

QUANTIFYING EXTERNAL NUTRIENT LOADS TO SAN FRANCISCO BAY

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Introduction

Nutrient concentrations in subembayments of San Francisco Bay (SFB) are comparable to or greater than those in other estuaries that have experienced beneficial use impairment due to nutrient overenrichment (Jassby and Cloern, 2012). Studies over the past 40 years have demonstrated that phytoplankton primary production and biomass accumulation in SFB are limited by a combination of factors that have maintained biomass at relatively low levels. However, more recent observations suggest that resistance in SFB to the harmful effects of nutrient overenrichment is weakening. To help inform nutrient management considerations, we estimated external nutrient loads to SFB, evaluated how those loads vary spatially and temporally in magnitude and speciation, and assessed the relative importance of various sources.

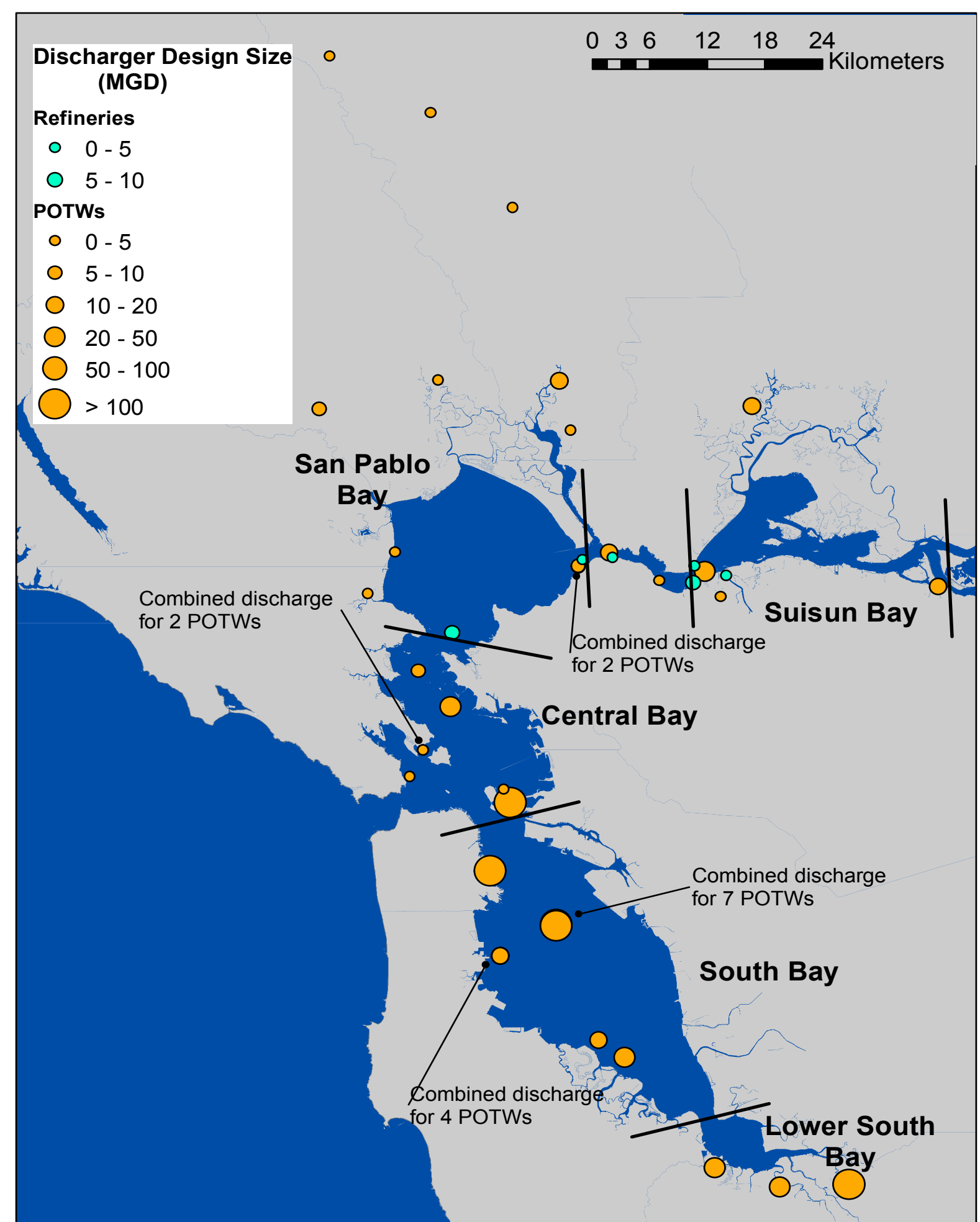
The major goals of this project were to:

1. Quantify external nutrient loads (NH₃, NO₃, DIN, PO₄) to San Francisco Bay for the period 2006-2011;
2. Explore how current loads vary spatially at the subembayment scale and seasonally;
3. Explore changes in loads over time in certain subembayments;
4. Identify major data needs and important uncertainties.

Sources Considered

Wastewater and Refinery Discharges

- We estimated annually-averaged and monthly nutrient loads from 42 publicly-owned treatment works (POTWs) and 6 refineries (referred to collectively as dischargers)
- Not all nutrients of interest were routinely monitoring prior to 2012, so data gaps from 2006-2011 were filled using 6 months of effluent nutrient concentration data from a nutrient monitoring study that begin in July 2012.
- Loads from smaller dischargers were estimated based on design size and 2012 concentration data.



