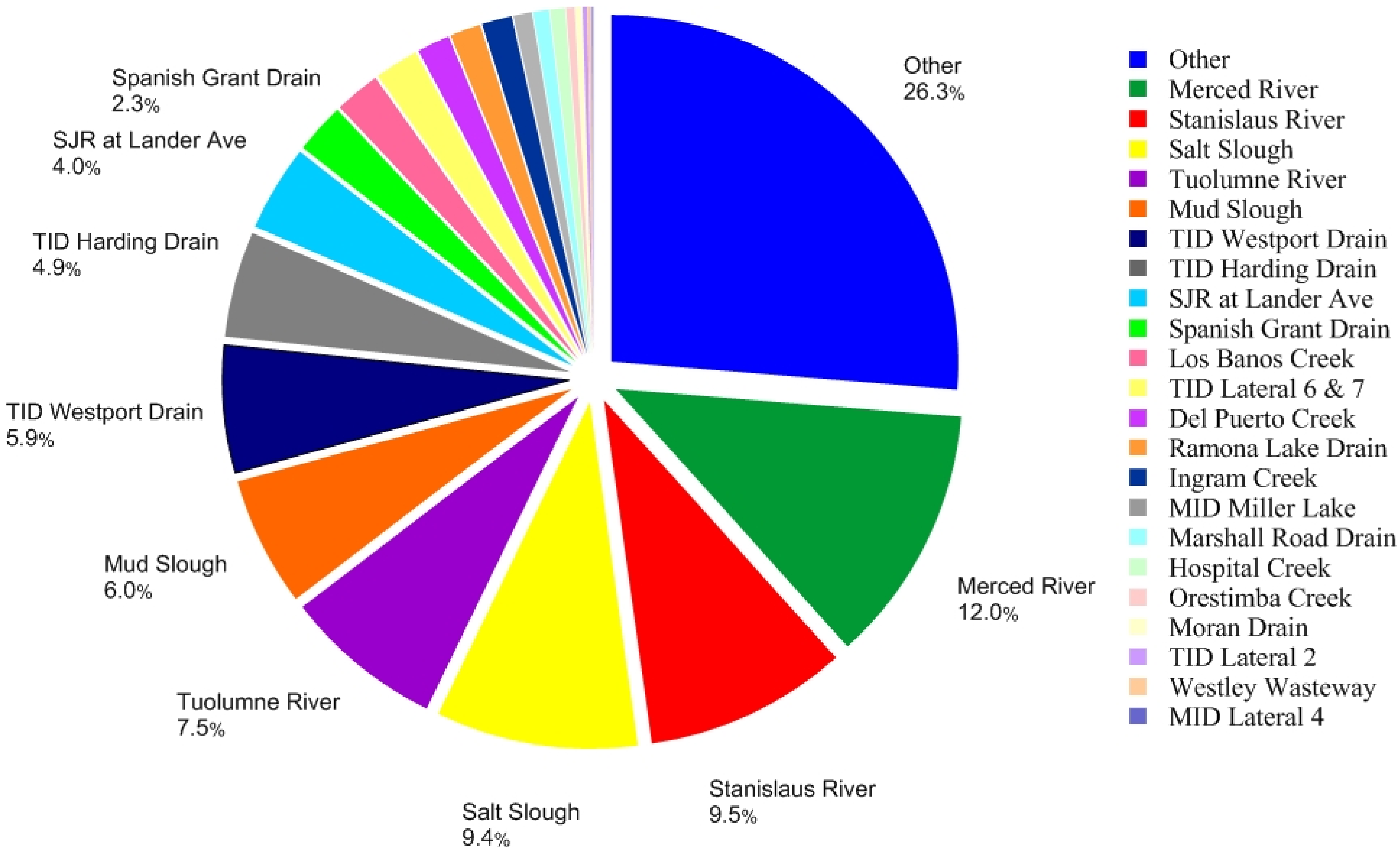

Figure 50. Irrigation Season Organic Nitrogen. Quadrant plot of discharged volume versus organic nitrogen load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

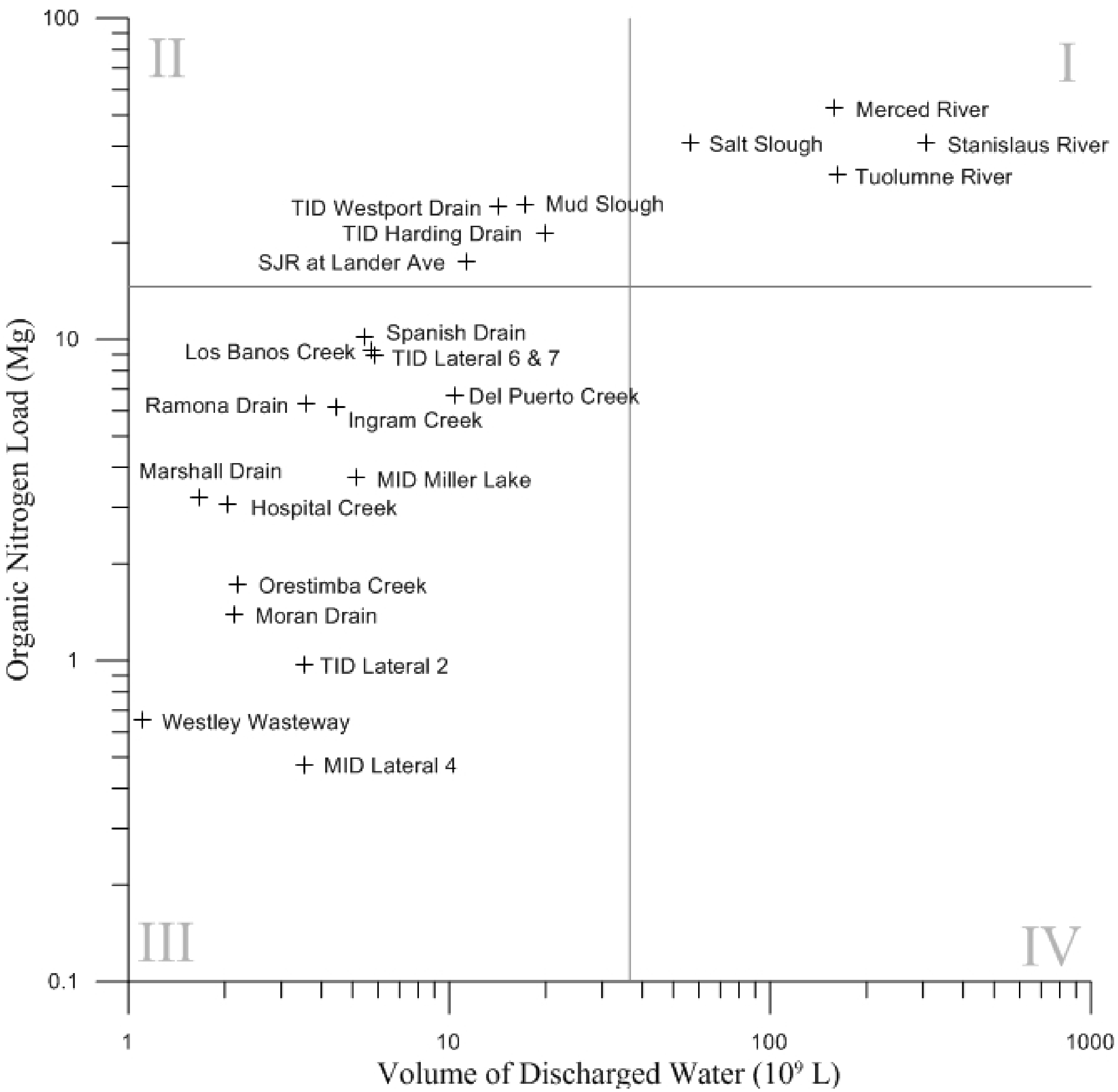

Figure 51. Annual Total Phosphorus. The following pie chart represents the proportional origins of total phosphorus from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. Total phosphorus load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to groundwater inputs.