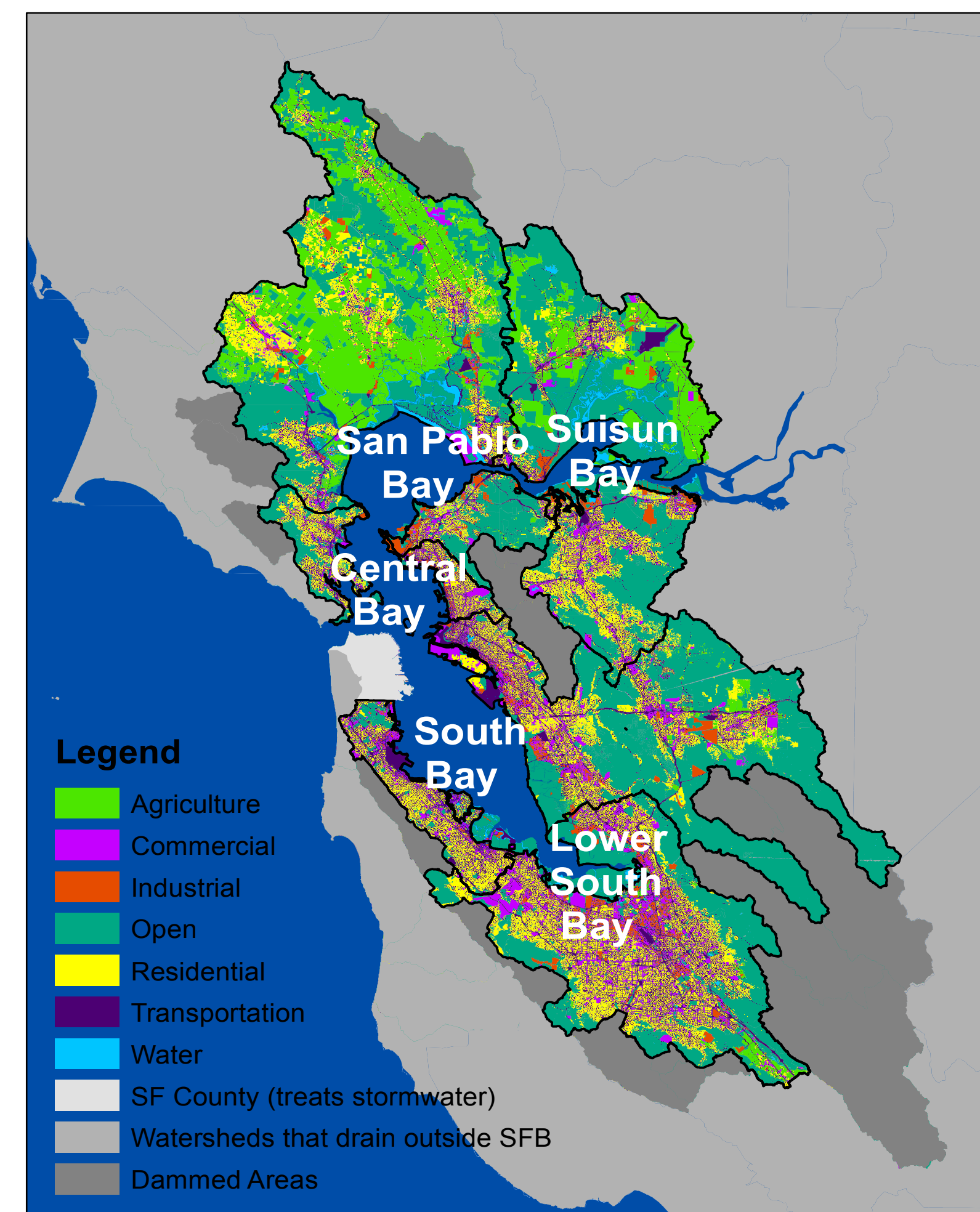
Location and size (in million gallons per day) of refineries and POTWs that discharge to SFB and SFB tributaries. Subembayment boundaries were drawn in accordance with the SFB Regional Water Quality Control Board.

Delta efflux loads

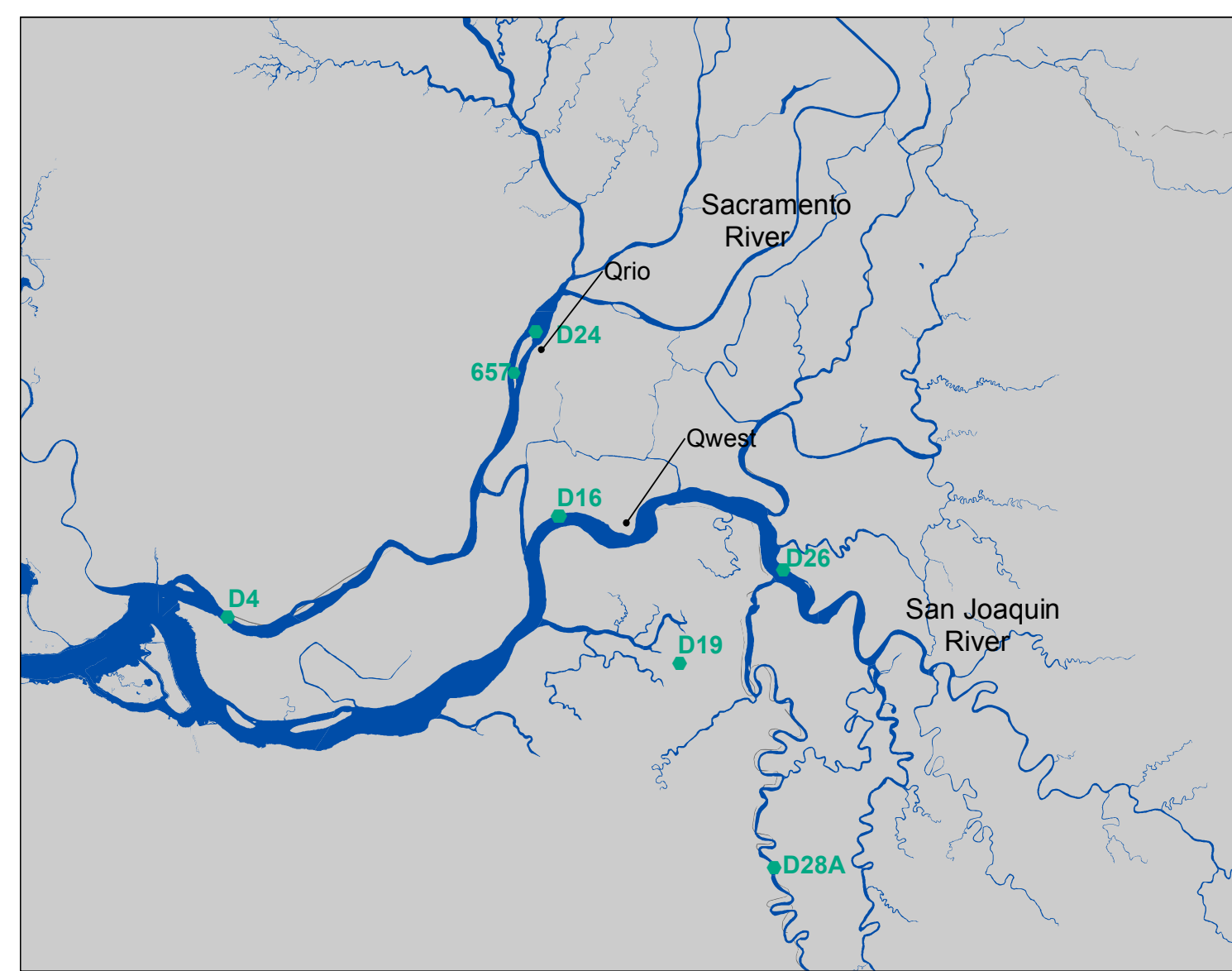
- We developed monthly time-series of NH₄, NO₃, and PO₄ loads to Suisun Bay from the Delta, following an approach similar to the one used by Jassby and Cloern (2000) to estimate organic matter loads from the Delta.
- The approach combines daily flow estimates at Rio Vista (Qrio) and Twitchell Island (Qwest) (DAYFLOW) and water quality data from nearby long-term monitoring stations (DWR, USGS) to estimate nutrient loads.
- The exact stations used for water quality data changed over time based on which stations were active.