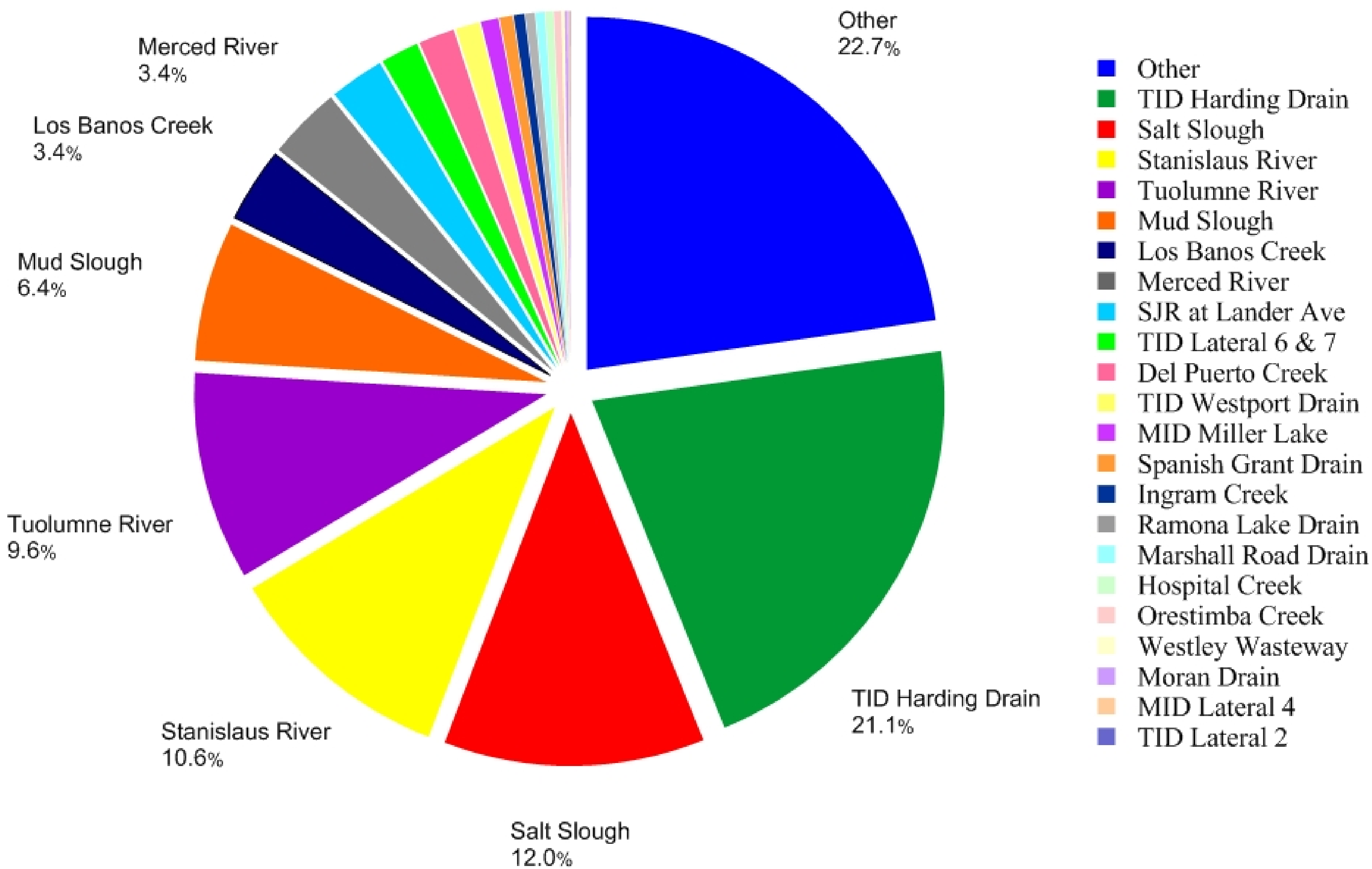

Figure 52. Annual Total Phosphorus. Quadrant plot of discharged volume versus total phosphorus load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

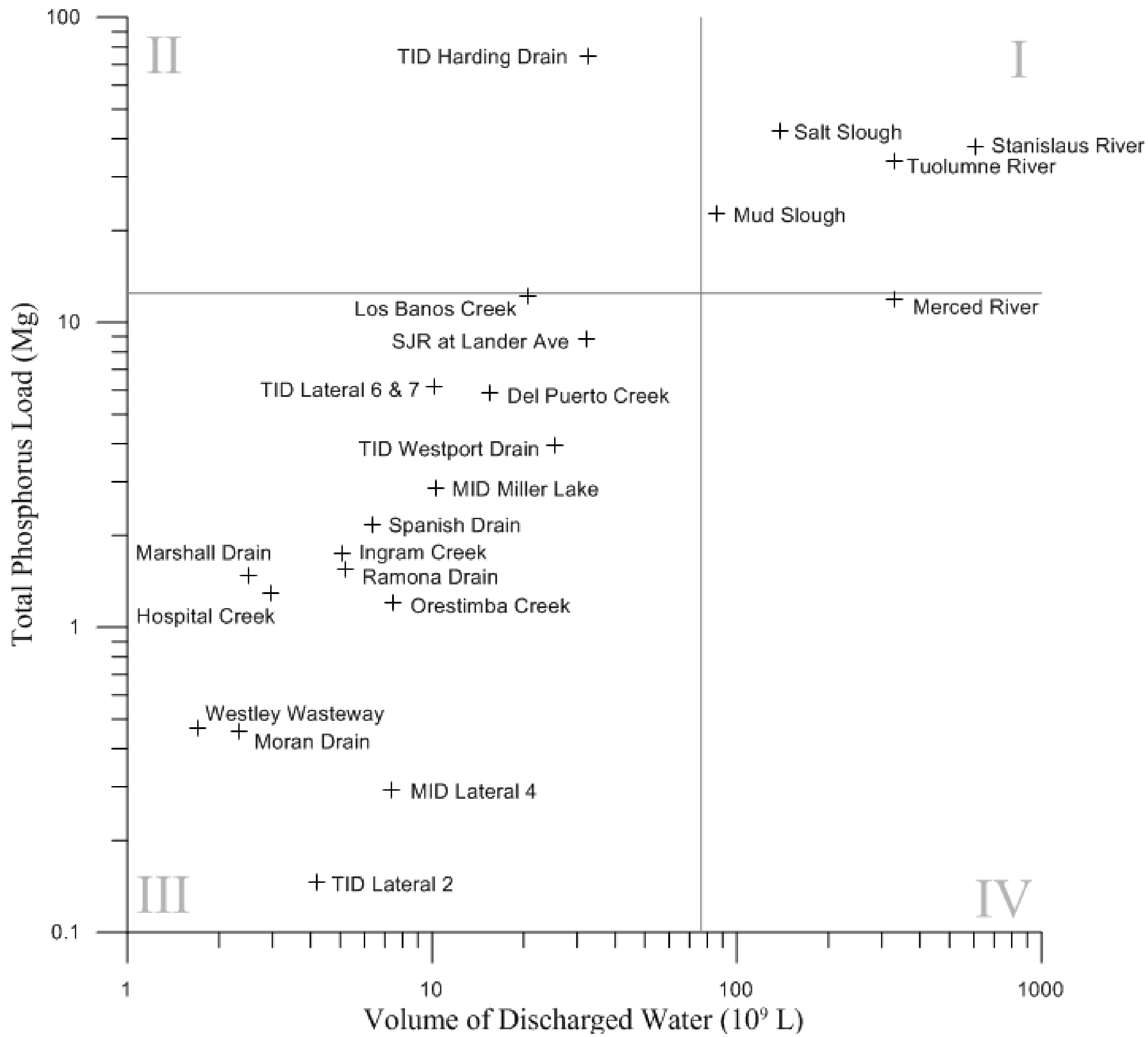

Figure 53. Irrigation Season Total Phosphorus. The larger pie chart represents the proportional origins of total phosphorus from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The total phosphorus load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to groundwater inputs.