Stormwater runoff

- Stormwater loads were calculated using the Regional Watershed Spreadsheet Model (RWSM; Lent 2011), which is under development by the San Francisco Estuary Institute (SFEI) and the Regional Monitoring Program (RMP).
- The RWSM combines hydrologic features and land-use specific nutrient concentrations to compute a 30-year average of nutrient loads from 331 distinct watersheds.
- Loads were distributed over the course of the year based on monthly distribution of annual rainfall.



Land use in watersheds that contribute load to SF Bay, by subembayment. Watersheds that do not contribute load are shown in shades of grey.



Location of DWR/IEP and USGS water quality stations used in Delta loads estimate, as well as location of flow estimates.

Bay-wide annual average results

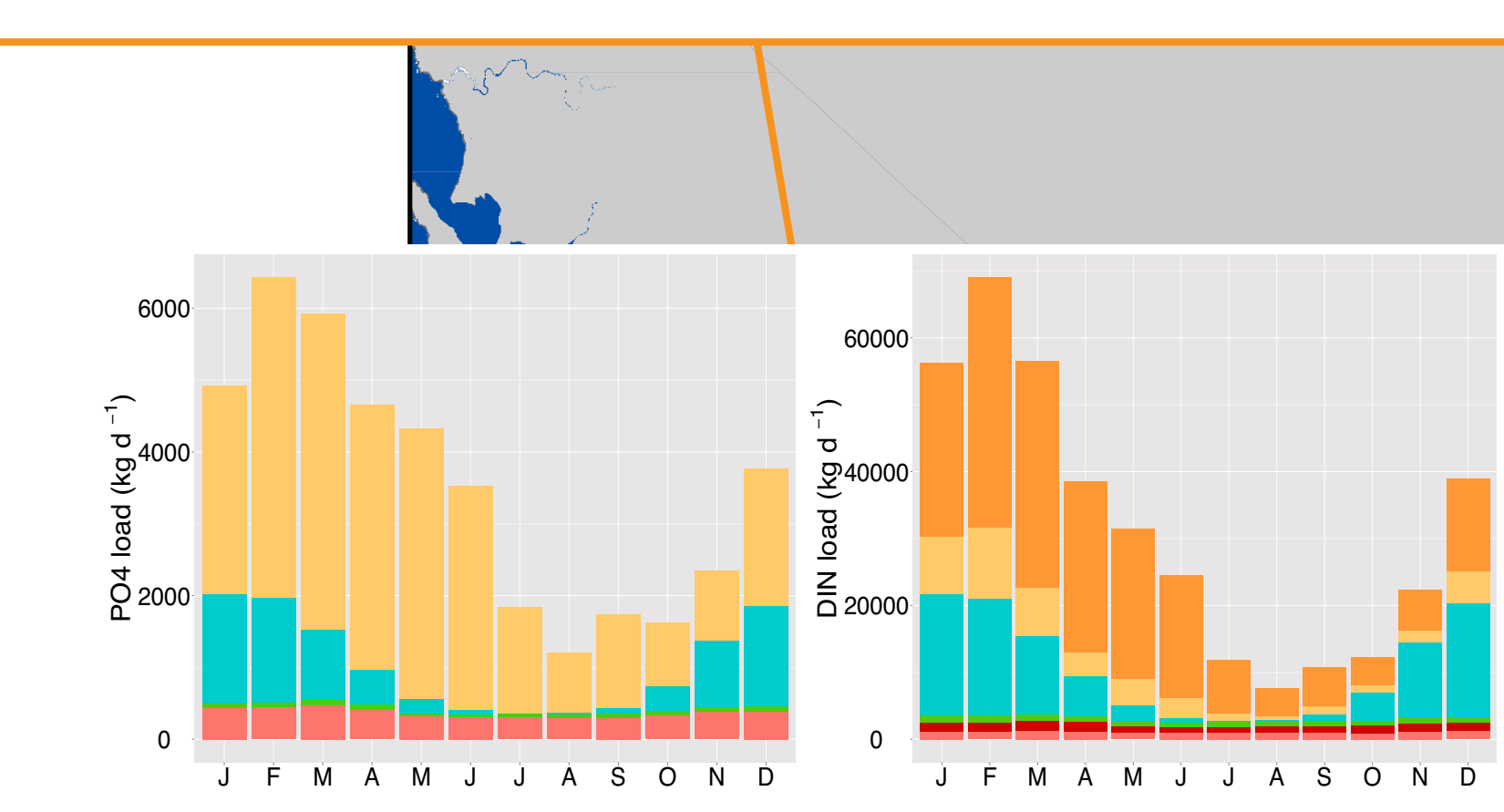
	NH ₄	NO ₃	DIN	PO ₄
POTWs	34000	12000	46000	4000
Refineries	200	800	1000	100
Stormwater	1800	9000	11000	1300
Delta	5800	10000	16000	1000
Total	42000	32000	74000	6400

Annually-averaged nutrient loads by source. All loads are reported as kg d⁻¹ N or P.