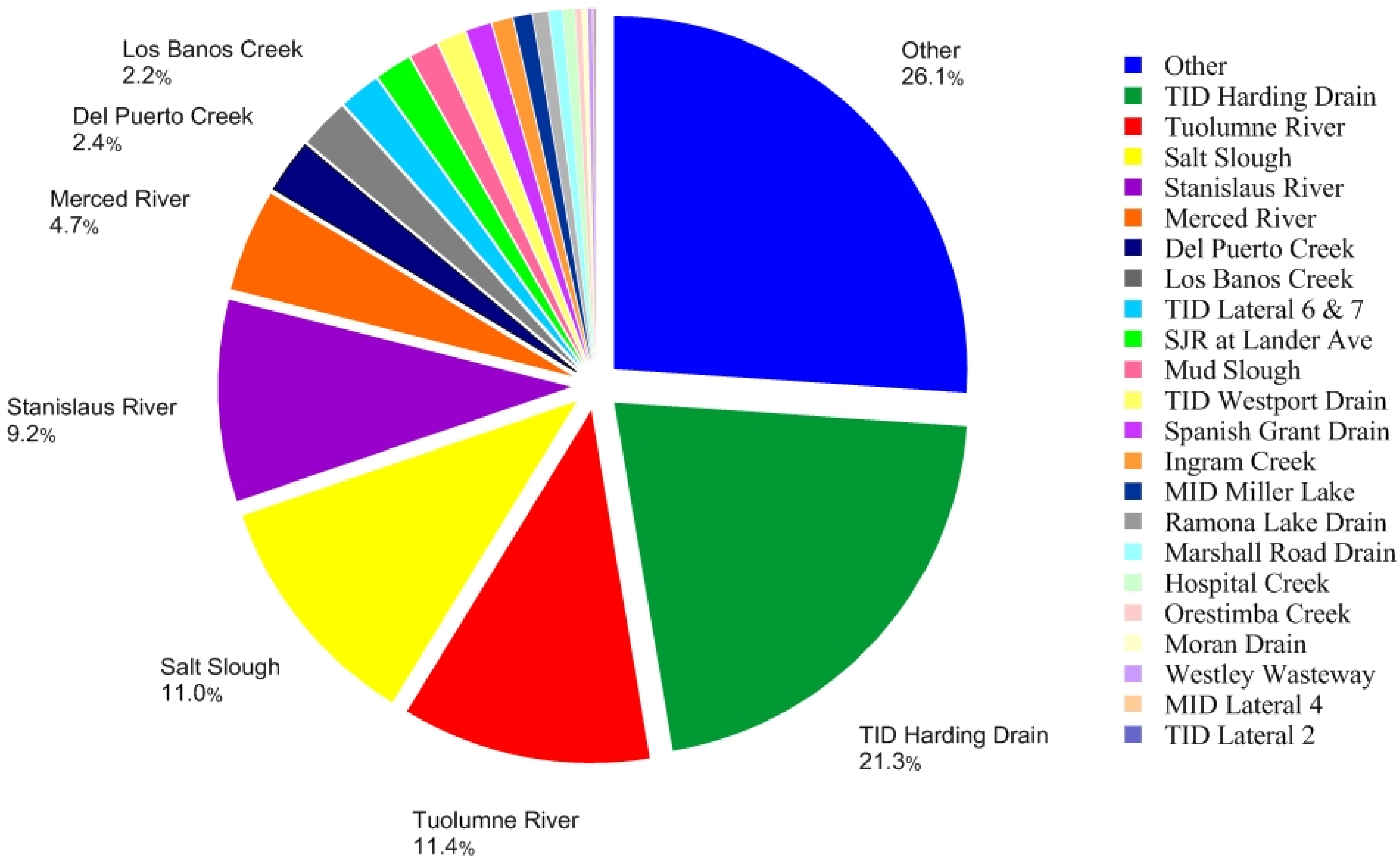

Figure 54. Irrigation Season Total Phosphorus. Quadrant plot of discharged volume versus total phosphorus load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.