Subembayment-scale annual and seasonal loads

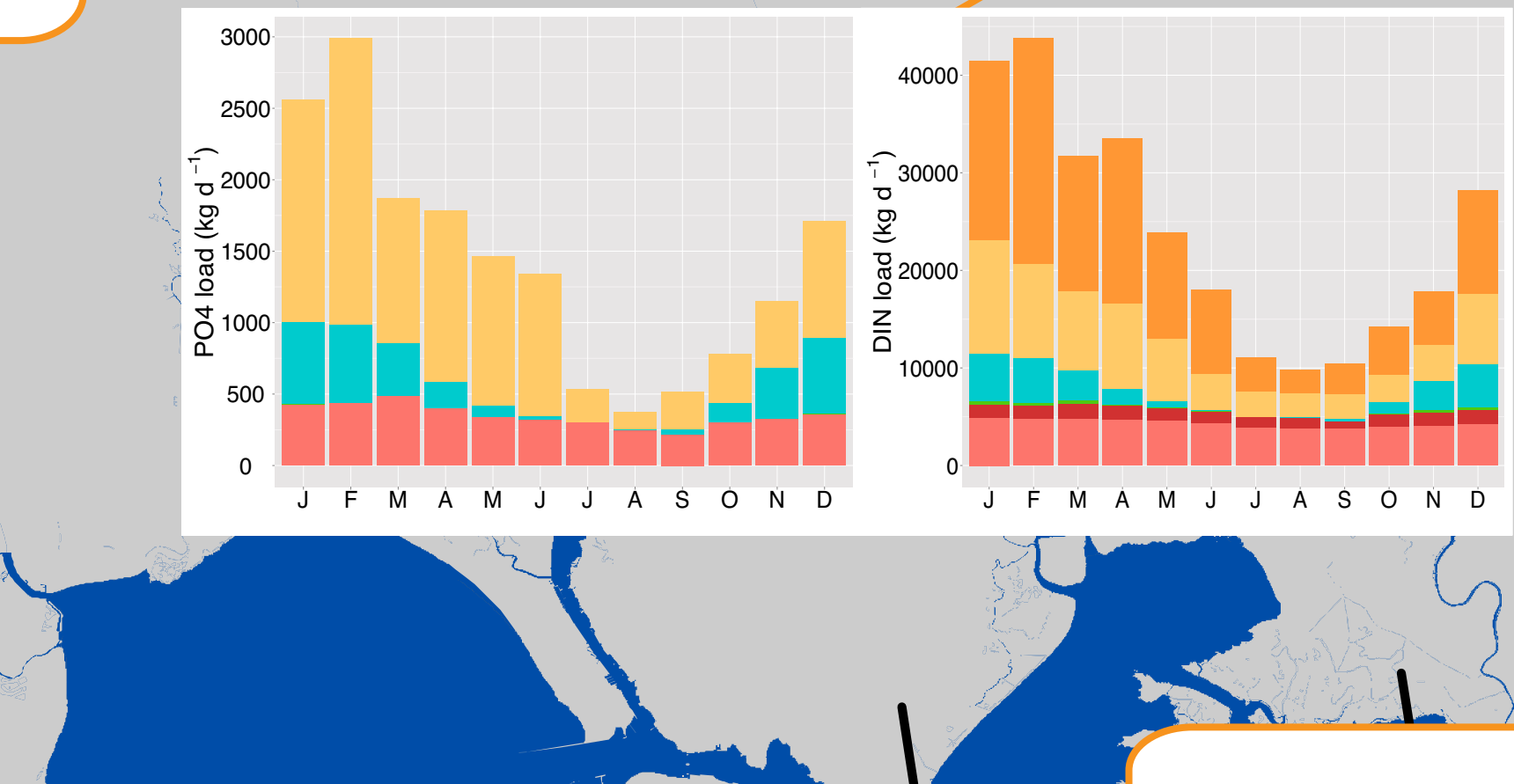
San Pablo Bay

Estimated stormwater loads exceed POTW loads during wet months. This result was driven by the size of the San Pablo Bay watershed and a large percentage of agriculture land-use within its watersheds region. However, San Pablo Bay is also directly influenced by nutrient loads from the Sacramento-San Joaquin Delta. A simple mass balance on Suisun Bay (Novick and Senn, 2013) reveals that at all times of the year, upstream inputs from Suisun Bay/Delta could be the dominant source of nutrients to San Pablo Bay.



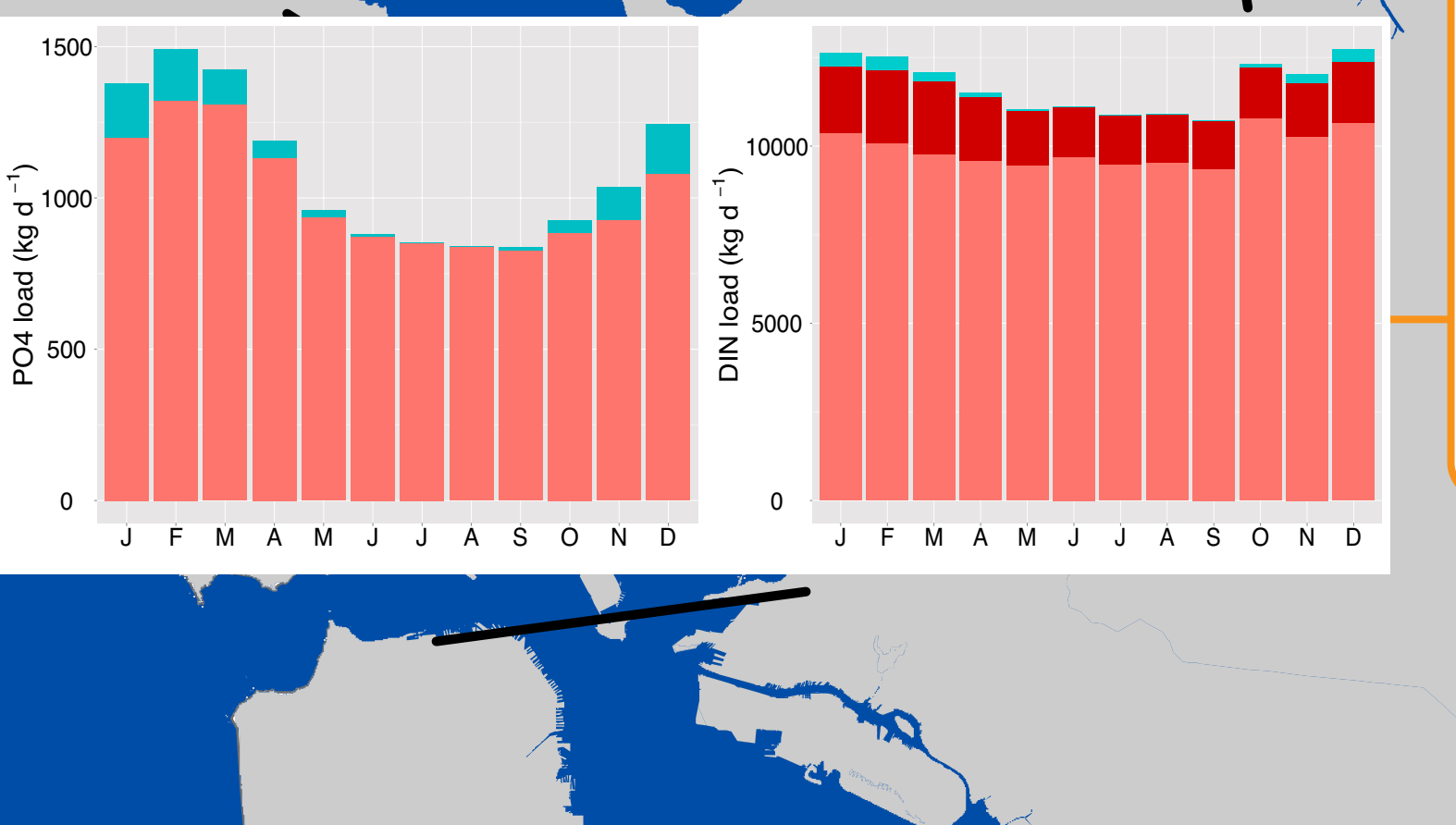
Suisun Bay

On an annual-average basis, loads from the Delta to Suisun Bay exceed loads from other sources to Suisun Bay. The majority of DIN coming from the Delta to Suisun was in the form of NO₃, although NH₄ loads were nontrivial. Direct POTW loads were the dominant source of nutrients to Suisun Bay in dry months.



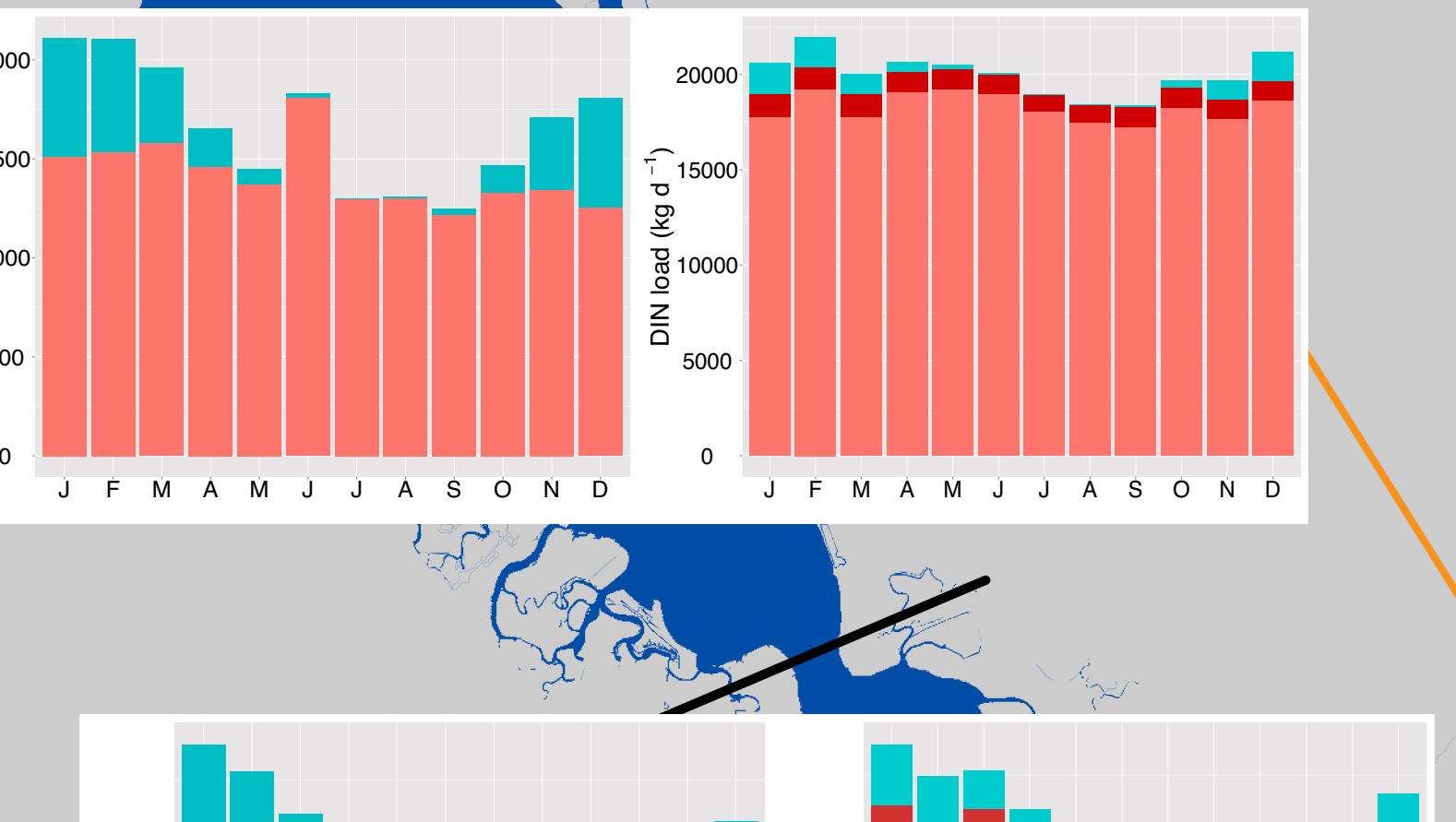
Central Bay

POTWs dominate nutrient loads to Central Bay, accounting for more than 90% of annual DIN and PO₄ loads. Only a small number of POTWs in this region nitrify effluent prior to discharging, so roughly 85% of DIN is NH₄. Stormwater runoff is not a major source of nutrient loads to this region in even the wettest months.



South Bay

POTWs account for more than 90% of annual DIN and PO₄ loads to South Bay. No POTW in this region practices nitrification and nearly all of the DIN was discharged as NH₄. Estimated stormwater loads account for less than 30% of total nutrient loads to the region in even the wettest months.



Lower South Bay

Year-round, POTWs were the dominant source of N and P to Lower South Bay. Unlike other subembayments, effluent from all POTWs is nitrified prior to discharge and DIN is discharged predominantly as NO₃.



References:

Jassby, A.D. and Cloern, J.E. (2000). Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). *Aquatic Conservation: Marine and Freshwater Ecosystems* 10: 323-352.
Cloern, J. E. and A. D. Jassby (2012). DRIVERS OF CHANGE IN ESTUARINE-COASTAL ECOSYSTEMS: DISCOVERIES FROM FOUR DECADES OF STUDY IN SAN FRANCISCO BAY. *Reviews of Geophysics* 50.
Lent, M.A. and McKee, L.J. (2011). Development of regional suspended sediment and pollutant load estimates for San Francisco Bay Area tributaries using the regional watershed spreadsheet model (RWSM). Year 1 progress report. A technical report for the Regional Monitoring Program for Water Quality, Small Tributaries Loading Strategy (STL). Contribution No. 666. San Francisco Estuary Institute, Richmond, CA.
Novick, E. and Senn, D. (2013) Quantifying External Nutrient Loads to San Francisco Bay. A technical report for the Regional Monitoring Program for Water Quality, San Francisco.