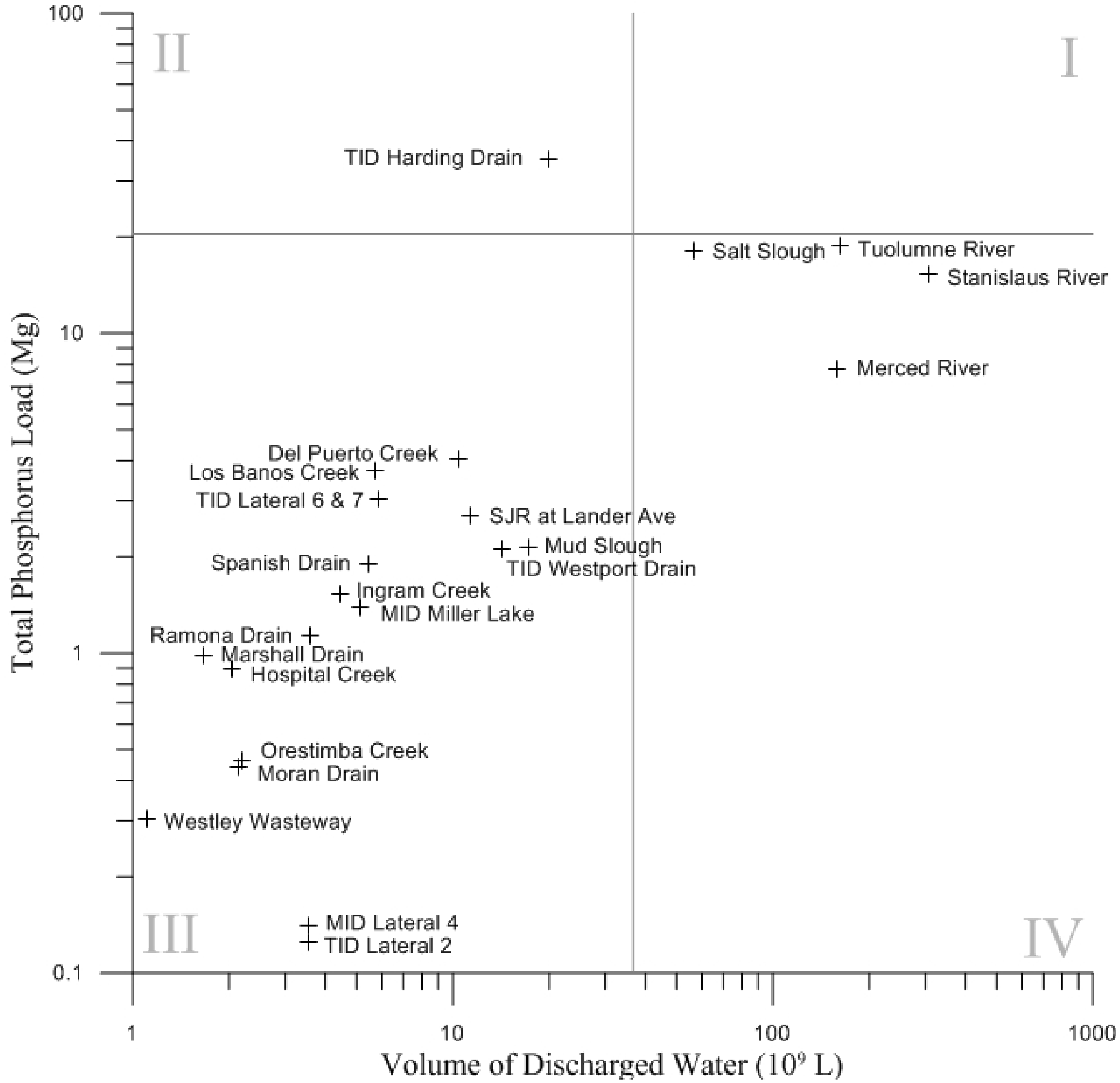

Figure 55. Annual Phosphate. The following pie chart represents the proportional origins of orthophosphate as phosphorus (phosphate) from surface water inputs in the San Joaquin River from January 1, 2007 to December 31, 2007. Phosphate load designated as "other" represents input load that was not accounted for by surface water loads and was likely due to phosphate transformation by algal biomass growth in the SJR in addition to groundwater inputs.