Data sources:

<http://www.water.ca.gov/dayflow/>
<http://www.water.ca.gov/dma/meta/Discrete/data.cfm>
<http://sfbay.wr.usgs.gov/access/wqdata/query/easy.html>

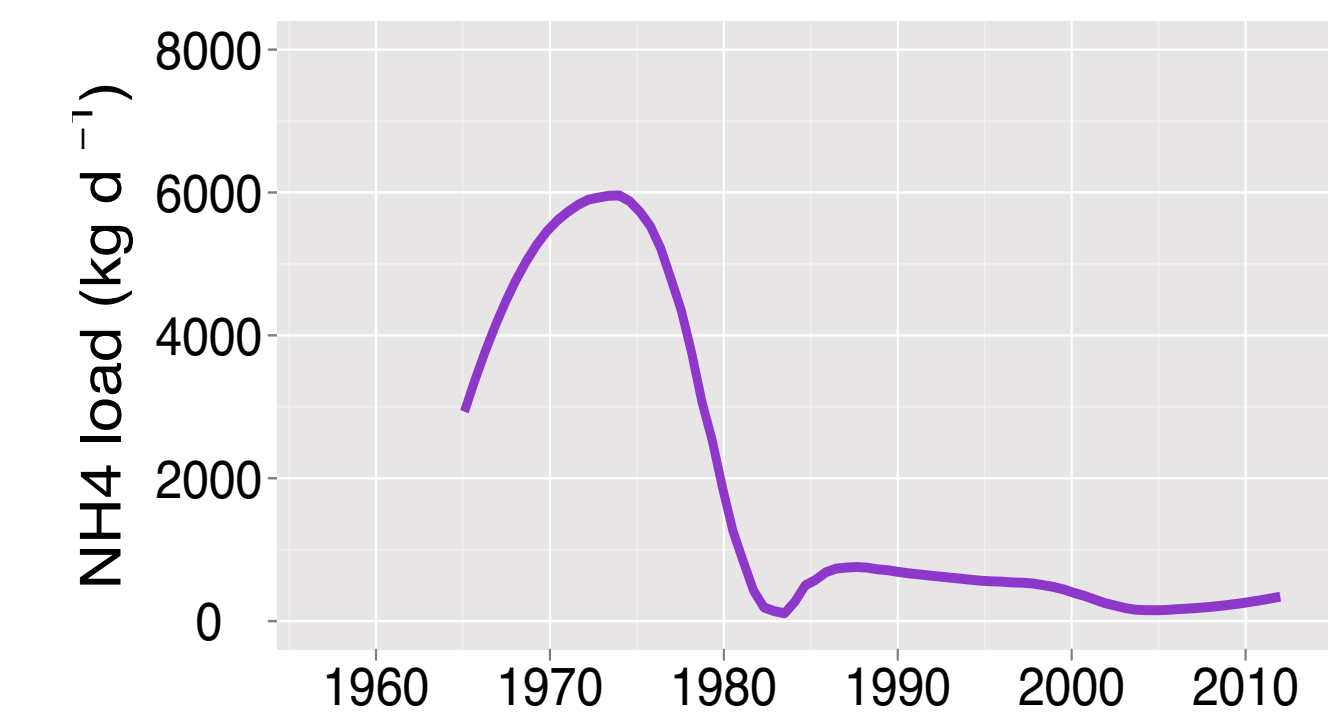
Case studies: changes over time

POTW and Delta load estimates were available for the last 3-4 decades, allowing for a comparison of loading profiles of Lower South Bay and Suisun Bay.

Lower South Bay

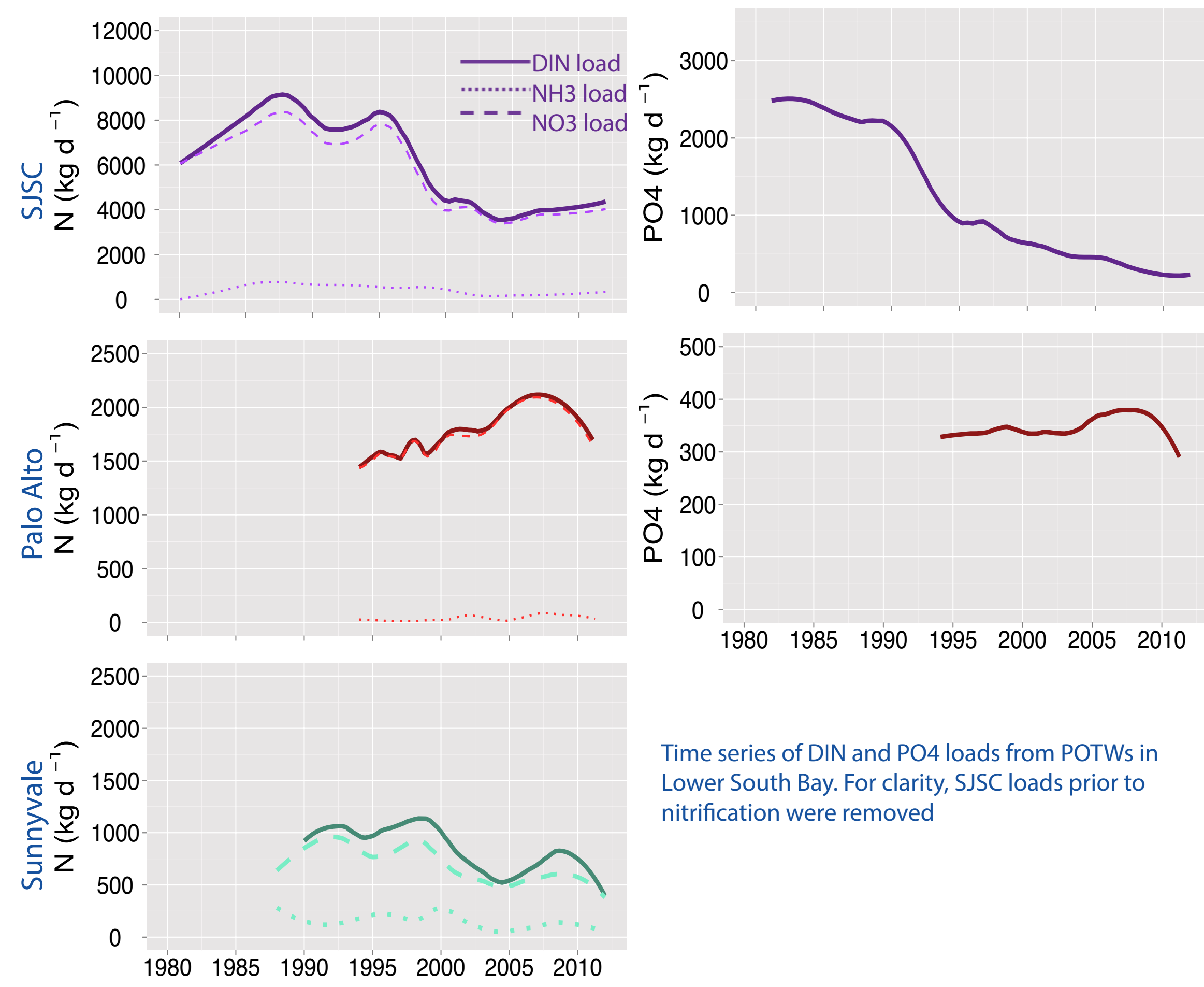
Changes in loading patterns in Lower South Bay are due mainly to changes in POTW treatment technology.