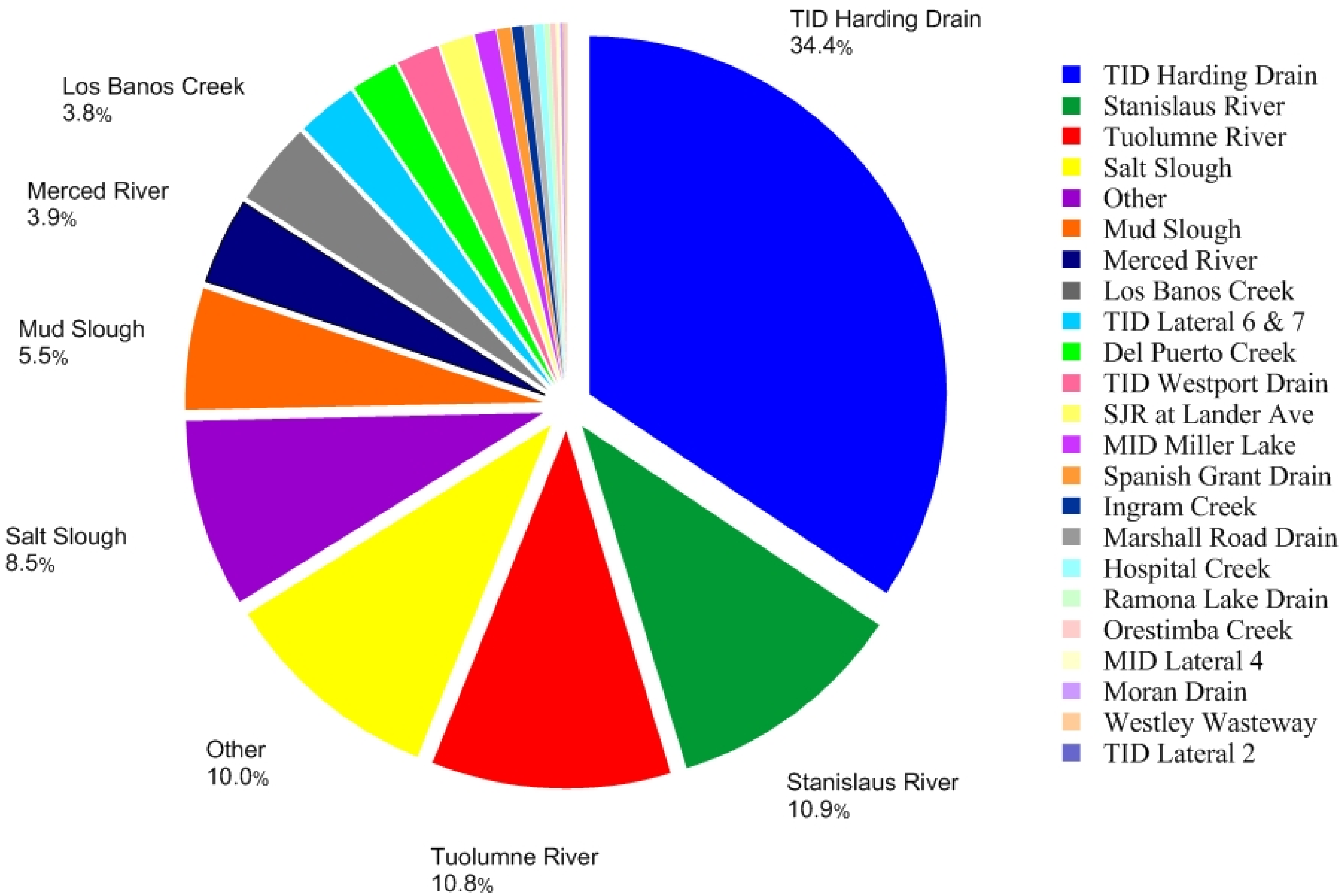

Figure 56. Annual Phosphate. Quadrant plot of discharged volume versus orthophosphate as phosphorus load for all San Joaquin River tributaries over the year 2007. Quadrants are divided by average load and average volume.

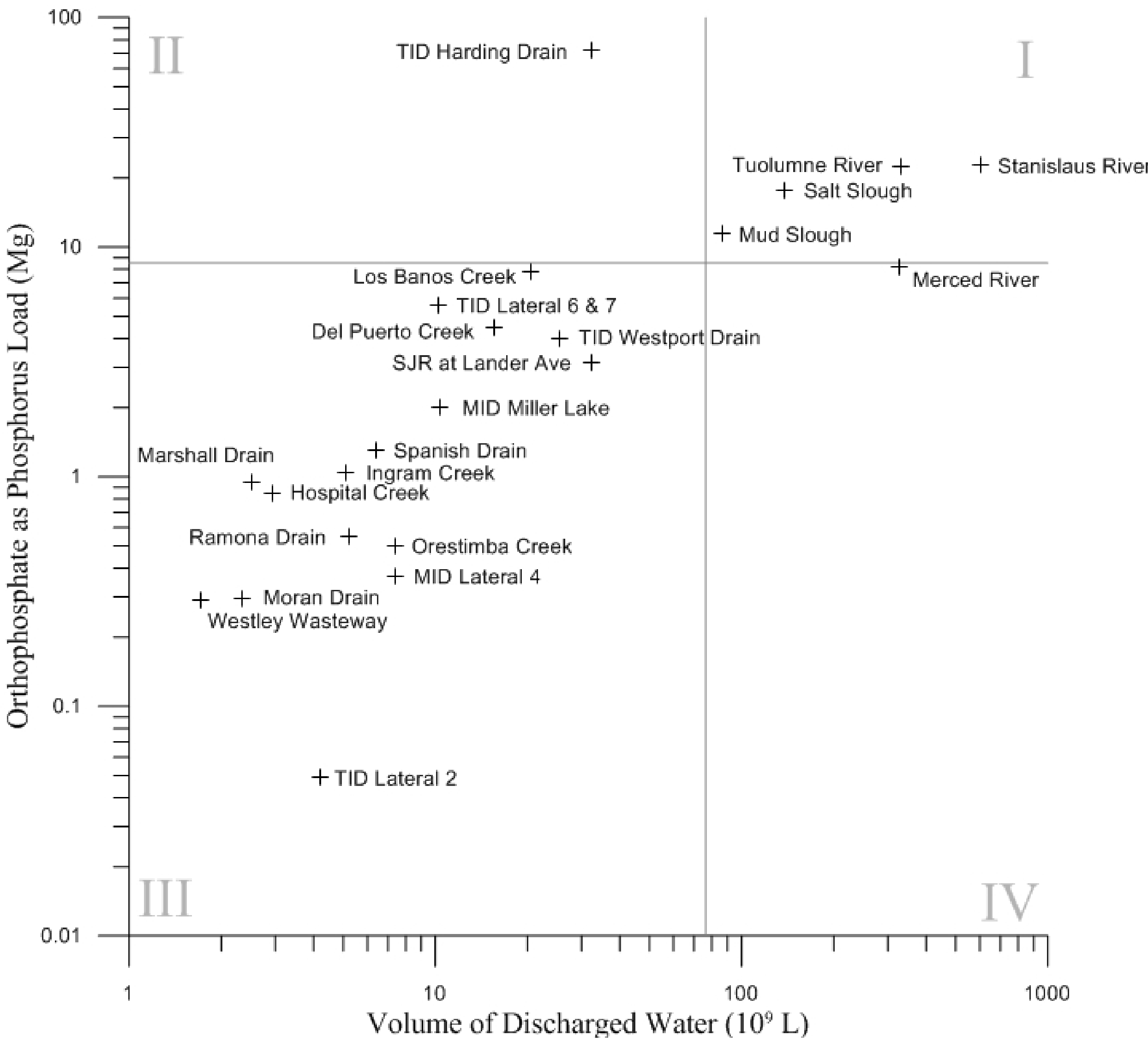

Figure 57. Irrigation Season Phosphate. The larger pie chart represents the proportional origins of orthophosphate as phosphorus (phosphate) from surface water inputs in the San Joaquin River from April 1, 2007 to September 30, 2007. The phosphate load designated as “other” represents input load that was not accounted for by surface water loads and was likely due to phosphate transformation by algal biomass growth in the SJR in addition to groundwater inputs.

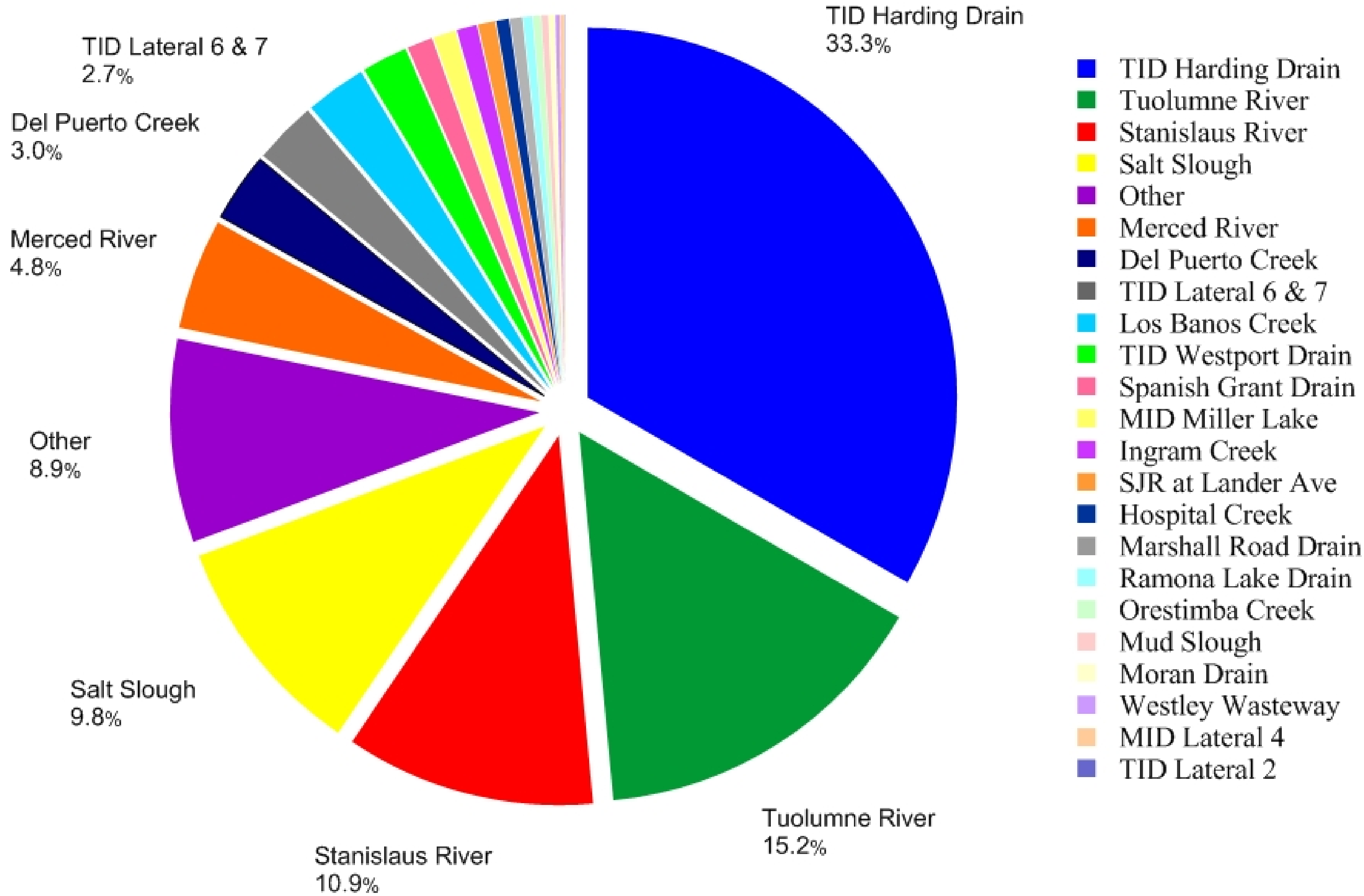

Figure 58. Irrigation Season Phosphate. Quadrant plot of discharged volume versus orthophosphate as phosphorus load for all San Joaquin River tributaries from April 1, 2007 to September 30, 2007. Quadrants are divided by average load and average volume.