- All POTWs in Lower South Bay now nitrify effluent prior to discharging. SJSC made this transition to nitrification in 1979 and NH₄ loads decreased by ~90%.



SJSC NH4 loads before and after nitrification in 1979

- Treatment upgrades at San Jose over the past 20 years have further decreased DIN loads by 35% and PO₄ loads by ~75%.
- Palo Alto's DIN loads have increased by approximately 30% since 1995 and Sunnyvale's DIN loads appear to have decreased by since 2000.



Time series of DIN and PO4 loads from POTWs in Lower South Bay. For clarity, SJSC loads prior to nitrification were removed

Next Steps

Refine Estimates

POTW effluent load estimates will continue to be refined upon the completion of a 2-year nutrient effluent characterization study.

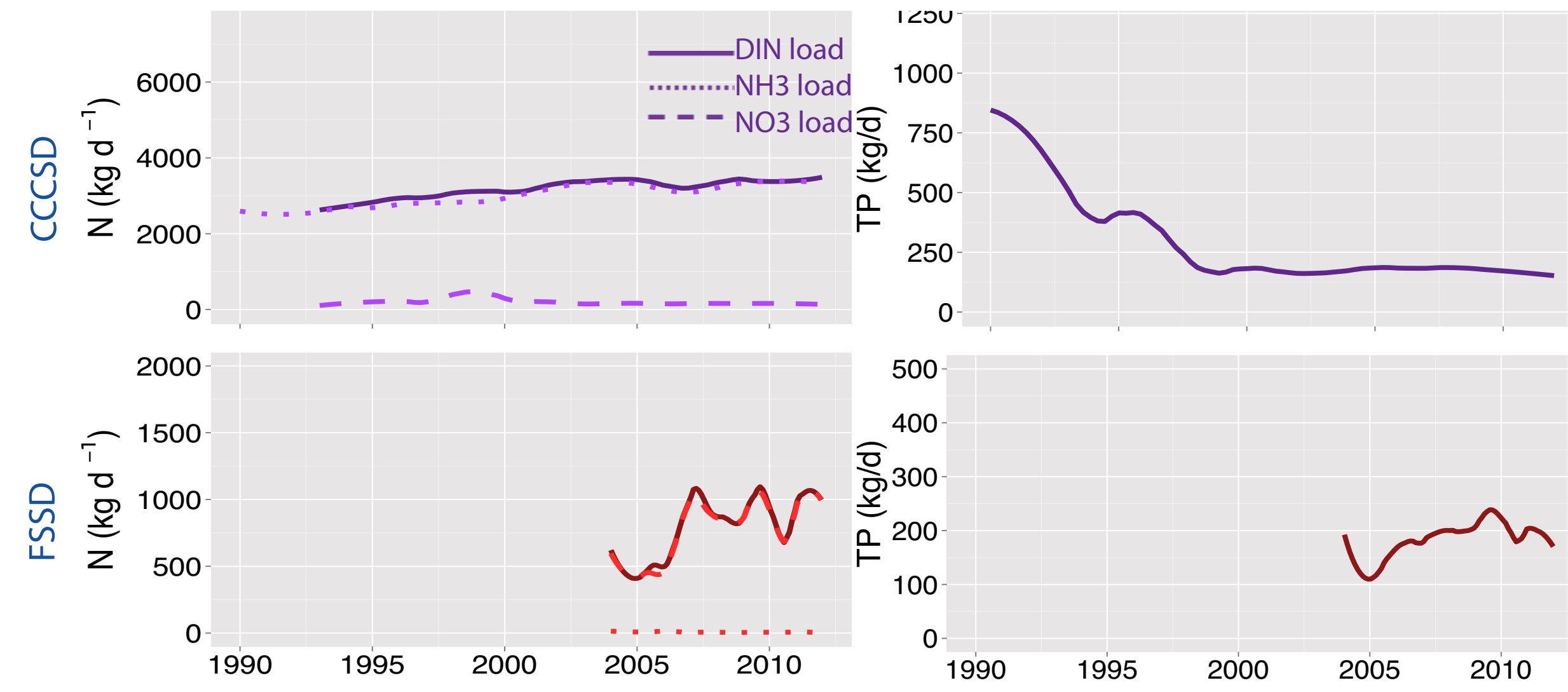
Hydrodynamic and reactive transport models need to be calibrated, validated, and applied to generate improved nutrient load estimates from the Delta to Suisun Bay. A modeling project for the Delta, slated to begin in Q3 of 2013, will help refine these estimates and quantify uncertainties (funded by the CA Department of Water Resources through the Interagency Ecological Program).

The Regional Watershed Spreadsheet Model is not yet calibrated for estimating nutrient loads and therefore estimates are highly uncertain. Across most subembayments, estimates showed stormwater was not a significant source of nutrients, but estimates may be refined in the future for locations or time periods where stormwater cannot not be considered insignificant.

Suisun Bay

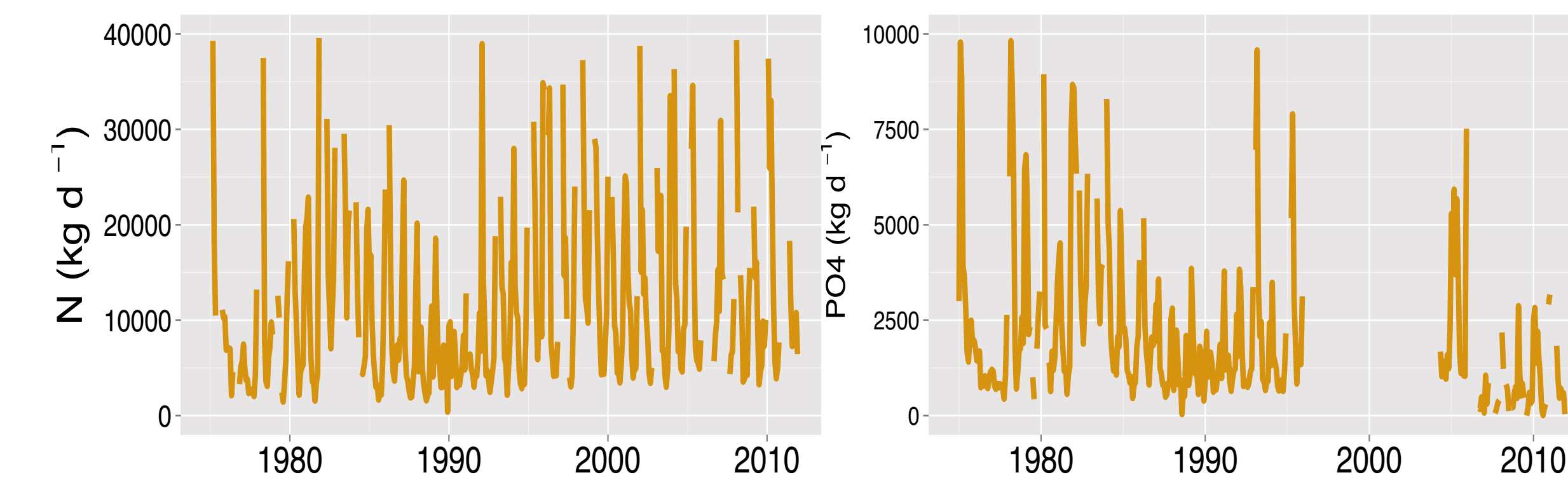
Suisun Bay receives large loads from both direct POTW loads and from the Delta.

- Direct POTW DIN loads to Suisun Bay have increased by 40-50% over the last two decades.
- NH₄ has been the dominant form of DIN emitted from CCCSD, while FSSD nitrifies its effluents and discharges primarily NO₃.
- TP loads are less variable. TP loads from CCCSD have been relatively constant in the last 15 years and TP loads from FSSD appear to have increased slightly since 2004.



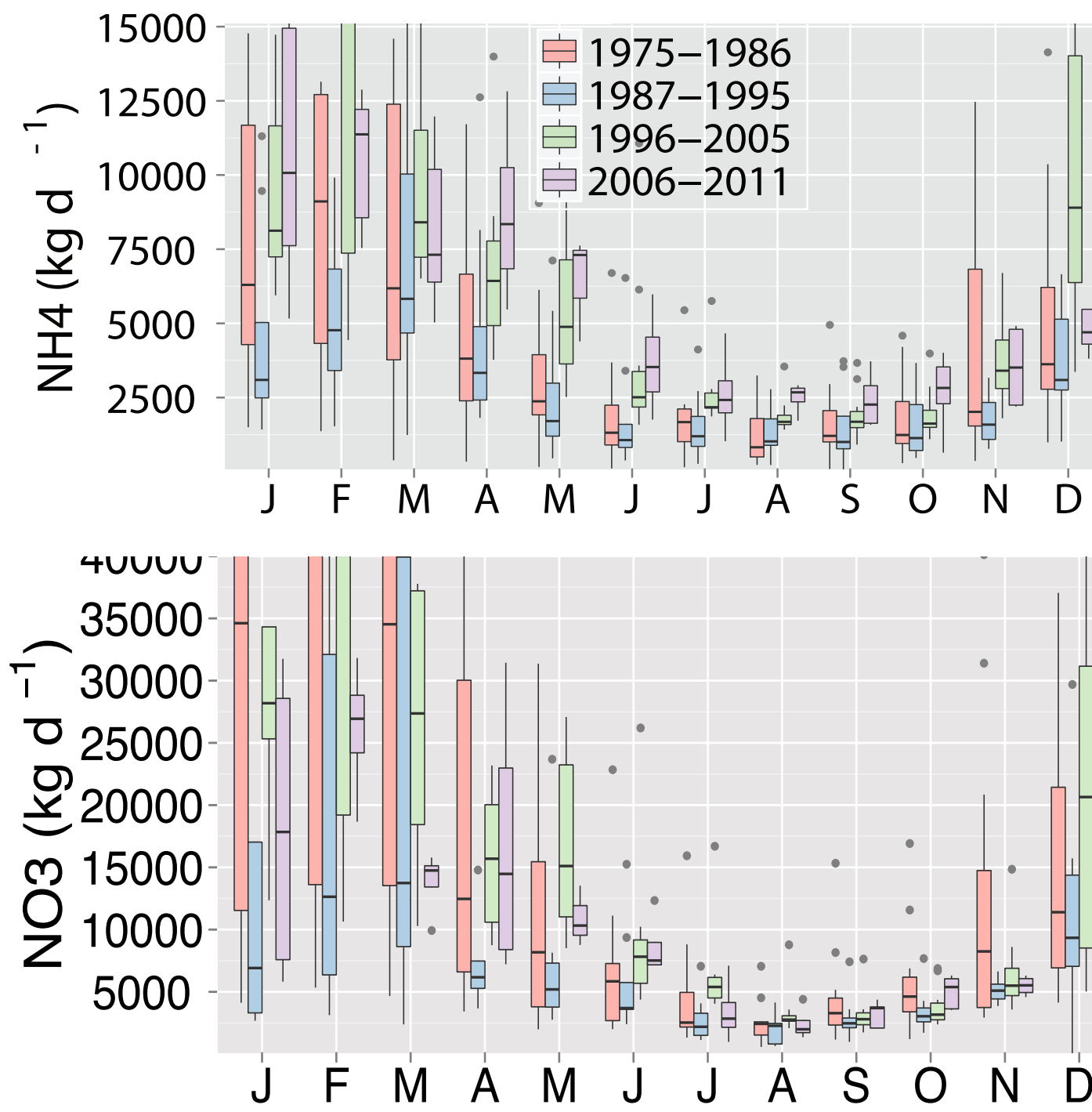
Time series of DIN and TP loads from POTWs in Suisun Bay. PO4 data was not available, so TP is presented here. DDSD also discharges to Suisun Bay, but was omitted due to limited data.

- Delta efflux loads showed strong seasonal trends and large interannual variability. NH₄ and NO₃ loads during low flow months of the year have typically been 4-5 times lower than wet season loads.



Estimates of DIN and PO4 loads from the Sacramento-San Joaquin Delta into Suisun Bay

- In addition to this seasonal variation, NH₄ loads have increased significantly in most months, while NO₃ loads have remained relatively constant over time.
- Some of the increase in NH₄ load is likely explainable by the 2-3 fold increase in NH₄ loads from Sacramento Regional Central Sanitation District (SRCSD) since 1985. Planned treatment upgrades at SRCSD will both shift the form of N released and decrease the total DIN load to Suisun Bay.



Monthly NH4 and NO3 loads from the Delta into Suisun Bay. Data were broken into 4 eras and averaged by month within each era.

Develop Hydrodynamic and Water Quality Models for Nutrient Fate

This project estimated "end-of-pipe" nutrient loads and did not consider nutrient fate and transport within SFB, which could be seasonally and spatially variable. Accurate estimates of nutrient loads at subembayment and finer scales need to consider nutrient exchange between subembayments. The need for such estimates is evident through the potential importance of loads coming from Suisun Bay (and the Delta) to total loads in San Pablo Bay/Carquinez, and potential similar exchanges between Lower South Bay and South Bay and SF Bay and the coastal ocean.